

MS THESIS

**EFFECT OF SELENIUM (Se) NANOPARTICLES TO MITIGATE
DROUGHT STRESS AND IMPROVE GROWTH, YIELD AND
YIELD ATTRIBUTES OF SESAME (*Sesamum indicum* L.)**

A THESIS

BY

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Student No. 1801157

Session: 2024-2025

Semester: January - June, 2025

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**MASTER OF SCIENCE
IN
AGRONOMY**



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**DEPARTMENT OF AGRONOMY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY
UNIVERSITY, DINAJPUR**

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DEDICATED
TO
MY BELOVED PARENTS

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ABSTRACT

The experiment was conducted in the Agronomy Shade House, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh from May 2024 to July 2024. The present study was conducted to evaluate the effect of foliar application of Selenium (Se) nanoparticles on mitigating drought stress and improving growth, yield, and physiological parameters of sesame (*Sesamum indicum* L.) variety BINA Til-3. The experiment was laid out in a Completely Randomized Design (CRD) with eight Se nanoparticle treatments namely (T_0 = Control, T_1 = 5 ppm, T_2 = 10 ppm, T_3 = 15 ppm, T_4 = 20 ppm, T_5 = 25 ppm, T_6 = 30 ppm, T_7 = 35 ppm). The experiment consisted with three replications *i.e.*, 24 pots during the Kharif season from May 2024 to July 2024. Results demonstrated that moderate Se dose T_5 = 25 ppm significantly improved number of leaves, leaf area, chlorophyll content, and photosynthetic pigments, while enhancing cell membrane stability and water retention under drought stress. Treatment T_5 exhibited the highest chlorophyll content (58.03 SPAD at 28 DAS) and optimal leaf morphology and achieved the maximum seed yield (1.22 t/ha), a 103% increase over the control. Higher Se concentrations (≥ 30 ppm) showed diminishing returns or potential toxicity, as evidenced by reduced growth and yield. Physiological analyses revealed that Se application enhanced antioxidant activity, proline accumulation and nutrient uptake (N, K) contributing to improved drought tolerance. The study concluded that foliar application of Se NPs at T_5 is optimal for enhancing sesame productivity under drought conditions, offering a sustainable strategy to combat water scarcity in sesame cultivation. These findings align with global research on nanotechnology in agriculture, highlighting Se NPs as a promising tool for stress mitigation and yield improvement in oilseed crops.

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LIST OF ABBREVIATION AND ACRONYMS

%	= Percentage
⁰ C	= Degree Celsius
AEZ	= Agro-Ecological Zone
BARI	= Bangladesh Agricultural Research Institute
BBS	= Bangladesh Bureau of Statistics
cm	= Centimeter
CV	= Co-efficient of Variation
DAS	= Days After Sowing
<i>et al.</i>	= and others
etc.	= Etcetera
FAO	= Food and Agriculture Organization
g	= Gram
Mg	= Miligram
Kg	= Kilogram
LAI	= Leaf Area Index
LS	= Level of Significance
LSD	= Least Significant Difference
M.S.	= Master of Science
M	= Meter
mL	= Milliliter
Ppm	= Parts Per Million
MoP	= Muriate of Potash
CRD	= Completely Randomized Design
ha	= Hectare
TSP	= Triple Super Phosphate
WHO	= World Health Organization
ANOVA	= Analysis of Variance

CHAPTER I

INTRODUCTION

The population of Bangladesh increasing rapidly and the environment is degrading day by day due to population pressure coupled with malnutrition is the main concern of present agricultural researchers. Scientists face significant difficulties in providing for the food and nutritional needs of our expanding population. Oil seeds are crucial components for vegetarians to consume in order to fulfill their need for protein because vegetable oil is a cheap source of protein in Bangladesh. Sesame (*Sesamum indicum* L.) is an oil seed crop that belongs to the family Pedaliaceae and is regarded as the earliest oil seed crop that has been domesticated by humans for more than 5000 years (Langham, 2011). It is grown widely in both tropical and subtropical regions for its edible oil, proteins, vitamins, and amino acids (Pusadkar *et al.*, 2015) India, Sudan, China, Myanmar, and Nigeria are the top sesame producing countries and China and Japan are the leading sesame importers (FAO, 2014) in the world. Sesame has the potential capacity to combat nutritional deficiencies and medicinal value in developing regions and countries (Wang *et al.*, 2016). Owing to its high nutritional and therapeutic value, sesame is also used extensively in confectionaries and baked goods globally (Vanisha *et al.*, 2013). Sesame seeds may be eaten fried mixed with sugar or in the form of sweetmeats. It is a crop with several uses and a variety of nutritional components, including 42–45% oil, 20% protein, and 14–20% carbohydrates (BARI, 2012). Sesame contains 42-50% oil, 25% protein, and 16-18% carbohydrate (Khan *et al.*, 2010). It is rich in fatty acids including oleic acid (41–45%), linoleic acid (37– 42%), palmitic acid (10%), and stearic acid (5%) (Kanu *et al.*, 2010). Sesame seed also contains some lipid-soluble natural antioxidants such as sesamin, sesamolin, and sesamol and some other components such as lignan glucosides, phytosterols, tocopherols *etc.*, which have health promoting properties (Gharby *et al.*, 2017). The oil usually contains 35% monounsaturated fatty acids and 44% polyunsaturated fatty acids. Sesame Seeds also have a wide range of phenolic compounds with heavy antioxidant activity (Bodoira *et al.*, 2017). Sesame ranks 9th among the existing oil seed crops of the world and gained much popularity due to its long durability, easy extraction, low rancidity, and drought resistance (Kafiriti and Mponda, 2013). Besides, among various oil crops grown in Bangladesh, sesame ranks next to rapeseed and mustard in respect of both cultivated area and production and is the 4th largest source of edible oil after mustard, soybean, and groundnut (BBS, 2022). Because Bangladesh's edaphic and climatic conditions are

excellent for growing sesame. In the past era of Bangladesh, the crop has been grown either as a pure stand or in a mixture of sugarcane, jute, groundnut, ground rice, and others. In Bangladesh, sesame is grown in both rabi and kharif seasons but the kharif season covers about two-third of the total sesame area. Khulna, Faridpur, Pabna, Barisal, Rajshahi, Jessore, Comilla, Dhaka, Patuakhali, Rangpur, Sylhet, and Mymensingh districts are the leading sesame producing areas of Bangladesh (BARI, 2014). In Bangladesh, the oil seed occupied 5.5% of the total cropped area, among these mustard covered 60.9%; sesame covered 7.7%; groundnut covered 8% and soybean covered 14.1% (BBS, 2019). In 2020-21, sesame covered an area of 77764.11 acres in Bangladesh with a total production of 28988.01Mtons which was in 2021-22, area of 74980.45 acres with a total production of 28389.20 M tons (BBS, 2023). Gradually year by year the yield and quality of sesame seeds are decreases in Bangladesh. The low yield of sesame in Bangladesh may be attributes to various reasons *viz.* availability of high yielding varieties, unavailability of quality seeds, proper fertilizer with nutrient management, disease, and pest infestation, and improper irrigation facilities. In the last decade, nanoparticles play an important role in agriculture due to their unique properties, such as greater absorption ability, higher surface area, efficient delivery method for a specific spot, and such technology used in many ways like additives, plant growth enhancers, nano-fertilizers, and plant protection agents (Janmohammadi, 2015). Among the most abundant trace elements, Selenium (Se) is the top most important one, which plays a significant role in improving the survival capacity of plants under different environmental stress through alterations morphological, physio-biochemical activities (producing antioxidants), expanding amino acids, chlorophyll a, chlorophyll b contents, lipids, proteins, leaf water contents in plants (Boureima, *et al.*, 2011). Similarly, under drought stress, the exogenous application of Se played a significant role for increasing the assimilation of higher photosynthesis. Many researchers have reported that selenium induces plant drought coping mechanisms by reducing water evaporation, increasing the activities of oxide enzymes such as superoxide dismutase and peroxidase, promoting the synthesis of chlorophyll and carotenoid and enhancing the accumulation of proline (Ahmad *et al.*, 2016).

From the above information, the study will be undertaken with following objectives:

- To determine the optimal concentration and number of foliar Selenium (Se) nanoparticles applications for the BINA Til 3 variety for drought tolerance.
- To find out the suitable doses of Selenium (Se) nanoparticles for maximum growth and yield of sesame.
- To measure the drought severity on sesame by different chemical analysis.

CHAPTER II

REVIEW OF LITERATURE

A review of literature in any research is very necessary because it provides a scope for reviewing the stock of knowledge, primary concepts, and relevant information to the proposed research. This knowledge, concept, and information give a guideline for designing and conducting the research successfully. It is essential for reviewing that gives proper instruction in designing future research problems and validating the new findings. Sesame is a crucial oil crop in Bangladesh and many other countries. Researchers typically pay less attention to the crop in diverse areas since it typically grows carelessly or without management techniques. Based on this, relatively little research has been done in our country on the growth, yield, and development of sesame. The best selenium (Se) nanoparticles are crucial for increasing sesame yield. However, Bangladesh only has a small amount of research on sesame that uses selenium (Se) nanoparticles. Nonetheless, this chapter has covered some of the significant and instructive research findings regarding the effects of selenium (Se) nanoparticles on sesame under the following headings:

2.1 Effect of selenium (Se) nanoparticles on yield performance of sesame

Ahmad *et al.* (2024) conducted an experiment in Pakistan Agriculture Research Station (PARC) to investigate the impact of sesame on sesame. The current study aimed to investigate the effects of plant-mediated selenium nanoparticles (SeNPs) on plant growth, photosynthetic pigments, antioxidant activity, and the triacylglycerol profile of sesame (*Sesamum indicum* L.). The green synthesis of SeNPs was achieved using garlic extract, resulting in spherical nanoparticles with an average size range of 70–75 nm. Three SeNP treatments (T₃, 30 ppm; T₄, 40 ppm; and T₅, 50 ppm) were applied through seed and foliar spray on six sesame varieties (V₁, TS-5; V₂, TH-6; V₃, Til-18; V₄, Niab Millennium; V₅, Niab Pearl; and V₆, NS-16). All enzymatic antioxidant parameters showed an increase in the treated groups, such as SOD (74.4% in V₁ at T₄), POD (43% in V₅ at T₅), APX (62% in V₁ at T₃), and GPX (31.56% in V₃ at T₄). CAT showed the highest percentage improvement in T₅ for V₁, V₂, V₄, and V₅, while V₃ and V₄ exhibited the highest values at T₄. Likewise, seed antioxidant parameters also showed increase in antioxidant activity, highest total phenolic content (6.06 mg GAE/g) was found at T₅ treatment with percent increase of 27.41%, but the highest percent increase was found to be at T₄ treatments in V₁ with increase of 46.83%. Percent oil yield was also noted to be

higher as highest percent (60%) oil yield was obtained at T₄ treatment in V₃. Ultra High Performance Mass-Spectrometry (UHPLC-MS) analysis and chemometric modeling suggested a total of 10 triacylglycerol (TG) biomarkers separating untreated groups, with higher relative abundance values at T₄ and T₅ treatments compared to control. PCA and correlation analysis showed clustering of untreated groups from T₄ and T₅, which suggests that these two treatments result in higher accumulation of oil. A generalized linear model with ANOVA showed a highly significant impact of treatments on all the growth and oil parameters, with significance involvement of varieties. The interaction between variety and treatment showed no significant effect on the growth and oil biomarkers of sesame. However, it can be concluded that the T₄ and T₅ treatments (40 ppm and 50 ppm) of SeNPs, applied through seed and foliar methods, have a strong influence on the overall growth and oil yield of sesame. This warrants further transcriptomic and molecular analysis to gain deeper insight into the mechanisms of action of SeNPs.

