Journal of Agricultural, Environmental and Veterinary Sciences (JAEVS) • Vol 8, Issue 1 (2024) • P: 37 - 8
https://journals.ajsrp.com/index.php/jaevs
ISSN: 2522-3364 (Online) • ISSN: 2522-3364 (Print)

Nano particles of Silicon effects on Photochemistry components (biological activity) and physiological properties of Coriandrum sativum plant under water stress

Abdullah Musfer Alghamdi*, Prof. Hassan Mohammed Rashad, Dr. Mordi Mohammed Algandaby
King Abdulaziz University

Received: 29/01/2024
Revised: 14/02/2024
Accepted: 30/02/2024
Published: 30/03/2024

* Corresponding author: mag_ali45@hotmail.com

Citation: Alghamdi, A. M., Rashad, H. M., & Algandaby, M. M. (2024). Nano particles of Silicon effects on Photochemistry components (biological activity) and physiological properties of Coriandrum sativum plant under water stress. *Journal of agricultural, environmental and veterinary sciences, 8*(1), 8 – 37. https://doi.org/10.26389/AJSRP.A290124

Abstract: The present study was accomplished to scrutinize the efficiency of Nano silicon (NSi) as a foliar spray on (Coriander sativum) plants under water stress conditions during 2021/2022 season. Coriander plants were subjected to three water levels (100, 70 and 30% of field capacity). Plant leaves were sprayed with NSi in three different concentrations (3, 5 and 10 ppm) 14 days after germination. The results revealed that Coriander plants growth was significantly decreased under water stress, while NSi treatment showed a significantly enhanced plant growth (length and number of leaves per plant). Regarding biochemical constituents activity, total of alkaloids, phenol, flavonoids and fatty acids increased under water stress. Also, nutrient elements (P & Mg and Na) increased. Plant hormones such as gibberellic acid (GA3) and ascorbic acid (vitamin C) significantly decreased under both 70% and 30% FC, while abscise acid (ABA) increased. In the interim, the three different concentrations of NSi significantly improved carbohydrates concentration and adjustment of osmotic stress. Application of NSi at different concentrations significantly improved nutrients contents (N, P, K, Mg, Ca, Fe, Zn, Mn) mainly under moderate and severe water stress (70%, 30% FC). Generally, the profound concentration of NSi tested during the experiment was 5 ppm for ameliorating water stress. The present investigation showed that the application of NSi might be a promising method to enhance the plant growth, biochemical ingredients and crop productivity of Coriander plants grown under water stress conditions.

Keywords: Coriander plant; Nano; Silicon; Plant morphology; Biochemical ingredients; Water stress.

تأثير جسيمات النانو من السيليكون على مكونات الفوتوكيمياء (النشاط البيولوجي) والخصائص الفسيولوجية لنبات الكزبرة تحت ضغط الماء.

عبدالله مسفر الغامدي*، برفسور. حسن محمد راشد، د. موردي محمد الجندبي
جامعة الملك عبدالعزيز

المستخلص: تم إجراء هذه الدراسة لفحص كفاءة استخدام الرش الورقي بجزيئات السيليكون متناهية الصغر مستخدما الرش الورقي على نبات الكزبرة Coriander sativum تحت ظروف ضغط الاجهاد المائي في خلال موسم /2021 .2022 وقد خضعت تجربة نباتات الكزبرة النامية على ثالث مستويات من ري مختلفة، (100%، 70% 30%) من السعة الحقلية، حيث تم رش الاوراق بثالثة تركيزات مختلفة من محلول جزيئات السيليكون متناهية الصغر، 10، 5، 3 جزء في المليون بعد فترة 14 يوم من الانبات. أوضحت النتائج أنه هناك انخفاض في نمو النباتات) طول وعدد الاوراق للنبات (بشكل معنوي أثناء معاملة الجفاف، بينما أدى رش جزيئات السيليكون متناهية الصغر الى تعزيز نمو النبات. ومن منظور نشاط المكونات البيوكيميائية، قد لوحظت زيادة واضحة في المحتوى الكلي من تركيز الفينول، الفلافونويد الفالفونويد، والأحماض الدهنية، بالإضافة إلى ارتفاع مخزون تركيز/ محتوي العناصر الغذائية مثل البوتاسيوم والمغنيسيوم والصوديوم تحت ظروف الاجهاد المائي. كما أنخفض مستوى الهرمونات النباتي مثل حمض الجبريليك)GA) 3وفيتامين ج) حمض أسكوربيك (بشكل معنوي عند مستوى %70 و30% من السعة الحقلية بينما زاد تركيز حمض الابسيسك ABA. واظهرت النتائج ايضا ان المعاملة بجزيئات السلبكون متناهية الصغر عند التراكيز الثلاثة المختلفة أدت إلى تحسين مستوى تركيز الكربوهيدرات بشكل كبير، كما أدى استخدام الرش بجزيئات السيليكون متناهية الصغر تحت التركيزات المذكورة الى تحسين مستوى العناصر الغذائية) نيتروجين، فسفور، بوتاسيوم، مغنيسيوم، صوديوم، حديد، زنك، منجنيز (بشكل ملحوظ تحت ظروف الاجهاد المائي عند مستويات (70% و 30%) من السعة الحقلية وتعديل الاجهاد التناضحي. بشكل عام، كان التركيز المثالي من معاملة السليكون عند 5 جزء في المليون أبدى درجة تحمل واضحة للجفاف. كما أشارت نتائج الدراسة الحالية إلى ان امكانية تطبيق جزيئات السيليكون متناهية الصغر قد يكون طريقة واعدة لتعزيز نمو النبات وزيادة تركيز المكونات البيوكيميائية وانتاجية محاصيل نباتات الكزبرة التي تتم زراعتها تحت ظروف ضغط الاجهاد المائي.

الكلمات المفتاحية : نبات الكزبرة؛ نانو؛ السيليكون؛ مورفولوجيا النبات .المكونات البيوكيميائية .ضغط الماء.