Thuc *et al.* (2021) conducted an experiment on foliar selenium application for improving drought tolerance of sesame (*Sesamum indicum* L.) at Can Tho University, Can Tho, Vietnam. Drought is the main constraint for crop growth worldwide. Selenium reportedly plays an important role in improving plant tolerance to drought stress. In this study, two experiments were conducted to investigate the effects of foliar selenium application on the drought tolerance of sesame. Five selenium concentrations (0, 5, 10, 20, and 40 mg/L) were used in the first experiment. Water deficit was triggered 25 days after sowing. The application of 5 or 10 mg/L of selenium maintained the number of leaves and increased the number of capsules. However, higher concentrations induced necrosis. The second experiment aimed to study the effect of selenium concentrations (5 and 10 mg/L) and the number of applications (one to three times). Drought stress was triggered 50 days after sowing, and selenium was sprayed 50, 55, and 60 days after sowing. The results indicated that a one-time foliar selenium application of 5 mg/L was able to maintain the number of leaves and to increase proline accumulation, plant biomass, and grain weight per plant. This finding confirms that selenium can be applied to enhance sesame's tolerance to drought stress.

Ahmad *et al.* (2023) conducted an experiment with selenium for improvement of sesame quality. Vegetable oil consumption is expected to reach almost 200 billion kilograms by 2030 in the world and almost 2.97 million tons in Pakistan. A large quantity of edible oil is imported annually from other countries to fill the gap between local production and

consumption. Compared to other edible oil crops such as soybean, rapeseed, peanut and olive, sesame has innately higher (55%) oil content, which makes it an excellent candidate to be considered to meet local edible oil production. Oil seed crops, especially sesame, are affected by various pathogens, which results in decreased oil production with low quality oil. Selenium nanoparticles (SeNPs) work synergistically, as it has antifungal activity along with improving plant growth. Different concentrations of SeNPs were used, on three different varieties of sesame (TS-5, TH-6, and Till-18). Plant growth and development were accelerated by SeNPs, which ultimately led to an increase in crop yield. Morphological parameters revealed that SeNPs resulted in a growth increase of 55.7% in root length, 48% increase in leaf number/plant, and 38% in stem diameter. Out of three sesame varieties, TS-5 seedlings treated with 40 mg/L SeNPs showed 96.7% germination and 53% SVI at 40 mg/L. Sesame varieties dramatically increased antioxidant capability using SeNPs, resulting in 147% increase in SOD and 140% increase in POD enzyme units in TH-6 and 76% elevation in CAT enzymes in TS-5 (mean \pm S.E). GCMS analysis revealed that bioactive compound I, sesamin, sesamol, and tocopherol contents were increased along with enhanced production of different unsaturated fatty acids. Kegg pathway analysis and MSEA revealed that these compounds were mainly involved in biosynthesis of unsaturated fatty acids, suggesting that SeNPs have elicited the biosynthesis of unsaturated fatty acids such as oleic acid, linoleic acid, and α -linoleic acid. This study concluded that SeNPs (40 mg/L) have an excellent capability to be used for crop improvement along with better oil quality.

Agnihotri *et al.* (2023) conducted an experiment during the kharif season of 2021 at CRC Farm, School of Agriculture, ITM University, Gwalior (MP). The goal of the study was to see how conventional and Nano-fertilizers affected sesame productivity and quality, as well as how they affected plant growth parameters, yield attributes, and yield, as well as sesame economics and quality. The soil in the experimental field had a sandy clay loam texture, was neutral in reactivity to normal EC, and had a medium OC, N, P, and K content. The total and average rainfall throughout the experimental year was 110.08 mm and 12.23 mm, respectively, while other climatic conditions were normal for better crop growth and development. In a randomized block design (RBD), ten treatments were tried with three replications. The crop was sown on August 5th, 2021, and harvested on November 11th, 2021. Soil samples from each plot were gathered before and after crop harvest and subjected to chemical analysis to determine changes in soil attributes over their baseline soil status. Finally, the treatments' economic viability was assessed in terms of cost of cultivation, gross returns, net returns, and the B: C ratio on a per-hectare

basis. Based upon this experiment it is concluded that application of Nano-fertilizer and conventional fertilizer treatments of 100 percent RDF through chemical fertilizers+ 25 percent RDF through vermicompost+ 750 g/ha nano fertilizer produced significantly higher seed yield (9.19 q/ha), maximum gross returns (76098 Rs/ha), maximum net returns (52345 Rs/ha), and the highest B: C ratio of 2.31: 1.

Khan *et al.* (2023) conducted an experiment on the role of selenium and nano selenium on physiological responses in plant. Selenium (Se), being an essential micronutrient, enhances plant growth and development in trace amounts. It also protects plants against different abiotic stresses by acting as an antioxidant or stimulator in a dose-dependent manner. Knowledge of Se uptake, translocation, and accumulation is crucial to achieving the inclusive benefits of Se in plants. Therefore, this review discusses the absorption, translocation, and signaling of Se in plants as well as proteomic and genomic investigations of Se shortage and toxicity. Furthermore, the physiological responses to Se in plants and its ability to mitigate abiotic stress have been included. In this golden age of nanotechnology, scientists are interested in nanostructured materials due to their advantages over bulk ones. Thus, the synthesis of nano-Se or Se nanoparticles (SeNP) and its impact on plants have been studied, highlighting the essential functions of Se NP in plant physiology. In this review, we survey the research literature from the perspective of the role of Se in plant metabolism. We also highlight the outstanding aspects of Se NP that enlighten the knowledge and importance of Se in the plant system.

Baghery *et al.* (2022) found that Sesame (*Sesamum indicum* L.) is one of the most important oilseed crops of the world, particularly tropical areas. Its production is significantly affected by drought stress. The present study was performed to assess the efficiency of existing criteria for the selection of tolerant cultivars while evaluating sesame genotypes under drought conditions. Various agro-morphological traits along with some drought tolerance indices were used to evaluate 15 sesame genotypes under drought conditions. A moderate to high heritability was estimated for plant height (0.55), no. of capsules (0.72), capsule diameter (0.60), no. of seeds per capsule (0.43) and seed yield (0.53). On average, the seed yield of genotypes was reduced by 45% under water stress. Seed yield was significantly positively correlated with the no. of capsules, capsule diameter, and no. of seeds per capsule under both normal and drought conditions. The number of capsules and capsule diameter were suggested as potential criteria for indirect yield selection under drought stress. Chinese (G01), Naz Chand Shakhe (G05), and Darab1 (G04) genotypes were identified as the most tolerant based on the average

ranking of indices. Stress/ non-stress production index (SNPI), yield index (YI), and drought resistance index (DI) were suggested as the most efficient drought tolerance indices according to principal component analysis and correlations. The evaluation criteria proposed in this study can be used for efficient selection of drought-tolerant genotypes in sesame. Moreover, reported tolerant and sensitive genotypes can be used in future studies and breeding programs in sesame under drought stress.

Qin *et al.* (2025) carried out an experiment in nanoparticle-based strategies have emerged as transformative tools for addressing critical challenges in sustainable agriculture, offering precise modulation of plant–environment interactions through enhanced biocompatibility and stimuli-responsive delivery mechanisms. Among these innovations, selenium nanoparticles (SeNPs) present unique advantages due to their dual functionality as both essential micronutrient carriers and redox homeostasis modulators. Compared to conventional selenium treatments, SeNPs offer a more efficient and environmentally friendly solution for improving plant resilience while minimizing toxicity, even at low doses. This review provides a comprehensive analysis of methods for synthesizing SeNPs, including chemical reduction, green synthesis using plant extracts, and biological techniques with microbial agents. Additionally, the review discusses the effects of SeNPs on biotic and abiotic stress responses in plants, focusing on how these nanoparticles activate stress-response pathways and enhance plant immune function. The primary objective of this study is to offer theoretical insights into the application of SeNPs for addressing critical challenges in modern agriculture, such as improving crop yield and quality under stress conditions. Moreover, the research highlights the role of SeNPs in advancing sustainable agricultural practices by reducing reliance on chemical fertilizers and pesticides. The findings underscore the transformative potential of SeNPs in crop management, contributing to a more sustainable and eco-friendly agricultural future.

Sharma *et al.* (2022) carried out a field experiment on Selenium (Se), a micronutrient required by plants, has a beneficial role in plant growth and development. It plays various morphological and physiological roles in plants including stimulating growth, producing antioxidants, enhancing chlorophyll content, and combating various biotic and abiotic stresses. However, higher selenium concentrations can lead to detrimental effects and toxicity in plants. Plants absorb selenium in the form of selenite and selenate from the soil and eventually assimilate it in to the plastids. This chapter provides an overview of the prevalent drought situation around the globe and the corresponding role of

selenium and nano-selenium in mitigating the same in plants. Herein, we have discussed the reactive oxygen species scavenging mechanism induced by selenium and nano-selenium, and also the ABA-dependent pathway and the plant water transport mechanisms that helps in the activation of the antioxidant defence system. The chapter also attempts to outline the mechanism of selenium-mediated drought alleviation in plants at the genic level. It highlights the numerous positive and negative effects of Se in plants giving special attention to the role of Se in combating drought stress by regulating plant–water status and relations.

Mondal *et al.* (2011) conducted an experiment in West Bengal, India during the rainy and summer seasons of 2009 and 2010. Six combinations with 2 levels of nitrogen (20 and 40 kg N/ha) and 3 levels of potassium (0, 33, and 66 kg K/ha) were applied to soybean and sesame as a sole crop or intercropped. Oil yield of sesame and soybean as sole crops was higher compared to the oil yield of both crops as intercrops. Highest oil yield of soybean and sesame was observed with 66 kg K/ha + 40 kg N/ha application. Nutrient uptake by soybean as a sole crop and combined uptake of nutrients by both intercrops were higher during the rainy season than their respective nutrient uptake during summer. However, nutrient uptake of sesame as a sole crop was higher in summer than during the rainy season. Maximum uptake of nutrients in both sesame and soybeans was observed with 66 kg K/ha + 40 kg N/ha application. Continuous N application resulted in higher N-status in soil. However, the application of K with N resulted in a decreased total N status in soil after the fourth cropping.

Ahmad *et al.* (2024) reported Sesame (*Sesamum indicum*) is abundant in a diverse range of lignans, including sesamin, and γ -tocopherol, constituting a cluster of bioactive phenolic compound used for food and medicinal purposes. Cardiovascular diseases remain a leading global health challenge, demanding vigilant prevention and innovative treatments. This study was carried out to evaluate the effect of plant mediated SeNPs on sesame metabolic profile and to screen and check the effect bioactive compounds against CVD via molecular drug docking technique. Three sesame germplasms TS-5, TH-6 and Till-18 were treated with varying concentrations (10, 20, 30, 40 and 50 ppm) of plant-mediated selenium nanoparticles (SeNPs). There were three groups of treatments group-1 got only seed pretreatments of SeNPs, Group-2 with only foliar applications of SeNPs and Group-3 with both seed pretreatments and foliar applications of SeNPs. It was found that plants treated with 40 ppm of SeNPS in group 3 exhibited the highest total phenolic and flavonoid content. Total phenolic content at T₄ was highest for TS-5 (134%), TH-6

(132%), and Till-18 (112%). LCMS analysis revealed a total of 276 metabolites, with phenolics, flavonoids, and free fatty acids being most abundant. KEGG analysis indicated enrichment in free fatty acid and phenylalanine tryptophan pathways. ADMET analysis and virtual screening resulted in total of five metabolic compounds as a potential ligand against Hemoglobin beta subunit. Lowest binding energy was achieved by Delta-Tocopherol (-6.98) followed by Lactoflavin (-6.20) and Sesamin (-5.00). Lipinski rule of five revealed that all the compounds completely safe to be used as drug against CVD and specifically for HBB. It was concluded that bioactive compounds from sesame could be an alternative source of drug for CVD related problems and especially for HBB.

Younas *et al.*, GC-MS study (2024) explored the impact of selenium nanoparticles (SeNPs) on the biochemistry and seed oil profile of sesame (*Sesamum indicum* L.). Sesame plants were treated foliarly with varying dosages of SeNPs (10, 20, 30, 40, and 50 mg/L) and 5 mg/L of selenium salt. UV-Visible spectrum indicated a peak absorption at 279 nm for SeNPs, while FTIR analysis confirmed the reduction of sodium selenite to SeNPs using *Allium sativum* extract. The highest total flavonoid content (TFC) and total phenolic content (TPC) were recorded at 14.72 and 14.24 mg/g, respectively, for the 40 mg/L treatment. Additionally, GC-MS analysis identified thirty-five chemical compounds in sesame seed oil. The Kyoto encyclopaedia of gene and genomics (KEGG) pathway analysis revealed significant metabolite enrichment across eight pathways, particularly in pyruvate metabolism. Overall, SeNPs enhanced the biochemical profile and metabolite detection in sesame seed oil, potentially improving crop yield and stress resilience.

Nasiri *et al.* (2025) investigate the effectiveness of selenium (Se) and Se nanoparticles (Se-NPs) in improving biochemical and physiological characteristics of savoury in drought stress conditions, a factorial experiment based on the completely randomised design with three replications was used. Results demonstrate that Se-NPs considerably enhanced several biochemical parameters, such as relative water content (RWC), antioxidant enzymes activity, and total soluble protein in drought and normal conditions. At the stress level from 100 to 40% of field capacity, a gradual decrease in chlorophyll and CARs contents was observed and under stress and normal conditions, the application of Se-NPs (10 mg L⁻¹) led to an increase in the content of pigments. Total soluble protein, total phenolic and flavonoid contents showed significant increases in plants treated with Se-NPs under drought stress. Generally, the use of Se-NPs in drought stress

conditions can be effective in improving the growth, biochemical, and physiological characteristics of savoury.

Polyamines (PAs) are plant growth regulators that attenuate the destructive impacts of water deficit on sesame plants, particularly in arid regions under abrupt climate change. Limited information is available on the physiological, biochemical, anatomical, and agronomic responses of sesame to exogenous application of PAs under water deficit under field conditions. Thus, a two-season field trial was carried out to assess the impact of exogenously sprayed spermine (Spm), spermidine (Spd), and putrescine (Put) on physio-biochemical and anatomical parameters and their influences on agronomic performance and crop water productivity of sesame plants. The sesame plants were assessed under three irrigation regimes; full irrigation (100% ETc), mild drought (75% ETc), and severe drought (50% ETc) conditions. Drought stress displayed negative impacts on all evaluated parameters. However, exogenously applied PAs, especially Put, restricted the destructive effects of water deficit. The application of PAs exhibited highly significant enhancement in photosynthetic pigments (chlorophyll a, b, and carotenoids), gas exchange (net photosynthetic rate, stomatal conductance, and rate of transpiration), water relations (relative water content, membrane stability index, excised leaf water retention), and plant nutrient content (N, P, and K) compared to untreated plants, particularly under severe drought stress. Moreover, PA application displayed highly significant amelioration in osmoprotectants (free proline, soluble sugars, α -Tocopherol, ascorbate, and glutathione), and antioxidant enzyme activities (catalase, peroxidase, superoxide dismutase, ascorbate peroxidase, and glutathione reductase). In addition, foliar nourishing with PAs exhibited a highly significant reduction in oxidative stress markers (malondialdehyde, electrolyte leakage, superoxide, and hydrogen peroxide). These positive impacts of PA application under drought stress were reflected in highly significant improvement in anatomical characteristics (midrib length and width, vascular bundle length and width, thickness of phloem, xylem and collenchyma, vessel diameter, and number of xylem rows in midvein bundle), and yield-related traits (plant height, leaf area, number of capsules per plant, 1000-seed weight, seed yield, and oil content). Consequently, exogenous application of PAs (in particular, Put) could be exploited to enhance the crop water productivity and yield traits of sesame plants under low water availability in arid regions.

Hartikainen *et al.* (2000) reported that selenium is an essential element for antioxidation reactions in human and animals. In order to study its biological role in higher plants,

ryegrass (*Lolium perenne*) was cultivated in a soil without Se or amended with increasing dosages of H_2SeO_4 (0.1, 1.0, 10.0 and 30.0 mg Se kg^{-1}). Ryegrass was harvested twice and the yields were analyzed for antioxidative systems and growth parameters. Selenium exerted dual effects: At low concentrations it acted as an antioxidant, inhibiting lipid peroxidation, whereas at higher concentrations, it was a pro-oxidant, enhancing the accumulation of lipid peroxidation products. The antioxidative effect was associated with an increase in glutathione peroxidase (GSH-Px) activity, but not with superoxide dismutase (SOD) and α -tocopherol, which was the only tocopherol detected. In the second yield, the diminished lipid peroxidation due to a proper Se addition coincided with promoted plant growth. The oxidative stress found at the Se addition level ≥ 10 mg kg^{-1} resulted in drastic yield losses. This result indicates that the toxicity of Se can be attributed, in addition to metabolic disturbances, to its pro-oxidative effects. Neither the growth-promoting nor the toxic effect of Se could be explained by the changes in the total chlorophyll concentration.

Patnaik *et al.* (2022) reported that the effects of foliar selenium (Se) spray on the reduction of drought stress are measured and the most critical stage of rice is identified. Three field experiments were carried out. In experiments I and II, the sensitive stage was determined by imposing drought stress at the panicle initiation and flowering stages by withholding irrigation for 10, 15, 20, and 25 days. In experiment III, drought stress was induced by depriving plants of moisture for 20 or 25 days. Se spray was then applied at rates of 0, 10, and 20 mg L^{-1} to alleviate the drought, and its effects were evaluated. Overall, it was reported that the panicle initiation stage was more vulnerable to drought stress than the flowering stage, as evidenced by a larger reduction in grain yield. Employing Se as a foliar spray at a rate of 20 mg L^{-1} under drought stress enhanced the number of filled grains m^{-2} , the total number of grains m^{-2} , and grain yield ha^{-1} by 22.0, 4.3, and 11.0%, respectively, over water spray. This shows a positive interaction or synergistic interaction between drought tolerance and selenium application. These results demonstrate that foliage supplementation of Se at a dosage of 20 mg L^{-1} alleviate the adverse effects of drought stress at the panicle initiation stage in rice cultivation. Se mitigated the negative effects of drought by improving the membrane stability index, relative water content, and proline content.

Kharkeshi *et al.* (2023) reported that Drought is one of the major limiting factors for crops that severely reduce plant growth and productivity. The application of cytokinin (Ck) and silicon (Si) fertilizers can help increase tolerance to drought stress in sesame

plants. The present study aimed to evaluate the effects of Ck and Si fertilizers on seed yield, malondialdehyde (MDA) content, proline content, and antioxidant enzyme activities in sesame plants under drought-stress conditions. The experiment was conducted as a split plot-factorial in a randomized complete block design with three replications at Firuzkandeh Agricultural Research Station during two crop years of 2020 and 2021. The main plot was three drought stress levels: control, moderate drought stress (MDS), and severe drought stress (SDS), whereas the subplots were three Si application levels: control or non-use of Si, calcium silicate and nano-Si, and two Ck application levels: control or non-use of Ck, Ck application. The results indicated that the sesame seed yield was reduced by 9.3% under MDS and by 32.7% under SDS when compared with control conditions. The highest MDA content and proline accumulation were observed when the plants were subjected to SDS, whereas the higher activity of antioxidant enzymes occurred under MDS. Higher activity of antioxidant enzymes and reduction of MDA content was observed in the plants treated by combined application of Si and Ck under MDS. However, the higher seed yield, greater proline content, and higher antioxidant enzyme activities were obtained from plants treated by nano-Si than calcium silicate. Overall, the results of the present study revealed that the foliar application of nano-Si+ Ck can be a promising option for mitigating the negative impacts of drought stress and improving sesame seed yield.

Daler *et al.* (2024) various vineyard management strategies have been developed to improve water use efficiency in vineyards and reduce drought-induced stress damage in grapevines. These strategies include; dry farming conditions, deficit irrigation applications, the use of tolerant varieties and rootstocks, mulching and cover crops, reducing the use of nitrogen-based fertilizers and certain training systems, and the use of remote sensing technologies to design more efficient irrigation programs. These developed techniques are vital in mitigating the damage caused by both high temperatures and drought due to climate change. However, today, strategies to adapt viticultural practices to the challenges of climate change are based on innovative management techniques. Recent studies have highlighted nanotechnology (NT) as an effective strategy for mitigating the adverse effects of environmental stress and reducing crop yield and quality losses. Although the use of NT in the agricultural industry is relatively new, nanoparticles (NPs), which form the basis of NT, have a wide potential for application in agricultural fields due to their distinctive physicochemical properties such as surface-to-volume ratios, size, and optical properties. Research has shown that NP applications are an effective strategy for increasing tolerance to various

environmental stress factors in plants and ensuring sustainability in agricultural areas . On the other hand, selenium (Se), by acting as an antioxidant, can protect plants from oxidative damage and modulate the adverse effects of abiotic stresses on plants. However, while the effectiveness of NPs in improving stress tolerance varies among plant species, the most effective concentration range also differs. Therefore, more research is needed to investigate the potential of NPs for use in agricultural areas, evaluate the advantages and potential disadvantages of their effects on plant growth and development, as well as biotic and abiotic stress tolerance in detail. Understanding the mechanisms of action of NPs is of great importance, especially for a plant species with a large production area and high economic value, such as grapevines. However, due to the lack of studies investigating the effects of Se-NPs on abiotic stress tolerance in grapevines in the current literature, significant gaps exist. In the reviews conducted, no study was found evaluating the effects of Se-NPs on the defence mechanisms developed against drought stress in grapevines.

Jeyaraj *et al.* (2024) reported that Drought is one of the most significant abiotic stresses that affect plant performance, lowers agricultural output, and, in extreme cases, results in crop loss. The major challenge faced by farmers is to ensure the production of crop varieties under extreme environmental conditions. Sesame (*Sesamum indicum* L.) is a traditionally important major cash crop for small and marginal farmers in some developing countries since it requires less intensive care and investment. Although sesame is considered as a resilient crop, it remains sensitive to severe drought. In this study, the morpho-physiological, biochemical, and antioxidant responses of wild and cultivar species of *Sesamum* viz., *S. radiatum*, and *S. indicum* subjected to different irrigation treatments such as mild (75 % Field capacity), moderate (50 % FC) and severe (25 % FC) drought and subsequent recovery (rewatered to 100 % FC) were evaluated in comparison with control groups. Present findings revealed that both species displayed differential responses to the drought stress and subsequent recovery. In particular, the wild taxa demonstrated better drought tolerance, probably due to their higher leaf-relative water content, decreased lipid peroxidation, enhanced accumulation of osmolytes, and increased activities of enzymatic and non-enzymatic antioxidants. On the other hand, the cultivar presented reduced leaf-relative water content, increased lipid peroxidation, higher electrolyte leakage, and reduced antioxidant activities, mostly at 25 % FC. Present data suggests that the cultivar was strictly exacerbated, mostly during severe water deficits; however, the wild species could re-adjust to the water deficit circumstances and recover completely. The current study implies the potential of wild

species that can be used to improve the drought tolerance of commercial sesame by utilizing the same in breeding programs.

El Sayed *et al.* (2023) reported that plants are exposed to the problem of drought. Trial conducted on increasing plant tolerance to drought and improving the quality of its yield throughout the use of phosphate and iron fertilizer. A field experiment was conducted at the Research and Production Station of the National Research Centre, Nubaria region, Behira Governorate, Egypt to test the effects of phosphorus (0, 25, 50, 100 Kg fed⁻¹) and ferrous sulphate (0, 50, 100 and 150 ppm) on the phytochemical composition of sesame seeds resulted from plants grown under sufficient and deficit irrigation regimens. Increasing phosphorus rates was affiliated with increasing the macro and micronutrient, oil, protein, carbohydrates %. `Also, Antioxidant compounds (Phenol and flavonoids) and total DPPH radical scavenging of sesame seeds were increased(P<0.05) significantly .Under both irrigation systems, the application of phosphorus (100 Kg fed⁻¹) with Fe sulphate (150 ppm) induced the most significant increase in all previous parameters. It can be concluded that, the use of triple phosphate fertilizer and spraying sesame plants with iron at 100 Kg/fed plus 150 ppm Iron improved the chemical components and consequently the nutritive value of sesame seeds due to increasing plant tolerant to water deficit.

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled, “Selenium (Se) nanoparticles to mitigate drought stress and improve growth, yield and yield attributes of Sesame (*Sesamum indicum* L.)” was carried out during May 2024 to July 2024 at the Agronomy Shade House of Hajee Mohammad Danesh Science and Technology University, Dinajpur. The details of the research work carried out, materials used and methodologies adopted in this research are described here under the following headings:

3.1 Geographical location of the experimental site

The experiment was conducted in the Agronomy Shade House, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh from May 2024 to July 2024. The experimental region is located between 25° 44.574'N and 88° 40.344'E and is 40 meters above sea level, as illustrated in (Figure 1a and 1b).