1.1 Introduction

Drought, a main abiotic stress, affects physiological and biochemical processes of plants, especially the synthesis and accumulation of secondary metabolites in wheat **(Bukhari MA *et al.*, 2020**). Between the abioticstresses, drought is a main reason affecting the growing and production of crops worldwide (**Sharma and Zheng, 2019**). The energy balance in plant is regulated by photosynthetic pigments and hence they are involved in *Moringa peregrine* plant at the adaptation of plants and their survival under drought stress (**Foroutan *et al.*, 2019**). Drought stress slowed the development of cotton plants before limiting photosynthesis i**(Wang *et al.*, 2016).** The effects of drought stress differ for different types of plants. The effects of plant stress differ for different types of ***Dracocephalum moldavica*** **L** plants (**Mohammadi *et al.*, 2016**.). Early recognition of the symptoms of waterstress can be decisive for maintaining crop growth. The most common indicator ofwater stress is wilting. When the plant is subjected to water deficit, the water potentialin the leaves declines leading to plant wilting. Drying and wilting will decrease growth in almost any plant (**Ahmad *et al.*, 2018)**. Nonetheless, Chlorophyll biosynthesis inhibition, activation of Chlorophyllase and/or chloroplast degradation decrease the pigment content under the abiotic stress in *Moringa peregrine* plant (**Soliman *et al.*, 2015).** Furthermore, Mejri (**2016**) recorded that water scarcity reduced chloroplast activity and contributed to chlorophyll breakdown. Under conditions of drought, *Saccharum officinarum* plants accumulate vast quantities of different osmo-protectants, such as soluble sugars, which eventually preserve the status of tissue water. ***et al***Carbohydrates perform various functions ***et al*** to achieve osmotic adjustment and carbon storage (**Mejri *et al.*, 2016)**, e.g. in **rice*, Oryza sativa* L.** (**Zhong *et al.*, 2018)**. The osmotic adjustment maintains cellular water balance with active accumulation of the substances dissolved in the cytoplasm, where the maintenance of high swelling increases photosynthesis and growth rate (**Abobatta, 2019).**

Coriander (*Coriandrum sativum* L.) is an annual plant species of *Apiaceae* family, which is widely used for its strong nutritional and medicinal values **(Amiripour *et al.*, 2019)**. Annual erect coriander plants are cultivated and produced worldwide for culinary, aromatic and medicinal uses. It is also commonly referred to as coriander when grown for its herbs, and is used in many foods. *Coriandrum sativum* L., originally belongs to the European-Mediterranean area, has recently been widely cultivated as a useful vegetable all over the world (Gastón *et al.*, 2016). It can be used as vegetable and food spice due to its nutritional value. Moreover, coriander exerts various medicinal uses such as treatment of disorders in skin inflammation, digestive, respiratory and urinary systems **(Beyzi *et al.*, 2017)**. In addition, it has essential oil (EO) in both leaves and seeds, with different EO profile **(Bukhari *et al.*, 2020.)**. The essential oil extracted from the coriander fruits (common as seeds) has many uses **(Diederichsen, 1996)**. The essential oil is one of the main flavor compounds in the world. Ground coriander seeds are used as a spice, for example in the preparation of curry. Additionally, coriander essential oil is used to flavor bread, sauces, soups, canned goods and desserts. It also has antimicrobial characteristics shown on the growth of some fungi and bacteria such as *Escherichia coli* (*E. coli*), *Yersinia enterocolitian*, *Staphylococcus aureus* and *Rhodotorula sp.* which were completely eliminated under in vitro conditions **(Elgayyar *et al.*, 2001).** The essential oil of coriander is most commonly extracted from the fruits by either hydro or steam distillation. It was found that the content of essential oil in coriander seeds ranges between 0.125 and 1.90% **(Jeliazkova *et al.*, 2019),** and main ingredient of the essential oil is linalool, which ranges from 40 to 82.9% of the oil **(Machado *et al.,* 1993).** The other main components of seed oil are pinene, terpinene, camphor, geranyl acetate, geraniol, borneol, terpineol, citronellol and nerol, and limonene **(Pino *et al.*, 2008).**

Nanoparticles (NPs) are proposed to be the materials for the new millennium. Nanomaterials consist of particles smaller than 100 nm. The small size of Si particles implicates new physical, chemical and biological properties (**Monica and Cremonini 2009)**. At the global level, the use of nanotechnology in agriculture is at a nascent stage, yet it is increasing. Agricultural applications of beneficial nanoparticles are currently interesting fields of research **(Karunakaran *et al.,* 2013).** The NPs interact with plants causing many morphological and physiological changes, depending on the properties of the particles. Among the NPs, nano-silicon has gained greater consideration during the last years. Silicon is plentiful in soils and the second most common element on earth after oxygen **(Ma, 2004)**, and has been recognized as a beneficial nutrient for plant growth and development **(Wainwright, 1997; Siddiqui *et al.*, 2015**). It was reported that exogenous application of nano-silicon on plants enhances the plant growth and development by increasing accumulation of proline, free amino acids, content of nutrients, antioxidant enzymes activity, gas exchange, and improves efficiency of the photosynthetic apparatus in *Indocalamus barbatus* plant **(Xie *et al.*,2012; Kalteh *et al.*, 2014.)**. However, the effectiveness of the same nanoparticle is dissimilar in different plant species or under various environmental conditions (Prasad *et al.*, 2012). The agricultural sector was one of the most important fields, which nanotechnology science involves leading to a revolution in many applications such as the agri-food industries **(Dasgupta *et al.*, 2015a & b; Handford *et al.*, 2015)**, remediation of soils and waters from pollutants or nanoremediation (**Belal and El-Ramady, 2016).**

Nanotechnology may have a hidden **face in soils**. The apparent face not only include the direct effects on soil microbial communities, and remediation of polluted soils, but also using natural nanoparticles like zeolites and nano-clays as soil amendments. Therefore, several applications of nanoparticles or nanomaterials in soils have evolved. Concerning the hidden face of nanotechnology in soils, it may include the interaction between different nanoparticles and different environments. These different environmental compartments include plants, microbes, air and soil, which have been extensively studied (e.g., **Abhilash *et al.*, 2016; Du *et al.*, 2016).** Thus, the fate and behavior of nanomaterials in soils including transport, bioavailability and bio-toxicity of these nanoparticles should be addressed (**Watson *et al.*, 2015; Gogos *et al.*, 2016).** On the other hand, this behavior of nanoparticles in soils is mainly controlled by soil characteristics particularly soil pH, soil clay content, soil organic matter and soil cation exchange capacity (**Watson *et al.*, 2015; Gogos *et al.,* 2016**).

The biological role of Si in plants has not been deeply studied by plant physiologists because it has not been classified as essential plant element (**Ma and Yamaji, 2006**). Nevertheless, many researchers believe that Si is an important element for plants (**Siddiqui & al-whaibi, 2013; Epstein, 2009; Gong & Chen, 2012; Currie & Perry, 2007** on *Lycopersicum esculentum*). Si, as a physicomechanical barrier, is part of the epidermal cell walls and vascular tissues in stems, pods, leaves and bark of tomato *Lycopersicum esculentum* plants (**Siddiqui & Al-Whaibi, 013**). Many beneficial effects have been reported. **liang *et al.* (2007), Ma (2004) and Pei *et al.* (2010)** indicated that Si might decrease the negative effects of oxidative stress and offer slight resistance to some abiotic and biotic plant stressors. Thus, using Si instead of herbicides and pesticides could reduce harmful environment effects (**Vasanthi *et al.,* 2012; Balakhnina and Borkowska, 2013; Karmollachaab *et al.*, 2013**). The positive effects of the Si (in bulk size) have been demonstrated in plants by investigators; however, compared with Si bulk size, absorption of Si in living plants as squash (*Cucurbita pepo*) is greater when nanoparticles of silicon are used (**Suriyaprabha *et al.*, 2012b**). Nanosciences led to the development of a wide range of applications for enhancing plant growth **(Nair *et al.*, 2010).** In recent years effects of Si in nanoscale on Changbai larch (*Larix olgensis*) plants have received increased attention, but research results are limited. **Bao-shan *et al.* (2004)** immersed the roots of changbai larch seedlings in 62–2000 μl.1 l–1 concentration of nanosilica for 6 hours. Their results clearly showed positive effects of silicon nanoparticles (Snps) on growth and quality of the seedlings of higher plant. **Suriyaprabha *et al.* (2012b).** Water is a vital resource for plant survival and is also needed for transport of nutrients. Thus, when the drought period and water stress emerged, vitality of Iberian peninsula plants weakened (**Martinez-Vilata & Pinol, 2002),** their growth reduced (**Bigler *et al.* 2006**), and mortality increased (**Rebetez & Dobbertin, 2004**).

Drought stress, as a multidimensional abiotic stress, strongly effects growth, development and yield of plants (**Mahajan and Tuteja, 2005**). Under drought conditions, the plants initiate two strategies for survival, namely- avoidance or tolerance; the strategies include morphological and/or physiological adjustments (**Bassett, 2013**). Finding genotypes resistant to biotic and abiotic stress is very important for plant research.

1.2 Problem Statement

Drought stress is a significant environmental challenge affecting crop productivity worldwide. Coriander (Coriandrum sativum L.) is a popular aromatic herb with diverse culinary and medicinal applications. However, its growth and development are highly susceptible to drought stress, leading to yield losses and reduced quality. Understanding the physiological and biochemical responses of coriander plants to drought stress is crucial for developing effective mitigation strategies. This research aims to investigate the effects of drought stress on coriander plants' physiological and biochemical processes and explore the potential use of nanoparticles, specifically nano-silicon, in alleviating these effects.

1.3 Study Questions

- How does drought stress impact the synthesis and accumulation of secondary metabolites in coriander plants?
- What physiological and biochemical adjustments do coriander plants undergo to tolerate drought stress?
- Can the application of nanoparticles, particularly nano-silicon, enhance the growth and development of coriander plants under drought stress?

- What are the underlying mechanisms responsible for the beneficial effects of nano-silicon on coriander plants under drought stress?
- How do soil characteristics, including pH, clay content, organic matter, and cation exchange capacity, influence the fate and behavior of nanoparticles in coriander plant-soil systems?

1.4 Study significance

The research significance can be summarized as follows:

- Understanding the impact of drought stress on plants: Drought is a significant abiotic stress that affects crop growth and production worldwide. Researching the physiological and biochemical processes affected by drought stress, such as the synthesis and accumulation of secondary metabolites and the regulation of energy balance in plants, can provide insights into the mechanisms of plant adaptation and survival under water scarcity.
- Recognizing early symptoms of water stress: Identifying the early indicators of water stress, such as wilting, is crucial for maintaining crop growth. Investigating the physiological changes associated with water deficit can help develop strategies for early detection and management of drought stress in agricultural systems.
- Exploring the effects of drought stress on chlorophyll content: Drought stress can lead to chlorophyll biosynthesis inhibition, chlorophyllase activation, and chloroplast degradation, resulting in a decrease in chlorophyll content. Understanding these effects can contribute to our knowledge of plant responses to water scarcity and provide insights into potential strategies to mitigate the negative impact of drought on photosynthesis and growth.
- Investigating osmotic adjustment under drought stress: Plants employ osmotic adjustment mechanisms to maintain cellular water balance under water deficit conditions. Researching the accumulation of osmo-protectants, such as soluble sugars, and their role in preserving tissue water can contribute to our understanding of plant response to drought stress and provide potential targets for breeding or biotechnological approaches to enhance drought tolerance in crops.
- Studying the nutritional and medicinal values of coriander: Coriander is a widely cultivated plant known for its nutritional and medicinal properties. Exploring the chemical composition of coriander, such as the essential oil extracted from its fruits, can have implications for its culinary, aromatic, and medicinal uses. Understanding the components and potential antimicrobial characteristics of coriander essential oil can contribute to its diverse applications in the food and healthcare industries.

1.5 Research objectives

- Investigate the physiological and biochemical responses of plants to drought stress, aiming to understand the mechanisms underlying plant adaptation and survival under water scarcity.
- Identify early indicators and physiological changes associated with water stress in plants to develop strategies for early detection and management of drought stress in agricultural systems.
- Examine the effects of drought stress on chlorophyll content and related processes, such as chlorophyll biosynthesis inhibition, chlorophyllase activation, and chloroplast degradation, to understand the impact on photosynthesis and plant growth.
- Investigate the nutritional and medicinal values of coriander, including the composition of its essential oil, to support its diverse applications in the food and healthcare industries.
- Investigate the biological role of silicon in plants, examining the physiological and molecular mechanisms underlying its positive effects on plant growth, development, and stress resistance to improve our understanding of plant nutrition and explore opportunities for sustainable agricultural practices.