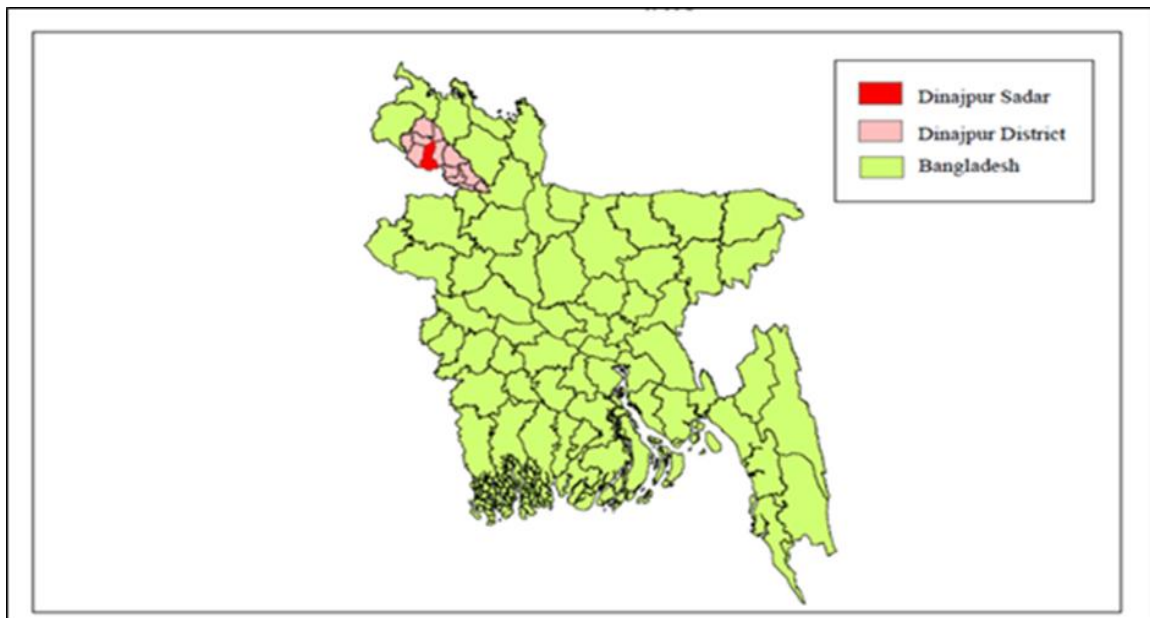


Figure 1 (a): Location of experimental area

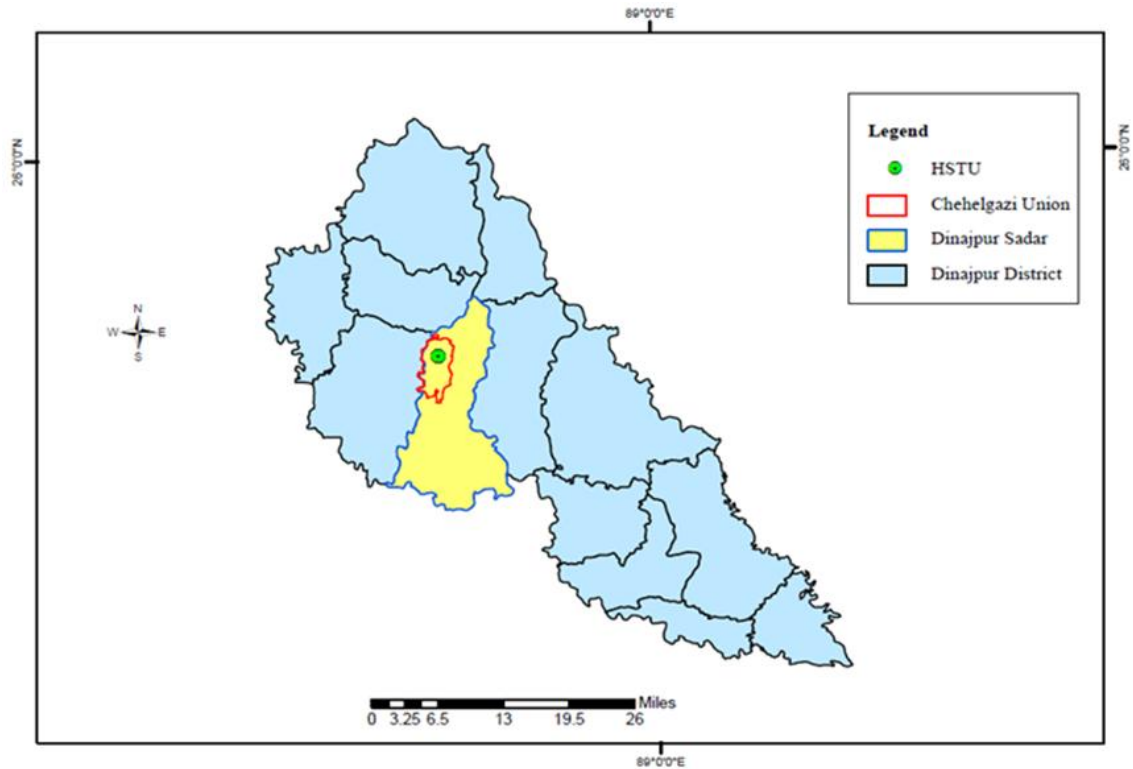


Figure 1 (b): Location of experimental field

3.2 Weather and Climate

The experimental site is suited to the sub-tropical climate zone and characterized by winter during the months of December to April and medium to high temperature during the rest of the year. The crop was grown in the winter season when the day length (sunshine period) was reduced to 8-12 hours per the temperature during the cropping period ranging between 12 and 16° C with generally 60-95% humidity in the air. The monthly average temperature, humidity, rainfall, and sunshine hours that prevailed at the experimental site during the cropping season are presented in (Appendix I).

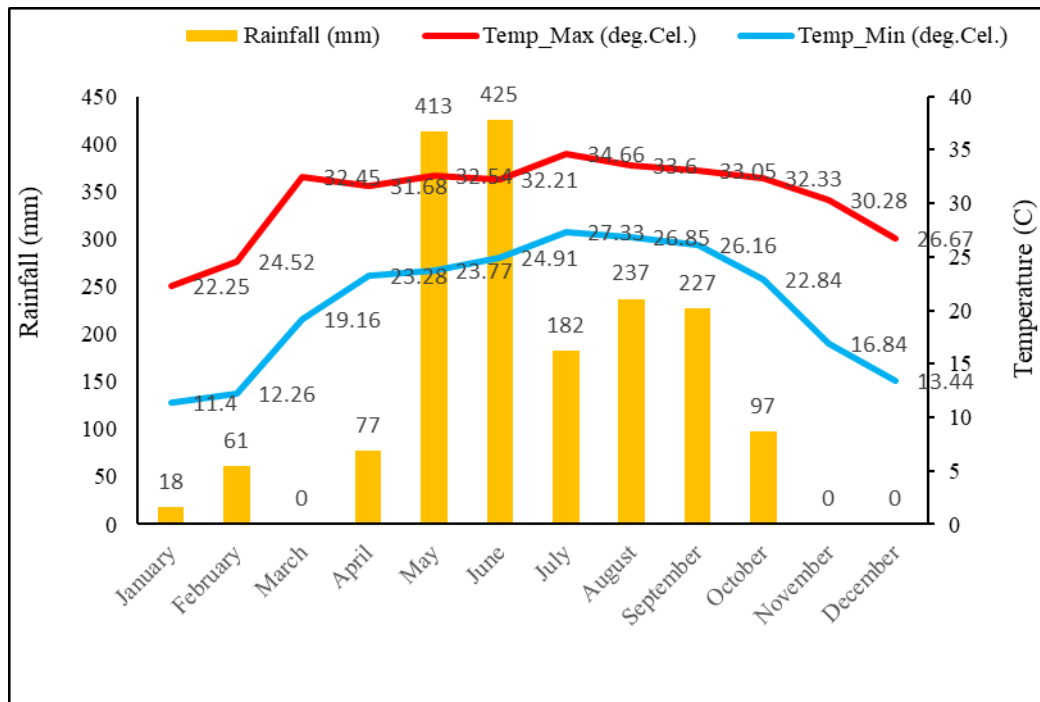


Figure 2(a). Maximum and minimum temperatures (2024)

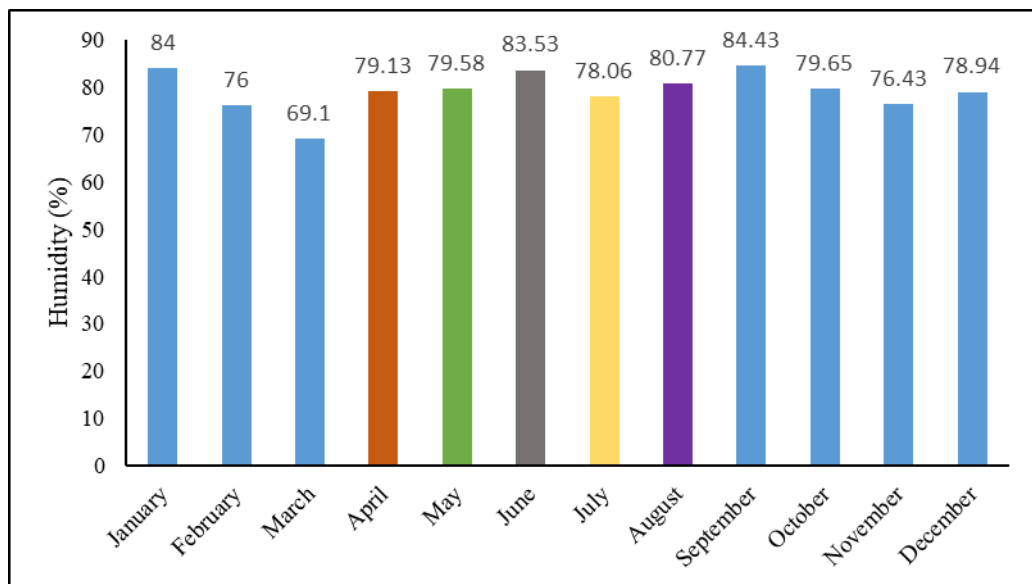


Figure 2(b).Relative humidity and rainfall (2024)

3.3. Soil Properties

The soil on the experiment field is from the Old Himalayan Piedmont Plain (AEZ-1). A variety of soil that drains well. The study plot was a medium-high piece of land with a pH range of 6.12, meaning that the soil is acidic. Before beginning the experiment, and after finishing the research experiment the soil's physical and chemical parameters at the test site were examined. The results of a soil analysis conducted by the Soil Resource

Development Institute (SRDI), Dinajpur, Bangladesh, are displayed in (Table 1). Soil analysis showed that the soil of the experimental plot was sandy loam. The morphological, physiological, and chemical characteristics of the soil have been presented in Appendix II.

3.4 Experimental periods

The experiment was carried out during the Kharif season from May 2024 to July 2024. Seeds were sown on 08th May 2024 and harvested up to last week of July 2024.

3.5 Planting material

One variety of sesame (common name Til) seeds were used in this experiment. The used variety was (BINA Til-3) seeds were collected from the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.

3.6 Description of the sesame variety:

BINA Til-3

- I. BINA Til-3 is moderately tolerant to drought and resistant to common sesame diseases like phyllody and leaf spot; it was released in 2014.
- II. It can be grown in Kharif-1 (mid-February to mid-March) season.
- III. It is suitable for cultivation in high land with sandy loam to loam soils.
- IV. This variety is moderately branched and has less hairiness.
- V. Stem, leaf, and capsule are light green in color with white seed coat.
- VI. Each node generally bears 2–4 medium to large-sized capsules.
- VII. It can produce a maximum seed yield of 1.5 t ha⁻¹ under favorable conditions.
- VIII. Maturity period ranges from 85–90 days.
- IX. The seed contains about 50–52% oil and is rich in vitamins A, D, and E.
- X. This variety is suitable for cultivation across various regions of Bangladesh.