1.6 Study Terminology

1.6.1 Drought stress

The condition of water scarcity or limited water availability that plants experience, leading to physiological and biochemical responses.

1.6.2 Physiological responses

The changes and adaptations that occur at the cellular or organismal level in plants in response to various stimuli or stressors, such as drought stress.

1.6.3 Biochemical processes

The chemical reactions and pathways that occur within living organisms, including plants, which are involved in various physiological functions and responses.

1.6.4 Secondary metabolites

Chemical compounds produced by plants that are not directly involved in primary metabolic processes but play important roles in plant defense, growth regulation, and other functions.

2. LITERATURE REVIEW

2.1 Drought Stress (An overview)

Drought is a major abiotic stress that has a significant impact on food production around the world. Water has become a more valuable natural resource as the region's population has put a pressure on supply. Irrigation is the most common agricultural use of water, hence a decrease in availability has an impact. Drought stress is a word used to describe a plant that has encountered water limitations due to a lack of water in the growing medium. Drought stress has a significant impact on plant productivity and growth, as well as on their geographic distribution. Water scarcity causes a variety of physiological and biochemical responses in plants, and it is one of the most complicated adverse situations since it is dependent not only on the severity and duration of the stress event, but also on the stage and morphology of the plant (FAO, 2019).

Plant drought stress has different impacts depending on the species. Early detection of water stress indicators is important to a crop's continued growth. Wilt is the most prevalent sign of plant water stress. Water stress causes the water pressure inside the leaves to drop, causing the plant to wilt. Almost any plant will grow slower if it dried to the point of wilt. Knowing plant water availability, identifying indicators of water stress, and planning ahead are all important aspects of water management for irrigators (Hussain *et al.*, 2018). When it comes to stomatal closure, carbon dioxide (CO_2) fuels the Calvin cycle, which suffers a severe reduction and, as a result, reduces biomass output. Drought stress affects root and shoot dry mass, leaf chlorophyll pigments, and leaf relative water content (RWC) in dragonhead plants, according to (Alaei *et al.* (2013). Water stress causes a variety of morphological and metabolic reactions in plants (Sharma and Zheng, 2019). Drought stress is a common and looming environmental element that has a negative impact on agricultural yield, particularly in drought-prone locations. Stomatal closure and overproduction of various types of secondary metabolites are the most prevalent plant responses to drought stress in order to reduce water loss and oxidative damage, respectively (Serraj and Sinclair, 2002).

Plant cells suffer oxidative damage as a result of the formation of reactive oxygen species during extreme drought stress (ROS). Antioxidant enzymes such as superoxide dismutase, which produces hydrogen peroxide, may detoxify some of these free radicals (H_2O_2). However, ROS can target the cell membrane's phospholipids, producing lipid peroxidation and electrolyte leakage. Malondialdehyde (MDA), which is one of the last products of lipid peroxidation, can be used to assess membrane damage in this scenario. Plants under drought stress have higher concentrations of suitable organic solutes like proline, which aid in subcellular structural stabilization and osmotic adjustment in the cell cytoplasm (Mohammadi *et al.*, 2016). Drought stress and multidimensional abiotic stress have a significant impact on plant growth, development, and production (Mahajan and Tuteja., 2005).

2.2 Effects of drought stress on plant morphological characters

2.2.1 Shoot and root lengths

Many authors have documented the impact of water stress on root elongation, which was reduced by water deficiency (Hannah *et al.*, 2018). Numerous reports documented that water stress reduces the height of many plants. Moreover, rate of shoot and leaves expansions are sensitive to irrigation which affects plant height and plant diameter (Wang *et al.*, 2016 and Li *et al.*, 2020). The length of the stem in many plants under drought stress has been reduced (Esmail *et al.*, 2019).

2.2.2 Shoot and root fresh and dry weights

Under water stress, plant fresh weight and relative water content decreased (Jun *et al.*, 2020). Zhao *et al.*, (2015) reported a reduction in dry biomass output during drought. Shoot and root biomass, root length density, and root depth were proposed as the primary drought avoidance features for better seed output in chickpea under drought circumstances. Drought-tolerant chickpea lines had a 93 percent higher root dry weight than regular check lines. Drought stress boosted the root/shoot ratio by reducing root biomass accumulation. Drought caused the barley roots to grow more lateral roots, whereas the number of vessels and root volume decreased (Li *et al.*, 2020). Following drought condition, the weight of root dry matter and root length density of two cowpea varieties decreased dramatically. Drought-induced dry weight loss could be related to reduced photosynthesis as a result of reduced water interactions and gas exchange activities (Nawaz *et al.*, 2015).

Effects of drought stress on physiological and biochemical characters of plants

2.3 Role of Nano Particles in Alleviating Drought Stress

Drought is one of the most serious factors affecting plant output and quality. Drought-relieving strategies are currently being researched (Semida *et al.*, 2021). Modern agricultural technology aiming at boosting output under stress conditions, particularly in poor nations, frequently ignore the environmental component. As a result, new ecological-friendly and cost-effective ways are required to address the issue of increased agricultural output and long-term environmental management during drought conditions (Feizi *et al.*, 2012). The impact of NPs on plant physiological condition has been examined on a variety of plants at various stages of their organization, beginning at the molecular level (Batsmanova et al., 2013). The colloidal solution of copper (Cu) and zinc (Zn) nanoparticles has a positive effect on pro- oxidative/antioxidative balance and morphometric indexes of leaves in drought conditions. There was an increase in antioxidative enzyme activity, which characterizes the increase of plant antioxidative status under the influence of nanoparticles. Another study found that foliar administration of ZnO-NPs at an adequate dosage (1.5 mg/ml) on chickpea boosted biomass output as compared to bulk form treatment (Burman *et al.*, 2013). According to research, ferrous and zinc nanoparticles aid in the enhancement or preparation of plants to withstand drought stress (Cakmak *et al.*, 2008).

3. Materials and Methods

3.1 Experimental design and treatments

Coriandrum sativum L. seeds were sown in plastic pots filled with 1.5 Kg homogenously mixed sand: clay soil (2:1), under natural light condition in the net greenhouse of King Abdulaziz University during (March to May, 2022). The pots were divided into two sets; one set did not treated with Nanosilicon (NSi) donor, while the other was sprayed with NSi at different level (10, 5 and 3 PPM), and dissolved in water at room temperature.

For drought stress conditions, each set subdivided into four subsets, these subsets irrigated with tap water at 100% FC (control), 70 and 30% FC respectively as mild, moderate and severe drought conditions. Drought and NSi treatments started after the growth of the fourth true leaf. The experiment was carried out in a Complete Randomized Design (CRD) with 3 replicates. At the end of the experimental period (60 days), plant shoots and roots were collected and transferred immediately to the laboratory for analysis. Shoot and root fresh and dry weights were determined. For all assays, plant samples were dried immediately then stored for further analysis.

Fig 3-1: Shoots and roots transferred to the laboratory for analysis

3.2 Growth parameter

3.2.1 Fresh and dry weight of shoots and roots

The samples were washed with distilled water and gently dried by tissue paper. A freshly harvested shoots and roots were weighted and recorded. Then the samples were wrapped in bag paper and kept in oven-dried by JSON-100 Natural Convection Oven at 70 °C until constant weight of each sample was reached (48 hours), to determine the dry weight.

Fig 3-2: Growth parameter

3.3 Chemical and Physiological analysis

3.3.1 Chemical analysis

The plant herbs were dried in an electric oven at 70 0C for 48 hours, and the crude dry weight was estimated for each treatment herb. The crude dry materials were ground to a fine powder in an electric wily mill, mixed thoroughly and stored in tightly stoppered Pyrex glass containers and kept for nutrients, and carbohydrates estimations.

Fig 3-3: Chemical analysis

3.3.1. Inorganic components

Determinations of macro-and micronutrients (N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B were carried out on the dry material. The wet digestion of 0.2g plant material with sulfuric and perchloric acids was carried out on herbs by adding concentrated sulfuric acid (5 ml) to the samples and the mixture was heated for 10 min. then 0.5 ml perchloric acid concentration was added,and heating continued till a clear solution was obtained. The digested solution was quantitatively transferred to a 100 ml volumetric flask using deionized water as reported by (Piper, 1950).

3.3.3 Determination of Nitrogen (N)

The total nitrogen content of the dried material was determined by using the modified- micro-Kjeldahel method as described by Peach and Tracy (1956) as follows:

Digestion apparatus: Kjeldahl flasks with a total capacity of 800 ml yield the best results. Digest over a heating device adjusted so that 250 ml water at an initial temperature of 25°C can be heated to a rolling boil in approximately 5 min. For testing, preheat heaters for 10 min if gas-operated or 30 min if electric. A heating device meeting this specification should provide the temperature range of 375 to 385°C for effective digestion.

Reagents

Dissolve 134 g K_2SO_4 and 7.3 g $CuSO_4$ in about 800 ml water. Carefully add 134 ml concentrated H_2SO_4. When it has cooled at room temperature, dilute the solution to 1 L with water. Mix well. Keep at a temperature close to 20°C to prevent crystallization.

Sodium hydroxide-sodium thiosulfate reagent: Dissolve 500 g NaOH and 25 g $Na_2S_2O_3$, 5H2O in water and dilute to 1 l.

Calculation:

% Nitrogen = (ml standard acid - ml blank) x N of acid x 1.4007

weight of sample in grams

3.3.4 Determination of Phosphorus (P)

Phosphorus content was determined calorimetrically by using the chlorostannous molybdophosphoric blue color method in sulphuric acid according to Jackson (1973). **As follows:**

3.3.4.1 Apparatus:

Spectrophotometer

3.3.4.2 Reagents

- Stock Solution of PO4 concentration 1000 mg/l - Dissolve 1.432 g potassium dihydrogen phosphate, KH_2PO_4 (see remark 2), in about 900 ml water in a volumetric flask of 1000 ml. Make up to 1000 ml with water
- Ascorbic Acid Solution - Dissolve 1.76 g ascorbic acid, C6H8O6, in 100 ml ultra-pure water and mix. Prepare fresh daily.
- Ammonium Molybdate Solution - Dissolve 40 g ammonium molybdate tetrahydrate, $(NH_4)_6Mo_7O_{24}.4H_2O$, in ultra-pure water and make up to 1000 ml. This solution should be stored in a bottle made of hard glass.
- Potassium Antimony l Tartrate Solution - Dissolve 0.274 g potassium antimonyl tartrate, $KSbOC_4H_4O_6.5H_2O$, in ultra-pure water and make up to 100 ml with ultra-pure water
- Sulphuric Acid Solution 2.5 mol/l - Dilute carefully, in portions, 140 ml concentrated sulphuric acid (96 %) in about 500 ml ultra-pure water in a 1000-ml volumetric flask. The mixture was cooled off and made up to volume with ultra-pure water.
- Mixed Reagent - Add successively with a graduated cylinder and mix after each addition: 50 ml sulphuric acid, 15 ml ammonium molybdate solution, 30 ml ascorbic acid solution and 5 ml potassium antimonyl tartrate solution. Prepared fresh daily.
- Standard Series - A volume of 0 – 1.00 – 2.00 – 3.00 – 4.00 – 5.00 ml of the stock solution was pipetted into 100-ml volumetric flasks, which already contain 40 ml ultra-pure water. 4.5 ml concentrated sulphuric acid (96 %) were added, cooled down and made up to the mark with ultra-pure water. This standard series has PO_4 concentrations of 0 – 10 – 20 – 30 – 40 – 50 mg/l.

3.3.4.3 Procedure

The measurement process involved the following steps:

The standard series, the blanks, and all digests 1+9 (v/v) were diluted with ultra-pure water. Then, 1.0 ml of the diluted standard series, diluted blanks, and diluted sample digests were pipetted into test tubes. Following that, 3.8 ml of the diluted mixed reagent (6.8) was added and mixed. The mixture was allowed to stand for either 10 minutes or 1 hour.

After the standing period, the absorbance was measured in a 1-cm cuvette at a wavelength of 880 nm.

The calculation for determining the total phosphorus content in the dried plant material, expressed in mmol/kg P, involved the following formula:

$0.01053 * (a - b) * V / w$

In this formula, "a" represents the concentration of phosphorus in the diluted sample digest, measured in mg/l, and "b" represents the concentration of phosphorus in the diluted blank digest, also measured in mg/l. "V" represents the total volume of digest at the end of the digestion procedure, measured in ml, and "w" represents the weight of the plant material sample, measured in grams.