3.7 Treatments of the experiment

The experiment comprises one factor:

Factor : Selenium (Se) nanoparticles

T₀ = Control

T₁ = 5 ppm = 5 mg/L water

T₂ = 10 ppm = 10 mg/L water

T₃ = 15 ppm = 15 mg/L water

T₄ = 20 ppm = 20 mg/L water

T₅ = 25 ppm = 25 mg/L water

T₆= 30 ppm= 30 mg/L water

T₇= 35 ppm = 35 mg/L water

3.8 Experimental layout and Design

The one-factor experiment was laid out in the Completely Randomized Design (CRD) with three replications. Total pots were divided into three equal blocks. Each block consisted of 8 pots where 7 treatment combinations of variety with selenium (Se) nano-particles doses were assigned randomly as per the design of the experiment. There were 24 pots altogether in the research experiment. The size of the pot was 0.06 m² therefore one treatment assigned with 0.06m² area (Figure 3).

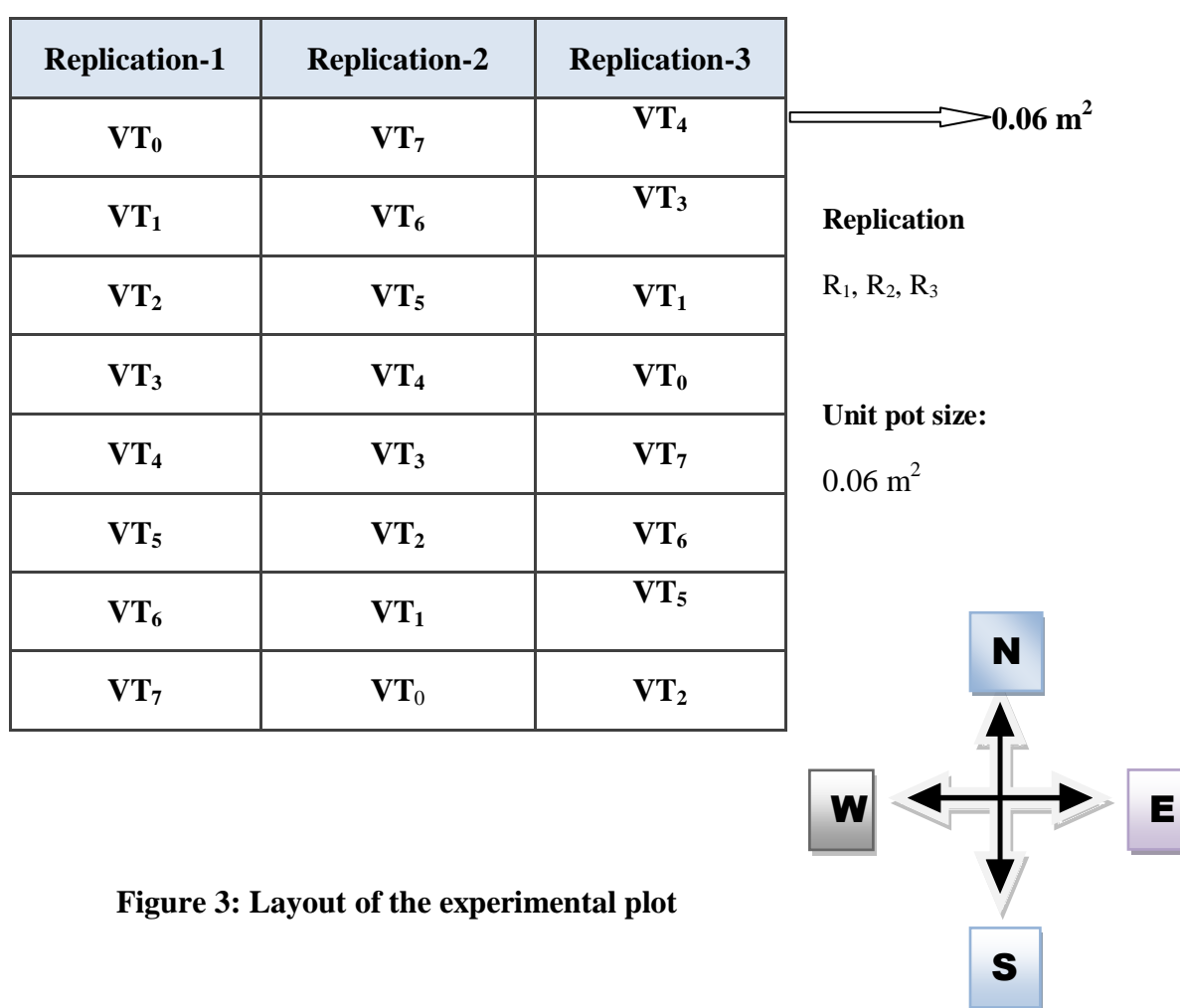


Figure 3: Layout of the experimental plot

3.9 Cultivation Procedure

3.9.1 Preparation of the field

The experimental pot was officially inaugurated on May 5, 2024, and soon after that the pots were repeatedly ploughed to get a better tilth. To provide a desirable tilth of friable soil for seedling transplantation, weeds and stubbles were removed, and the huge clods were broken into smaller pieces. The experiment's design called for subdividing the

entire experimental region into blocks and pots for the sesame crop. Additionally, channels for drainage and irrigation were created in all the pots.

3.9.2 Application of manures and fertilizers

After final land preparation, the following fertilizers were used:

Name of the fertilizers	Doses/pot
Urea	16g
TSP	19.68g
MoP	6.36g
Zinc Sulphate	710.16mg
Gypsum	15.36g
Boric acid	1.44g

3.9.3 Treatment application

In this experiment, which aimed to identify the optimal foliar selenium application for sesame growth under drought conditions, five treatments (different concentrations of Se: 0, 5, 10, 15, 20, 25, 30, and 35 mg/L) were used 25 days after sowing. These treatments were applied separately, while three other sets of pots were left untreated as controls. On the same day, the drought stress began. A Completely Randomized Design was used with three replications. SeNPS solution was sprayed using a hand pump sprayer. The applications were done once in the morning to ensure uniform coverage and maximize absorption by the plants.

3.9.4 Seed rate and sowing

The recommended seed rate 2 g/0.06 m² of different Sesame/Til variety seed was used for a single pot. After placing the seeds on pot, the seeds were covered with loose friable soil. After preparing the pots, seeds were sown on 8May 2024 as per the experimental layout.

3.10. Intercultural operations

3.10.1 Thinning and weeding

Seeds started germination five days after sowing (DAS). Thinning was done two times; at 12 DAS and at 18 DAS to maintain optimum plant population in each plot. The first weeding was done at 20 DAS (28th May, 2024), and then weeded as necessary of the experimental plots.

3.10.2 Gap Filling

Gap filling was not necessary for Til cultivation.

3.10.3. Irrigation

Irrigation was done whenever it was necessary. Minimum irrigation were applied to the crop from the sowing to the harvesting period.

3.10.4 Plant Protection

The crop was protected from the attack of insect-pest by spraying insecticide. The insecticide application was made fortnightly as a matter of routine work from seedling emergence to the end of harvest.

3.11 Harvesting and threshing

The harvesting of the crop was done on 28 July 2024, when the plants dried up and capsules turned brown in color. The harvested crop was tied in well labeled bundles and then threshing was done manually on 2th August 2024.

3.12 Drying, cleaning, and weighing

The seeds thus collected were dried in the sun for reducing the moisture in the seeds to a constant level. The dried seeds and straw were cleaned and weighed.

3.13 Recording of data

Data were collected based on the yield and yield characteristics of the sesame plant. The characteristics were;

- Plant Height (cm)
- Branch Number Plant⁻¹(no.)
- Leaf Area Index (%)
- Capsule Length (cm)
- Capsule Width (cm)
- Capsule Fresh Weight Plant⁻¹ (g)
- Capsule Dry Weight Plant⁻¹ (g)
- Total Plant Weight (g)
- Stover Yield pot⁻¹
- Seed yield pot⁻¹

These data were taken when the crop attained maturity. With this point of view, three plants were randomly collected from each plot. From these, plant height, numbers of

branches Plant⁻¹, leaf area index (%), capsule length (cm), capsule width (cm), capsule fresh wt Plant⁻¹ (g), capsule dry weight plant⁻¹, total plant wt (g), stover yield pot⁻¹ and seed yield pot⁻¹ were noted.

3.13.1 Plant Height (cm)

Plant height of the main shoot was measured from the base of the main shoot up to the top of the highest leaf and expressed in cm.

3.13.2 Number of branches per plant

Three representative plants from each plot were selected randomly and number of primary as well as secondary branches were counted, and then presented on plant⁻¹ basis. These were recorded periodically at 25 days intervals.

3.13.3 Leaf Area index (%)

The leaf area index is a reliable parameter for studying the effects of the environment on plants. Leaves are one of the main plant organs and are responsible for the productivity of a plant. Selected three plants from each pot were used to measure the leaf area. Leaf area (A) can be simply calculated by multiplying the product of leaf length (L) and leaf width (W) by a constant. It was recorded in cm. Finally, the leaf area index (LAI) was calculated using the following ratio:

Leaf area Index (LAI) = Total leaf area (cm²)/ Total ground area (cm²) from where the plants were sampled.

3.13.4 Capsule Length (cm)

The capsules from each randomly selected plant were measured using a centimeter scale and the mean value was calculated and expressed in centimeters.

3.13.5 Capsule Width (cm)

Ten representative pods were harvested from each plot at maturity and capsule width was measured and averaged.

3.13.6 Capsule Fresh Weight plant⁻¹(g)

As per the treatment combination, fresh plant sample weight of unit plant were taken by a digital weighing machine accordingly and expressed in gram.

3.13.7 Capsule Dry Weight plant⁻¹(g)

The plant samples were dried and weight of a dry plant were taken by a digital weighing machine accordingly and expressed in gram.

3.13.8 Total Plant weight (g)

As per the treatment combination, the weight of plant samples from all plot were taken by a digital weighing machine accordingly and expressed in gram.

3.13.9 Cell Membrane Stability (CMS)

Leaf samples (1.0 g) were carefully gathered and thoroughly washed with distilled water to eliminate any electrolytes. The samples were then put in vials containing 10 mL of distilled water to test the cell membrane stability. The vials were sealed and incubated for 6 hours at 25°C before measuring the solution's electrical conductivity (EC1). Following that, the samples were placed in an electric oven set to 90°C for two hours, and the solution's electrical conductivity (EC2) was measured.

$$\text{CMS (\%)} = 100 \times (\text{EC1}/\text{EC2})$$

3.13.10 Canopy Temperature

Canopy temperature was assessed utilizing a portable infrared thermometer (Model: Crop TRAC, item no. 2955L, Spectrum Technologies, Inc., Beijing-10000, China). Measurements were obtained from roughly 50 cm above the canopy at a 30° angle relative to the horizon. The canopy temperature differential (CTD) was measured at 79 days after sowing (DAS) in clear sunlight and negligible wind conditions, utilizing the method established by Ayeneh *et al.* (2002).

3.13.11 Seed Yield ha⁻¹

Mature capsule pods were harvested from each plot and seeds were separated from capsules their weight was recorded. The seed yield per pot was finally converted to yield per pot and expressed in gram (g).

3.13.12 Stover Yield pot⁻¹

Mature sesame plants were harvested from each plot and seeds and stover was separated and weight of the stover was recorded. The stover yield per plot was finally converted to stover yield per pot and expressed in gram (g).

3.14 Statistical Analysis

The statistical analysis of recorded data for various parameters was done according to Completely Randomized Design (CRD), by using R programming (version 4.2.3) and the mean differences were adjusted by the Least Significant Difference (LSD) test at 5% level of significance. Comparison graphs were done by Microsoft Excel programming. Weather graphs were done by using Origin pro (2022) software.

CHAPTER IV

RESULTS AND DISCUSSION

The present experiment investigated the foliar application of selenium for improving drought tolerance for growth and yield of sesame (*Sesamum indicum* L.) The results of the experiment analyzed statistically are discussed in this section through tables, figures and other information with cause, effects and corroborative research findings of the scientists.