For the determination of potassium (K) concentration, the flame photometer apparatus (CORNING M 410, Germany) was used. The following steps were involved:

The preparation of reagents included the stock solution of potassium with a concentration of 5000 mg/l. It was prepared by dissolving 9.534 g potassium chloride (KCl) in water in a 1000-ml volumetric flask and making up to the mark with water. Additionally, the cesium solution with a concentration of 1.1 g/L was prepared by dissolving 1.4 g cesium chloride (CsCl) in a 1000-ml volumetric flask and making up to the mark with water. The cesium-lanthanum solution with cesium concentration 1.1 g/l and lanthanum concentration 1.1 g/l was prepared by dissolving 1.4 g cesium chloride (CsCl) and 3.43 g lanthanum nitrate hexahydrate ($La(NO_3)_3.6H_2O$) in a 1000-ml volumetric flask and making up to the mark with water.

To prepare the standard series, specific volumes of the standard solution were pipetted into 100-ml volumetric flasks and diluted with about 40 ml water. Depending on the desired concentration, either concentrated sulfuric acid (96%), concentrated nitric acid (65%), or concentrated hydrochloric acid (36%) was added. The mixture was allowed to cool down, and then water was added to make up to the mark. The standard series had potassium concentrations of 0 – 100 – 200 – 300 – 400 – 500 mg/l.

The concentrations of calcium, magnesium, sodium, iron, manganese, zinc, and copper were determined using an Atomic Absorption Spectrophotometer with air-acetylene fuel (Pye Unicam, model SP-1900, US).

For the determination of calcium (Ca), the following procedures were followed:

This determination could be carried out on various digests such as digest (digestion with H_2SO_4 – salicylic acid - H_2O_2 - Se), digest 2.2 (digestion with H_2SO_4 - salicylic acid - H_2O_2), digest 2.3 (microwave digestion with HNO_3 - H_2O_2 - HF), digest 2.4 (digestion with HNO_3 - H_2O_2 - HF), and digest 2.7 (digestion by dry-ashing followed by treatment with HF).

The apparatus used was a flame atomic emission spectrometer.

The required reagents were as follows:

- Stock Solution, Ca concentration 1000 mg/l: Calcium carbonate ($CaCO_3$) that had been dried at 105°C for 2 hours was weighed out (2.497 g) and transferred to a 1000-ml volumetric flask with the help of approximately 150 ml water. Then, 13 ml of 4 M hydrochloric acid was added and boiled to expel CO_2. If any visible calcium carbonate particles remained, an additional 1 ml of 4 M hydrochloric acid was added. The solution was allowed to cool and made up to volume with water.
- Hydrochloric Acid 4 mol/l: 34 ml of concentrated hydrochloric acid (36%) was added to approximately 400 ml water and made up to 1 liter.
- Lanthanum Solution, La concentration 1.1 g/l: 3.43 g of lanthanum nitrate hexahydrate ($La(NO_3)_3.6H_2O$) was dissolved in a 1000-ml volumetric flask and made up to the mark with water.
- Cesium-Lanthanum Solution, Cs concentration 1.1 g/l, La concentration 1.1 g/l: 1.4 g of cesium chloride (CsCl) and 3.43 g of lanthanum nitrate hexahydrate ($La(NO_3)_3.6H_2O$) were dissolved in a 1000-ml volumetric flask and made up to the mark with water.
- Standard Series: Specific volumes (0 – 10.0 – 20.0 – 30.0 – 40.0 – 50.0 ml) of the stock solution (6.1A or 6.1B) were pipetted into 100-ml volumetric flasks containing 40 ml of water. Depending on the digestion method used, concentrated sulfuric acid (96%) (digestion 2.1 or 2.2), concentrated nitric acid (65%) (digestion 2.3), concentrated nitric acid (65%) (digestion 2.4), or concentrated hydrochloric acid (36%) (digestion 2.7) was added. After cooling down, the flasks were made up to the mark with water. The standard series had calcium concentrations of 0 – 100 – 200 – 300 – 400 – 500 mg/l.

The standard series, blanks, and sample digests 1 + 9 (v/v) were diluted with lanthanum solution or cesium-lanthanum solution and mixed. The diluted standard series, diluted blanks, and diluted sample digests were measured for calcium concentration using flame AES at a wavelength of 622.0 nm, utilizing an air-acetylene flame.

The calculation for the calcium content of the dried plant material, expressed in mmol/kg, is performed as follows: 0.02495 * (a - b) * V / w where:

- a represents the concentration of calcium in the sample digest, in mg/l.
- b represents the concentration of calcium in the blank digest, in mg/l.
- V represents the total volume of the digest at the end of the digestion procedure, in ml.
- w represents the weight of the plant material sample, in grams.

For the determination of magnesium (Mg), the following procedures may be carried out on various digests such as digest 2.1 (digestion with H2SO4 – salicylic acid - H2O2 - Se), digest 2.2 (digestion with H2SO4 - salicylic acid - H2O2), digest 2.3 (microwave digestion with HNO3 - H2O2 - HF), digest 2.4 (digestion with HNO3 - H2O2 - HF), and digest 2.7 (digestion by dry-ashing followed by treatment with HF).

The apparatus used is an Atomic Absorption Spectrophotometer.

The required reagents are as follows:

- Stock Solution, Mg concentration 1000 mg/l: Dissolve 10.130 g of magnesium sulphate heptahydrate (MgSO4.7H2O) in some water in a 1000-ml volumetric flask and make up to the mark with water.
- Standard Series: Pipette specific volumes (0 – 1.00 – 2.00 – 4.00 ml) of the standard solution into 100-ml volumetric flasks containing 40 ml of water. Depending on the digestion method used, either 4.5 ml of concentrated sulfuric acid (96%) (as digestion), 10 ml of concentrated nitric acid (65%) (digestion), 3.0 ml of concentrated nitric acid (65%) (digestion), or 1.0 ml of concentrated hydrochloric acid (36%) was added. After cooling down, the flasks were made up to the mark with water. This standard series had magnesium concentrations of 0 – 10 – 20 – 40 mg/l.

In the procedure, the measurement of magnesium concentration in the standard series, blanks, and sample digests was conducted using ICP-OES at a wavelength of 280.270 nm. A fitted background correction was utilized at this wavelength.

The calculation for the total magnesium content in the dried plant material, expressed in mmol/kg Mg, is performed as follows:

0.04114 * (a - b) * V / w where:

- a represents the concentration of magnesium in the sample digest, in mg/l.
- b represents the concentration of magnesium in the blank digest, in mg/l.
- V represents the total volume of the digest at the end of the digestion procedure, in ml.
- w represents the weight of the plant material sample, in grams.

3.3.4.4 Iron (Fe)

This determination can be carried out on digestions (microwave digestion with HNO3 - H2O2 - HF), (digestion with HNO3 - H2O2 - HF), digest (digestion with HNO3 - HClO4 - H2SO4), and digest (digestion by dry-ashing followed by treatment with HF).

The Atomic Absorption Spectrophotometer is used as the apparatus.

The following reagents are required:

- Stock Solution, Fe concentration 1000 mg/l.
- Stock Solution, Fe concentration 1000 mg/l - Ammonium iron sulphate hexahydrate, (NH4)2Fe(SO4)2.6H2O, is dissolved in a 1000-ml volumetric flask containing 200 ml water and 10 ml concentrated nitric acid (65 %). It is made up to the mark with water.
- Standard Solution Fe concentration 50 mg/l - 25.0 ml of the stock solution (6.1A or 6.1B) is pipetted into a 500-ml volumetric flask. 1 ml concentrated nitric acid (65 %) is added, and it is made up to the mark with water.
- Standard Series - Specific volumes (0 – 2.00 – 4.00 – 6.00 – 8.00 – 10.00 ml) of the standard solution (6.2) are pipetted into 100-ml volumetric flasks containing 40 ml water. Depending on the digestion method used, either 10 ml concentrated nitric acid (65 %), 3.0 ml concentrated nitric acid (65 %), 0.45 ml concentrated sulphuric acid (96%), or 1.0 ml concentrated hydrochloric acid (36 %) is added. After cooling down, the flasks are made up to the mark with water. This standard series has Fe concentrations of 0 – 1 – 2 – 3 – 4 – 5 mg/l.
- The iron content of the dried plant material, expressed in mg/kg Fe, is calculated using the formula:

(a - b) * V / w

where:

- a represents the concentration of iron in the sample digest, in mg/l.
- b represents the concentration of iron in the blank digest, in mg/l.
- V represents the total volume of the digest at the end of the digestion procedure, in ml.
- w represents the weight of the plant material sample, in grams.

3.3.4.5 Manganese (Mn)

This determination can be carried out on digestions 2.1 (digestion with H_2SO_4 – salicylic acid - H_2O_2 - Se), (digestion with H_2SO_4 - salicylic acid - H_2O_2), (microwave digestion with HNO_3 - H_2O_2 - HF), digest 2.4 (digestion with HNO_3 -H_2O_2 - HF), (digestion with HNO_3 - $HClO_4$ - H_2SO_4), and digest (digestion by dry-ashing followed by treatment with HF).

The Atomic Absorption Spectrophotometer is used as the apparatus.

The following reagents are required:

- Stock Solution, Mn concentration 1000 mg/l.
- Stock Solution, Mn concentration 1000 mg/l - Potassium permanganate, $KMnO_4$, is dissolved in water in a beaker. 1 ml concentrated nitric acid is added, and the permanganate is reduced with a few drops of hydrogen peroxide (30 %). The excess H_2O_2 is boiled off, and the contents of the beaker are transferred quantitatively to a 1000-ml volumetric flask and made up to the mark.
- Standard Solution, Mn concentration 100 mg/l - 10.00 ml of the stock solution is pipetted into a 100-ml volumetric flask and made up to volume with water.
- Standard Series - Specific volumes (0 – 1.00 – 2.00 ml) of the standard solution are pipetted into 100-ml volumetric flasks containing 40 ml water. Depending on the digestion method used, either 4.5 ml concentrated sulphuric acid (96 %), 10 ml concentrated nitric acid (65 %), 3.0 ml concentrated nitric acid (65 %), 0.45 ml concentrated sulphuric acid (96 %), or 1.0 ml concentrated hydrochloric acid (36 %) is added. After cooling down, the flasks are made up to the mark with water. This standard series has Mn concentrations of 0 – 1.0 – 2.0 mg/l.
- Calibration Curve - The emission counts are plotted versus the mg/l manganese in the standard series.

  The Mnconcentration is measured in the standard series, the blanks, and the sample digests at a wavelength of 257.610 nm. A (fitted) background correction is used at this wavelength.

CALCULATIONThe total manganese content in the dried plant material, expressed in mg/kg Mn, is calculated by:

(a - b) * V / w

in which:

a is the concentration of manganese in the sample digest, in mg/l;

b is the concentration of manganese in the blank digest, in mg/l;

V is the total volume of digest at the end of the digestion procedure, in ml;

w is the weight of plant material sample, as gm.

3.3.4.6 Copper (Cu)

Solutions with copper compounds are nebulised into an argon plasma, where all components are vaporised. The ions produced are entrained in the plasma gas and introduced into a mass spectrometer, where they are sorted according to their mass-to-charge ratios and quantified with a channel electron multiplier. Copper is determined at mass 63 amu.

APPARATUS

Atomic Absorption Spectrophotometer

REAGENTS

This determination may be carried out on digest 2.3 (microwave digestion with HNO_3 - H_2O_2 - HF), digest 2.4 (digestion with HNO_3 - H_2O_2 - HF), digest 2.6 (digestion with HNO_3 - $HClO_4$ - H_2SO_4) and digest 2.7 (digestion by dry-ashing followed by treatment with HF).

- Stock Solution, Cu concentration 1000 mg/l

- Stock Solution, Cu concentration 1000 mg/l - 3.929 g copper sulphate pentahydrate, $CuSO_4.5H_2O$, are dissolved in some ultra-pure water in a volumetric flask of 1000 ml. It is made up to 1000 ml with ultra-pure water.
- Standard Solution, Cu concentration 1 mg/l - 1 ml concentrated nitric acid (65 % s.p.) are pipetted in a 1000-ml polythene volumetric flask which already contains about 500 ml ultra-pure water. 1.00 ml stock solution is added and it is made up to volume with ultra-pure water.
- Standard Series - 0 – 1.00 – 2.00 – 5.00 ml of the standard solution (6.2) are pipetted in about 40 ml ultra-pure water in a 100-ml polythene volumetric flasks. Either 1.0 ml concentrated nitric acid (65 %), 0.3 ml concentrated nitric acid (65 %), 0.045 ml concentrated sulphuric acid (96 %) or 0.1 ml concentrated hydrochloric acid (36 %) are added. They are let cool down and made up to the mark with ultra-pure water. This standard series has Cu concentrations of 0 –10 – 20 – 50 μg/L.