4.1 Plant height

Table 1 showed that at 28 DAS, treatments T₄ (22.96 cm) and T₆ (23.54 cm) produced the tallest plants, significantly outperforming the control (T₀) and lower Se doses (T₁-T₃). By 60 DAS, the growth pattern shifted remarkably, with T₄ (1732.73 cm) and T₅ (1699.28 cm) showing the maximum heights, followed by T₂ (1485.29 cm) and T₃ (1522.86 cm). Interestingly, the highest 28 DAS performer (T₆) showed reduced growth by 60 DAS (979.41 cm), suggesting possible Se toxicity at this concentration (30 mg/L) over extended periods. The control (T₀) consistently showed the poorest growth at both stages (28 DAS and 60 DAS). These results indicate that moderate Se doses (T₄: 20 mg/L and T₅: 25 mg/L) optimally promote sustained growth, while higher concentrations may initially stimulate but ultimately inhibit plant development which was aligned with Ahmad *et al.* (2024) concluded that the T₄ and T₅ treatments (40 ppm and 50 ppm) of SeNPs, applied through seed and foliar methods, have a strong influence on the overall growth. Thuc *et al.* (2021) confirms that selenium can be applied to enhance sesame's tolerance to drought stress.

4.2 Number of leaves

Table 1 showed that at 28 DAS, leaf numbers ranged from 5.06 (T₀, control) to 7.60 (T₆), showing a general increasing trend with higher Se concentrations. Treatment T₆ (30 mg/L Se) produced significantly more leaves (7.60) than other treatments. However, by 60 DAS, the pattern changed substantially where T₁ (5 mg/L Se) showed the highest leaf number (73.85), followed by T₅ (25 mg/L Se, 63.24), the initially high-performing T₆ at 28 DAS produced only moderate leaf numbers (51.05) at 60 DAS. The superior performance of T₁ at 60 DAS suggests that very low Se concentrations may be most beneficial for long-term leaf development in sesame, while higher concentrations show diminishing returns or possible inhibitory effects over time. The control (T₀) consistently showed the lowest leaf counts at both stages (39.94 at 60 DAS). Both Ahmad *et al.*

Table 1. Effect of foliar application of selenium on plant height and number of leaves at different DAS for improving drought tolerance of sesame

Treatments	Plant height at 28 DAS	Plant height at 60 DAS	Number of leaves at 28 DAS	Number of leaves at 60 DAS
T ₀	19.14 e	784.7 c	5.06 d	39.94 c
T ₁	20.4 de	1193.27 bc	5.73 cd	73.85 a
T ₂	21.23 cd	1485.29 ab	6.53 bc	44.66 bc
T ₃	21.9 bc	1522.86 ab	6.06 bc	45.28 bc
T ₄	22.96 ab	1732.73 a	6.7 ab	54.94 abc
T ₅	21.8 bcd	1699.28 a	6.73 ab	63.24 ab
T ₆	23.54 a	979.41 c	7.6 a	51.05 bc
T ₇	21.66 bcd	1091.26 bc	5.93 bcd	34.21 c
CV%	3.76	10.6	8.37	11.09
LSD	1.42	11.75	0.92	12.58

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD = Least Significant difference, CV = Co-efficient of variance.

(2023) and Thuc *et al.* (2021) reported that plant growth and development were accelerated by SeNPs and maintained the number of leaves, which ultimately led to an increase in crop yield.

4.3 SPAD value

The data demonstrates a significant relationship of chlorophyll content to selenium (Se) application at both 28 and 51 days after sowing (DAS) (Table 2). At 28 DAS, chlorophyll levels increased progressively from 52.86 SPAD units (T₀, control) to a maximum of 58.03 (T₅, 25 mg/L Se), also higher Se concentrations (T₄-T₆) showing significantly greater values than the control. This trend became even more pronounced at 51 DAS, where T₆ (30 mg/L Se) reached 58.26 SPAD units compared to 41.43 for control treatment. This might be that Se enhances chlorophyll biosynthesis and stability by acting as an antioxidant to reduce ROS-induced chlorophyll degradation and activating enzymes involved in chlorophyll synthesis which maintaining chloroplast membrane integrity under drought stress though the slight decrease in T₇ (35 mg/L) may indicate the threshold for beneficial effects. These results align with selenium's known roles in antioxidant defense and stress mitigation. Similarly, Se enhancing chlorophyll content, and combating various biotic and abiotic stresses as observed by Sharma *et al.* (2022).

Table 2. Effect of foliar application of selenium on SPAD value, chlorophyll and carotene at different DAS for improving drought tolerance of sesame

Treatments	Chlorophyll at 28 DAS	Chlorophyll at 51 DAS	Chl a	Chl b	Carotene
T ₀	52.86 d	41.43 f	0.35 c	0.55 d	0.63 d
T ₁	53.7 cd	43.6 ef	0.62 ab	0.74 cd	0.81 cd
T ₂	54.96 cd	44.93 e	0.33 c	0.78 bcd	1.18 abcd
T ₃	55.56 bc	46.8 de	0.72 a	1.35 a	1.29 abc
T ₄	57.63 ab	48.7 cd	0.73 a	1.48 a	1.71 a
T ₅	58.03 a	54.93 b	0.46 bc	1.25 abc	1.61 ab
T ₆	57.76 a	58.26 a	0.5 abc	1.29 ab	0.94 cd
T ₇	53.66 cd	51.6 c	0.48 abc	1.14 abc	1.06 bcd
CV%	2.21	3.82	27.47	27.37	28.28
LSD	2.14	3.26	0.25	0.52	0.57

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD= Least Significant difference, CV= Co-efficient of variance.

4.4 Photosynthetic pigment

The data reveals significant variations in photosynthetic pigment composition (Chl a, Chl b, and carotene) across different selenium (Se) treatments in sesame plants (Table 2). Treatment T₄ (20 mg/L Se) emerged as optimal, showing the highest values for chlorophyll a (0.72 mg/g), chlorophyll b (1.48 mg/g), and carotene (1.71 mg/g), representing increases of 106%, 169%, and 171% respectively compared to the control (T₀). These findings highlight that 20 mg/L Se represents the ideal concentration for maintaining photosynthetic apparatus integrity, optimizing light harvesting efficiency, and providing comprehensive photo protection in sesame plants under drought conditions. Beyond the optimal concentration, treatments T₅-T₇ (25-35 mg/L) showed declining pigment levels, suggesting potential oxidative stress or disruption of chlorophyll synthesis machinery at higher Se doses. Sharma *et al.* (2022) also found similar results.

Table 3. Effect of foliar application of selenium on leaf temperature, canopy temperature and cell membrane stability at different DAS for improving drought tolerance of sesame

Treatments	Leaf temp at 28 DAS	Leaf temp at 51 DAS	Canopy temp at 28 DAS	Cell membrane stability at 115 DAS
T ₀	30.71 c	28.97 e	28.6 bc	35.4 d
T ₁	30.99 c	30.39 d	28.92 b	48.67 bc
T ₂	32.15 ab	31 cd	29.06 b	47.12 c
T ₃	32.25 ab	31.59 abc	29 b	54.01 abc
T ₄	32.59 a	31.51 abc	29.28 b	60.1 a
T ₅	32.41 a	32.11 ab	29.53 b	59.28 ab
T ₆	32.8 a	32.29 a	30.63 a	57.6 abc
T ₇	31.33 bc	31.12 bcd	27.76 c	47.87 c
CV%	1.65	1.96	1.87	11.84
LSD	0.92	1.07	0.95	10.63

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD = Least Significant difference, CV = Co-efficient of variance.

4.5 Leaf temperature

The leaf temperature data demonstrates selenium's significant influence on sesame plants' foliar temperature regulation under drought conditions (Table 3). Here, at 28 DAS, leaf temperatures increased progressively with higher Se concentrations, ranging from 30.71°C (T₀ control) to 32.80°C (T₆, 30 mg/L Se), with T₄-T₆ showing significantly higher temperatures than the control. This trend continued at 51 DAS, where T₆ maintained the highest temperature (32.29°C), followed by T₅ (32.11°C), while the control remained coolest (28.97°C). At both 28 and 51 DAS, selenium-treated plants consistently maintained higher leaf temperatures than the control, with the most pronounced effects observed at concentrations of 20-30 mg/L (T₄-T₆). This temperature elevation suggests selenium mediates important physiological adaptations, likely through modulation of stomatal conductance and transpiration rates (Yadav *et al.*, 2023).

4.6 Canopy temperature

The canopy temperature data reveals significant variations among selenium treatments at 28 DAS (Table 3). The control (T₀) exhibited moderate canopy temperature (28.6°C), while treatments T₁-T₅ (5-25 mg/L Se) showed slightly higher but statistically similar

temperatures (28.92-29.53°C). Notably, T₆ (30 mg/L Se) recorded the highest canopy temperature (30.63°C), significantly warmer than all other treatments. In contrast, T₇ (35 mg/L Se) displayed an unexpected cooling effect (27.76°C), becoming significantly cooler than even the control. This non-linear response suggests a concentration-dependent shift in selenium's physiological action - while moderate doses (5-25 mg/L) maintain stable canopy temperatures, the highest dose (30 mg/L) may induce stomatal closure and reduced transpiration, whereas the extremely high dose (35 mg/L) might trigger alternative stress responses leading to cooler canopies. Zhong *et al.* (2024) conducted an experiment and found that exogenous applications of Se could modulate canopy temperature of tomato.

4.7 Cell membrane stability

The cell membrane stability (CMS) data demonstrates significant effect of Se on sesame plants under drought conditions (Table3). The control plants (T₀) showed the lowest CMS (35.4%), indicating substantial membrane damage from prolonged drought stress. Selenium application markedly improved membrane integrity across all treatments where the maximum CMS (60.1%) was achieved with 20 mg/L Se (T₄) over the control, followed by 25 mg/L Se (T₅) at 59.28%. Interestingly, higher selenium concentrations (T₆-T₇) showed reduced effectiveness compared to T₄-T₅, suggesting a threshold beyond which additional selenium may not further enhance membrane stability or could potentially induce mild stress. Semida *et al.* (2021) found that the optimal concentration range provides sufficient antioxidant protection to maintain membrane fluidity and prevent electrolyte leakage.

4.8 Leaf Length

The selenium treatments significantly influenced leaf length (Table 4), with T₄ (20 mg/L Se) producing the longest leaves (65.13 cm), while T₀ (control) and T₇ (35 mg/L Se) showed the shortest lengths (42.2 cm and 42.51 cm, respectively). The superior performance of T₄ suggests that moderate selenium doses enhance cell elongation and expansion, likely through improved auxin metabolism and cell wall loosening (Malheiros *et al.*, 2020). In contrast, the poor growth in T₀ reflects selenium deficiency impairing these processes, while the similarly stunted growth in T₇ indicates potential selenium toxicity at high concentrations, possibly due to oxidative stress disrupting normal cell development.

Table 4. Effect of foliar application of selenium on leaf morphology for improving drought tolerance of sesame

Treatments	Leaf length	Leaf width	Leaf area	Ratio
T ₀	42.2 d	39.94 c	784.7 c	1.26 ab
T ₁	51.6 bcd	73.85 a	1193.27 bc	0.76 b
T ₂	48.05 cd	44.66 bc	1485.29 ab	1.27 ab
T ₃	56.24 abc	45.28 bc	1522.86 ab	1.02 b
T ₄	65.13 a	54.94 abc	1732.73 a	1.06 b
T ₅	63.52 ab	63.24 ab	1699.28 a	0.83 b
T ₆	54.84abcd	51.05 bc	979.41 c	1.06 b
T ₇	42.51 d	34.21 c	1091.26 bc	1.64 a
CV%	13.91	23.99	19.47	29.48
LSD	12.91	21.38	447.15	0.57

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD = Least Significant difference, CV = Co-efficient of variance.

4.9 Leaf Width

Table 4 showed that treatment T₁ (5 mg/L Se) achieved the maximum leaf width (73.85 cm), whereas T₀ and T₇ again showed the narrowest leaves (39.94 cm and 34.21 cm). The exceptional performance of T₁ suggests that very low selenium concentrations may optimally stimulate lateral leaf expansion, potentially by regulating cytokinin activity and promoting cell division in the leaf primordia. The narrow leaves in control plants demonstrate selenium's essential role in leaf development, while the poorest performance in T₇ reinforces the concept of a narrow optimal selenium range beyond which growth becomes inhibited.

4.10 Leaf Area

Table 4 showed that the largest leaf area (1732.73 cm²) occurred in T₄ (20 mg/L Se), with T₀ showing the smallest area (784.7 cm²). This pattern mirrors the leaf length results, confirming that moderate selenium doses optimally promote overall leaf expansion by enhancing photosynthetic activity and carbohydrate availability for growth. The control plants' limited leaf area reflects impaired carbon assimilation due to selenium deficiency, while the better but still suboptimal performance of higher doses (T₆-T₇) suggests excessive selenium may partially compensate for but not fully overcome the deficiency effects.

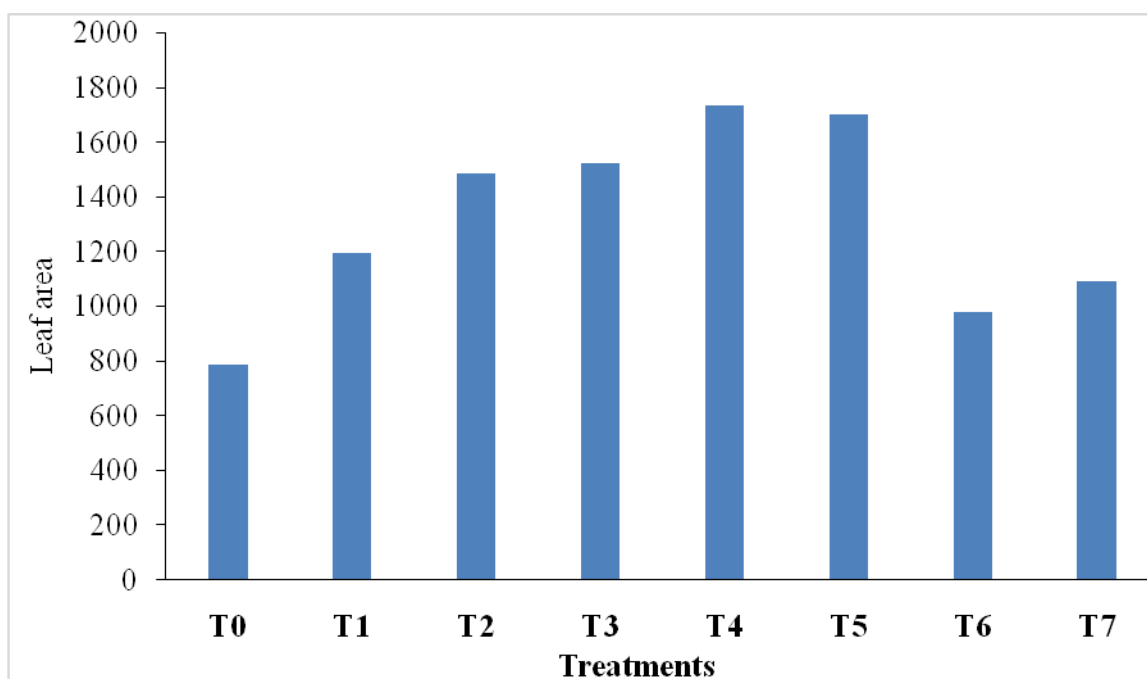


Figure 4. Effect of Se on leaf area of sesame

4.11 Leaf Ratio (Width/Length)

Table 4 showed that the highest ratio (1.64) occurred in T₇, indicating disproportionately wide leaves, while T₁ showed the most elongated form (0.76), with low doses (T₁) promoting elongation for better light capture and high doses (T₇) causing abnormal expansion, possibly due to disrupted hormone balance or water relations. The control plants maintained a balanced ratio (1.26), indicating that while selenium deficiency reduces overall size, it doesn't severely distort leaf morphology like toxicity can. Selenium concentration affects leaf shape regulation as found by Sun *et al.*, (2020),

4.12 Canopy Temperature Depression

The canopy temperature depression (CTD) data reveals distinct patterns among selenium treatments across different times of day (Table 5), highlighting their varying effects on plant thermoregulation. During morning measurements (9:30 am), selenium-treated plants generally showed greater CTD than the control, with T₃ (15 mg/L) exhibiting the strongest cooling effect (27.36°C versus control's 20.66°C), indicating enhanced stomatal opening and transpiration at optimal selenium doses. However, this pattern reversed dramatically by midday (12:30 pm), where the control surprisingly showed the highest CTD (27.1°C), while the highest selenium treatments (T₆-T₇) demonstrated reduced cooling (23.5-23.9°C), suggesting these concentrations may induce stomatal closure during peak heat to conserve water. The afternoon data (3:30 pm) maintained this

general trend but with smaller differences among treatments. This suggests 15 mg/L selenium may optimally regulate stomatal behavior throughout the day.

Table 5. Effect of foliar application of selenium on canopy temperature for improving drought tolerance of sesame

Treatments	Canopy temp depression 9.30 am	Canopy temp depression 12.30 pm	Canopy temp depression 3.30 pm
T ₀	20.66 c	27.1 a	29.1 a
T ₁	24.73 b	25.6 ab	27.43 ab
T ₂	26.06 ab	25.53 ab	27.4 ab
T ₃	27.36 a	25.36 ab	28.13 ab
T ₄	26.86 ab	25.33 ab	27.2 b
T ₅	27 ab	24.83 ab	28.16 ab
T ₆	25.66 ab	23.9 b	27.53 ab
T ₇	25.03 ab	23.5 b	26.83 b
CV%	5.45	5.46	3.63
LSD	2.42	2.4	1.76

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD = Least Significant difference, CV = Co-efficient of variance.

4.13 No. of pods per plant

The data on pod production per plant (Table 6), reveals a clear influence of selenium (Se) application on sesame reproductive performance. Treatment T₃ (15 mg/L Se) produced the highest number of pods (9.75 per plant) closely followed by T₄ (20 mg/L Se) with 9.31 pods and T₂ (10 mg/L Se) with 9.12 pods, demonstrating selenium's positive effect on reproductive development. But the poorest performance in the control (T₀) and near-control values in T₁ (5 mg/L Se, 7.91 pods) highlight the importance of adequate selenium for optimal pod formation, likely through its roles in flower fertility, pollination efficiency, and photosynthate allocation to reproductive structures.

4.14 Pod weight per plant

The pod weight data (Table 6), demonstrates a clear positive response to selenium (Se) application, with treatment T₄ (20 mg/L Se) producing the highest pod weight per plant (1.34 g) followed by T₅ (25 mg/L Se, 1.12 g) and T₃ (15 mg/L Se, 1.00 g), forming an optimal concentration range of 15-25 mg/L Se for maximizing pod weight. Meanwhile,

the control treatment (T₀) showed the lowest pod weight, highlighting the essential role of selenium in pod development and seed filling.

Table 6. Effect of Se on no of pods plant⁻¹, pod weight plant⁻¹, number of seed pod⁻¹, total seed weight plant⁻¹ of sesame

Treatments	No. of pods per plant	Pod weight per plant	Number of seeds per pod	Total Seed weight per plant
T ₀	7.89	0.76	5.56	0.79
T ₁	7.91	0.77	5.76	0.84
T ₂	9.12	0.89	13.44	0.97
T ₃	9.75	1.00	19.89	1.65
T ₄	9.31	1.34	26.34a	1.24
T ₅	8.78	1.12	26.56a	1.41
T ₆	7.98	1.08	26.00	1.23
T ₇	8.99	1.06	26.02	1.36
CV	4.26	3.95	4.27	3.22
LS	**	**	**	**
LSD _(0.05)	0.37	0.91	0.10	0.83

Here, T₀ = Control, T₁ = 5 ppm = 5 mg/L water, T₂ = 10 ppm = 10 mg/L water, T₃ = 15 ppm = 15 mg/L water, T₄ = 20 ppm = 20 mg/L water, T₅ = 25 ppm = 25 mg/L water, T₆ = 30 ppm = 30 mg/L water, T₇ = 35 ppm = 35 mg/L water, LSD= Least Significant difference, CV= Co-efficient of variance.

4.15 Number of seeds per pod

The Pod weight per plant number of seeds per pod (Table 6), showed a remarkable variation to selenium (Se) application. While the control (T₀) and low Se treatment T₁ (5 mg/L) produced few seeds (5.56 and 5.76 respectively), treatment T₂ (10 mg/L) showed higher value (13.44 seeds), demonstrating critical role of Se in reproductive development. The most significant number of seeds recorded from treatments T₄-T₇ (20-35 mg/L), which all achieved statistically similar high seed numbers (26.00-26.56 seeds) compared to control treatment. These results demonstrate that proper selenium nutrition can dramatically improve sesame's reproductive efficiency, with 20 mg/L emerging as the most effective dose for maximizing seed number per pod under the experimental conditions.

4.16 Total seed weight per plant

The total seed weight per plant (Table 6), data reveals significant variations among selenium treatments, with T₃ (15 mg/L Se) producing the highest yield (1.65 g/plant) - more than double the control (T₀, 0.79 g/plant). This peak performance was followed by T₅ (25 mg/L Se, 1.41 g) and T₇ (35 mg/L Se, 1.36 g), while T₄ (20 mg/L Se) showed a slightly lower but still substantial yield (1.24 g). On the other hand, the lowest total seed weight per plant was recorded in the control treatment (T₀) at 0.79 g, significantly underperforming compared to all selenium-treated plants. This poor yield outcome clearly demonstrates the detrimental effects of selenium deficiency on sesame productivity, particularly in terms of reproductive success and seed development.

4.17 Na content

The sodium (Na) content in sesame seeds showed minimal variation across most selenium treatments. However, a modest increase appeared at higher selenium concentrations, with T₄ (20 mg/L Se) reaching the highest Na level (180 mg/100g), followed by T₆ to T₇ (30-35 mg/L Se) at 170 mg/100g. This pattern suggests that selenium application ≥ 20 mg/L may influence ion accumulation, possibly by altering membrane permeability to Na⁺ ions, affecting sodium transporter activity, modifying plant water relations under stress conditions. While treatments T₀ to T₃ (0-15 mg/L Se) maintained consistently lower sodium levels of 150 mg/100g compared to T₄ treatment.

4.18 K content

The potassium (K) content in sesame seeds showed significant variation across selenium treatments, with T₅ (25 mg/L Se) recording the highest concentration at 260 mg/100g, representing a 30% increase over the control (T₀, 200 mg/100g). This peak was closely followed by T₄ (20 mg/L Se) and T₇ (35 mg/L Se) at 245 mg/100g, demonstrating that moderate to high selenium doses between 20-35 mg/L effectively enhance potassium accumulation. In contrast, the untreated control (T₀) showed the lowest potassium levels, highlighting selenium's role in improving mineral nutrition.

4.19 N content

The nitrogen (N) content in sesame seeds exhibited considerable variation across selenium treatments, with T₅ (25 mg/L Se) showing the highest concentration at 0.80% over the control (T₀, 0.44%). This peak nitrogen accumulation was followed by T₆ (30 mg/L Se) and T₇ (35 mg/L Se) at 0.68% and 0.67% respectively, while the lowest value in the untreated control (T₀) demonstrated selenium's crucial role in nitrogen metabolism. These results highlight that selenium application, particularly at 25 mg/L, can

substantially improve seed nitrogen content a critical factor for both nutritional quality and protein synthesis in sesame.

4.20 Yield (t ha^{-1})

The yield data demonstrates a clear positive response to selenium application (Figure 5), with T_5 (25 mg/L Se) achieving the highest yield of 1.22 t ha^{-1} more than double the control (T_0 , 0.6 t ha^{-1}) closely followed by T_4 (20 mg/L Se) at 1.2 t ha^{-1} and T_3 (15 mg/L Se) at 1.15 t ha^{-1} , forming an optimal concentration range of 15-25 mg/L Se for maximum productivity. In stark contrast, the untreated control (T_0) yielded just 0.6 t ha^{-1} , highlighting the substantial yield penalty under selenium deficiency. These results establish that appropriate selenium supplementation can dramatically improve sesame productivity, with 25 mg/L emerging as the optimal dose for maximizing yield under the experimental conditions, while selenium deficiency leads to severe yield limitations.

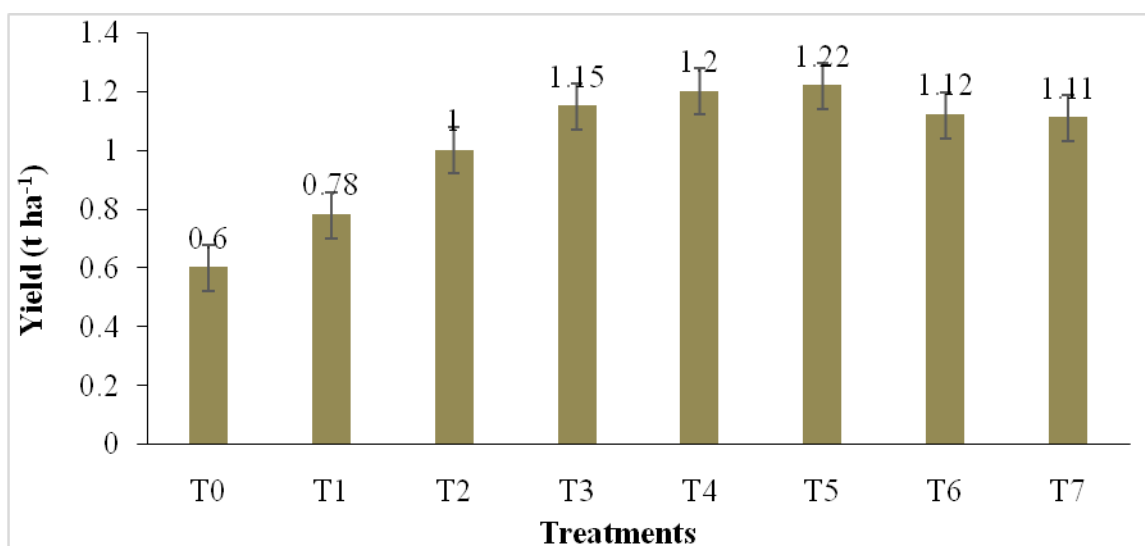


Figure 5. Effect of selenium application on grain yield of sesame

CHAPTER V

SUMMARY AND CONCLUSION

This thesis explores the influence of selenium nanoparticles (SeNPs) on sesame (*Sesamum indicum* L., cultivar BINA Til-3) cultivated under drought stress. Sesame, a nutritionally and economically significant crop in Bangladesh, is particularly vulnerable to moisture deficiency, highlighting the necessity for novel strategies to enhance drought resilience and productivity. A pot experiment was carried out at Hajee Mohammad Danesh Science and Technology University, Dinajpur from May to July 2024. Plants were subjected to varying foliar applications of SeNPs (T_0 = Control, T_1 = 5 ppm, T_2 = 10 ppm, T_3 = 15 ppm, T_4 = 20 ppm, T_5 = 25 ppm, T_6 = 30 ppm, T_7 = 35 ppm) under controlled drought conditions. Evaluated parameters included: Plant height, leaf number, and leaf area index (LAI) significantly improved with Se application, peaking at 20 ppm–25 ppm (T_4 to T_5). Higher concentrations (≥ 30 ppm) showed diminishing returns or toxicity. Chlorophyll content (SPAD value) and photosynthetic pigments (Chl a, Chl b, carotene) were highest at 20 ppm–25 ppm, indicating enhanced photosynthetic efficiency under drought. Cell membrane stability (CMS) and canopy temperature regulation improved with Se, with optimal results at 20 ppm (60.1% CMS). Leaf morphology (length, width, area) was positively influenced by Se, with 20 ppm yielding the largest leaves (65.13 cm length, 1732.73 cm² area). Pod number, seed number per pod, and total seed weight peaked at 15 ppm–25 ppm Se. T_5 (25 ppm) produced the highest yield (1.22 t/ha), doubling the control (0.6 t/ha). Nutrient content (N, K) in seeds increased with Se, with T_5 showing the highest nitrogen (0.80%) and potassium (260 mg/100g). Se enhanced drought tolerance by improving antioxidant activity, water retention, and osmotic adjustment (e.g., pro-line accumulation). Moderate Se doses (20 ppm–25 ppm) optimized stress responses, while higher doses (≥ 30 ppm) risked oxidative stress.

The study demonstrates that foliar application of selenium nanoparticles (20 ppm–25 ppm) significantly enhances sesame growth, physiological resilience, and yield under drought stress. Optimal Se concentrations improved chlorophyll synthesis, membrane stability, and reproductive output, with 25 ppm (T_5) emerging as the most effective dose for maximizing yield (1.22 t ha⁻¹) and seed quality. These findings highlight Se nanoparticles as a sustainable strategy to combat drought-induced yield losses in sesame cultivation. Future research should explore molecular mechanisms and field-scale validation to optimize Se-based interventions for broader agricultural applications.

Recommendations:

- Apply 20ppm–25 ppm Se nano-particles foliarly to sesame crops under drought conditions.
- Avoid excessive Se (>30 ppm) to prevent toxicity.
- Integrate Se with other agronomic practices (e.g., irrigation management) for synergistic effects.

This study contributes to climate-resilient agriculture by leveraging nanotechnology to address food security challenges in drought-prone regions.

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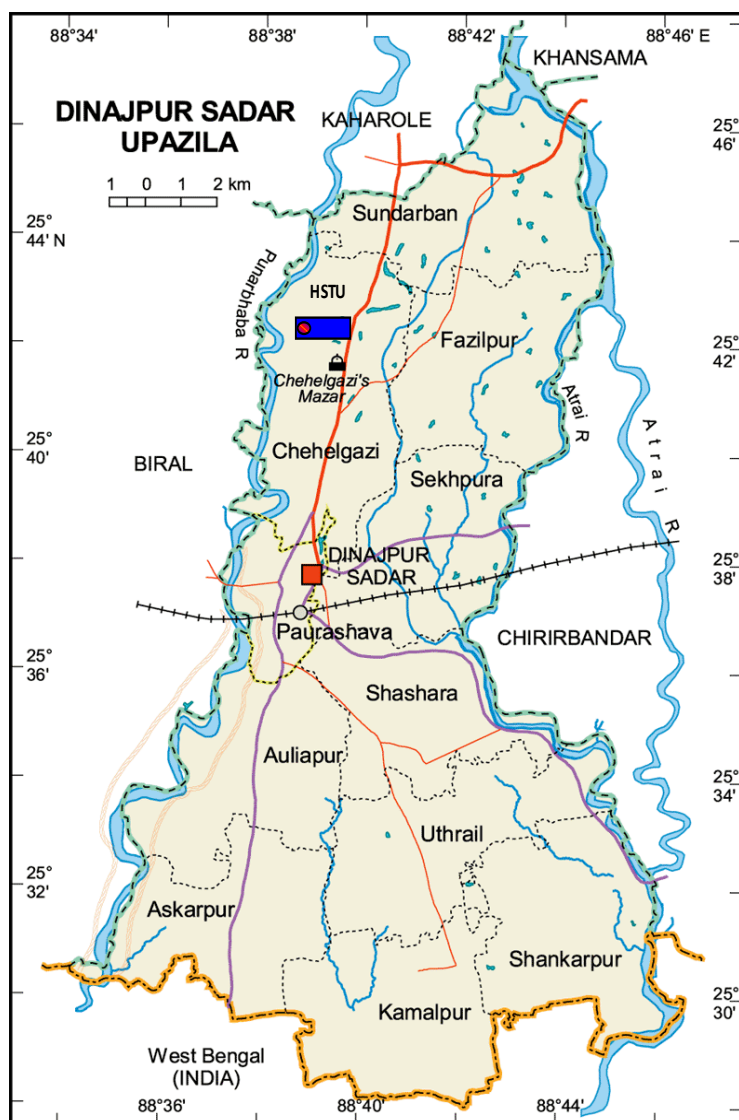
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APPENDICES

Appendix I. Location of the experimental site (map of Dinajpur Sadar Upazila showing the research plot)



The geographical position of the experimental area and location is between 25°41'46.3"N and 88°39'01.1" E and 40 m above sea level

Appendix II. Morphological and Physiological Characteristics of soil

Morphology	Characteristics
Location	Department of Agronomy research field, Hajee Mohammad Danesh Science and Technology University, Dinajpur.
AEZ	Old Himalayan Piedmont Plain (AEZ-1)
General soil type	Non calcareous Brown Floodplain Soil
Parent material	Piedmont Alluvium
Soil series	Rainshankail
Drainage	Moderately well drained
Flood level	Above flood level
Topography	High Land
Physical characteristics	Value
Sand (2.0-.02)	60.00
Silt (.002-.05)	27.00
Clay (<.002)	13.00
Textural class	Sandy loam

Source: The morphological and physiological characteristics of soil samples were done by SDRI, Dinajpur, Bangladesh.

Appendix III. Chemical characteristics of initial soil samples

Characteristics	Content	Interpretation
p ^H	5.40-5.50	Moderately acidic
Organic carbon (%)	0.69	Low
Organic matter (%)	1.19	Low
Sulphur	21.44 µg/g soil	Medium
Boron	3.39 µg/g soil	Low
Zinc	3.00 µg/g soil	Low
Sodium	0.12 me/ 100g soil	Low
Calcium	1.80 me/ 100g soil	Medium low
Magnesium	0.30 me/ 100g soil	Low

Source: The morphological and physiological characteristics of soil samples were done by SDRI, Dinajpur, Bangladesh.

Appendix IV. Calculated mean sum of squares of different sources of variances of plant height and leaf number of sesame varieties under drought conditions.

Source of variation	df	Mean square			
		Plant height at 30 DAS	Plant height at 60 DAS	Leaf number at 30 DAS	Leaf number at 60 DAS
Replication	2	0.43 ^{ns}	130.56 ^{ns}	1.16*	198.11*
Treatment	7	5.74**	196.8**	1.76**	139.95 ^{ns}
Residual	14	0.66	45.04	0.27	51.68
Total	23				

Here: ns: non-significant, *: significant at 0.05, **: significant at 0.01 probability level

Appendix V. Calculated mean sum of squares of different sources of variances of chlorophyll content and carotene of sesame varieties under drought conditions.

Sources of variation	df	Mean square				
		Chlorophyll at 28 DAS	Chlorophyll at 51 DAS	Chla at 53 DAS	Chl b at 53 DAS	Carotene at 53 DAS
Replication	2	0.6 ^{ns}	2.63 ^{ns}	0.1*	0.47*	0.151 ^{ns}
Treatment	7	12.82**	100.86**	0.07*	0.34*	0.423*
Residual	14	1.5	3.47	0.02	0.08	0.106
Total	23					

Here: ns: non-significant, *: significant at 0.05, **: significant at 0.01. probability level

Appendix VI. Calculated mean sum of squares of different sources of variances of leaf temperature, canopy temperature and CMS of sesame varieties under drought conditions

Sources of variation	df	Mean square			
		Leaf Temp at 28 DAS	Leaf temp at 51 DAS	Canopy temp at 28 DAS	CMS at 115 DAS
Replication	2	0.638 ^{ns}	1.16 ^{ns}	0.39 ^{ns}	130.19 ^{ns}
Treatment	7	1.842**	3.38**	1.98**	204.54**
Residual	14	0.278	0.37	0.29	36.87
Total	23				

Here: ns: non-significant, *: significant at 0.05, **: significant at 0.01. probability level

Appendix VII. Calculated mean sum of squares of different sources of variances of leaf length, leaf width, leaf area and ratio of sesame varieties under drought conditions

Sources of variation	df	Mean square			
		Leaf length	Leaf width	Leaf area	Ratio
Replication	2	7.77 ^{ns}	71.39 ^{ns}	191818 ^{ns}	0.01 ^{ns}
Treatment	7	224.93*	499.02*	365563*	0.23 ^{ns}
Residual	14	54.41	149.1	65199	0.1
Total	23				

Here: ns: non-significant, *: significant at 0.05, **: significant at 0.01, probability level

Appendix VIII. Calculated mean sum of squares of different sources of variances of canopy temperature depression at different time of sesame varieties under drought conditions

Sources of variation	df	Mean square		
		Canopy temp depression 9.30 am	Canopy temp depression 12.30 pm	Canopy temp depression 3.30 pm
Replication	2	5.37 ^{ns}	44.56**	3.22 ^{ns}
Treatment	7	13.74**	3.69 ^{ns}	1.52 ^{ns}
Residual	14	1.92	1.88	1.01
Total	23			

Here: ns: non-significant, *: significant at 0.05, **: significant at 0.01, probability level

Appendix IX: Visual Representation of Field and Laboratory Work