PROCEDURE

Measurement – In the standard series, the blanks and the sample digests the Cu concentration is measured with 63 amu???.

CALCULATION

The total copper content in the dried plant material, expressed in μg/kg Cu, is calculated by:

(a - b) * V / w

in which:

a is the concentration of copper in the sample digest, in Pg/l;

b is the concentration of copper in the blank digest, in Pg/l;

V is the total volume of digest at the end of the digestion procedure, in ml;

w is the weight of plant material sample, as gm.

3.3.4.7 Zinc (Zn)

This determination may be carried out on digest 2.1 (digestion with H_2SO_4 – salicylic acid - H_2O_2 - Se), (digestion with H_2SO_4 - salicylic acid - H_2O_2), (microwave digestion with HNO_3 - H_2O_2 - HF), (digestion with HNO_3 - H_2O_2 - HF), (digestion with HNO_3 - $HClO_4$ - H_2SO_4) and digest (digestion by dry-ashing followed by treatment with HF).

APPARATUS

Atomic Absorption Spectrophotometer

REAGENTS

- Stock Solution, Zn concentration 1000 mg/l.
- Stock Solution, Zn concentration 1000 mg/l - 4.398 g zinc sulphate heptahydrate, $ZnSO_4.7H_2O$, are dissolved in about 500 ml ultra-pure water in a 1000-ml volumetric flask and it is made up to volume.
- Standard Solution, Zn concentration 20 mg/l - 2.00 ml stock solution are pipetted into a 100-ml volumetric flask and it is made up to volume.
- Standard Series - 0 – 2.00 – 4.00 – 6.00 – 8.00 – 10.00 ml of the standard solution are pipetted into 100-ml volumetric flasks which already contain 40 ml water. Either 4.5 ml concentrated sulphuric acid (96 %), 10 ml concentrated nitric acid (65 %), 3.0 ml concentrated nitric acid (65%), 0.45 ml concentrated sulphuric acid (96 %) or 1.0 ml concentrated hydrochloric acid (36 %) are added. They are let cool down and made up to the mark with water. This standard series has Zn concentrations of 0 - 0.2 – 0.4 – 0.8 – 1.2 – 1.6 – 2.0 mg/l.

PROCEDURE

Measurement – In the standard series, the blanks and the sample digests the Zn concentration is measured with flame AAS at a wavelength of 213.9 nm, using a just blue (stoichiometric) air-acetylene flame. Background correction is used.

CALCULATION

The total zinc content in the dried plant material, expressed in mg/kg Zn, is calculated by:

(a - b) * V / w

in which:

a is the concentration of zinc in the sample digest, in mg/l;

b is the concentration of zinc in the blank digest, in mg/l;

V is the total volume of digest at the end of the digestion procedure, in ml;

w is the weight of plant material sample, in gm.

3.3.4.8 Plant pigments

Fresh leaves were extracted with dimethyl formamide)DMF) and placed overnight at cool temperature (5°C). Chlorophyll (A), (B), total chlorophylls and total carotenoids were measured by a Spectrophotometer at wavelengths 663, 647 and 470 nm, respectively. Chlorophylls and carotenoids were calculated according to the equation described by (Moran, 1982).

Chl. a = 12.70A663 - 2.79A647

Chl. b = 20.76 A647 - 4.62 A663

Total Chl. = 17.90 A647 + 8.08 A663

Total carotenoids = [1000xA470 - (3.72 Chl. a - 104 Chl. b]/229

3.3.5 Determination of carbohydrates

Total carbohydrates in plant herbs were determined by the phosphomolybdic acid method according to (A.O.A.C, 1970). As follow:

Carbohydrate is first hydrolyzed into simple sugars using dilute hydrochloric acid. In hot acidic medium glucose is dehydrated to hydroxymethyl furfural. This compound forms with anthrone a green colored product with absorption maximum at 630 nm.

Reagents

Glucose stock standard: 100 mg of glucose was dissolved in 100 ml of water in a standard flask.

Working standard: 10 ml of the stock was diluted to 100 ml. 1.0 ml of this solution contains 100 μg of glucose.

Anthrone reagent: 0.2% anthrone was dissolved in ice cold concentrated sulphuric acid. Prepared fresh before use 4. 2.5 N HCl.

Procedure

100mg of the sample was weighed into a boiling tube, hydrolysed by keeping it in a boiling water bath for three hours with 5.0 ml of 2.5 N HCl and cooled to room temperature. It was neutralized with solid sodium carbonate until the effervescence ceased and made up the volume to 100 ml and centrifuged, the supernatant was collected and 0.2 to 1.0 ml was taken for analysis. The standards were prepared by taking 0.2-1.0 ml of the working standards. 1.0 ml of water serves as a blank made up the volume to 1.0 ml in all the tubes with distilled water, then 4.0 ml of anthrone reagent was added, heated for eight minutes in a boiling water bath, cooled rapidly and read the green to dark green color at 630 nm.

Calculation

A standard graph was drawn by taking the concentration of glucose on X axis and spectrophotometer reading on Y axis. From the graph the concentration of glucose in the sample was calculated.

3.3.6 Determination of Total phenolics:

Total phenolic contents of leaves extracts were determined spectrophotometrically according to the Folin-Ciocalteu colorimetric method (Singleton and Rossi 1965).

3.3.7 Determination of Total flavonoids:

Total flavonoids were determined using the method of (Meda et al., 2005) as follow:

A portion of the plant material was weighed out and extraction was carried out in two steps, firstly with MeOH: H2O (1:1). at each step, sufficient solvent was added to make liquid slurry and the mixture was left for 6-12 hrs, filtration to separate the extract from the plant material was carried out rapidly by using a glass wool or cotton wool plugged in the neck of a filter funnel. The two extracts were then combined and evaporated to about one third the original volume or until most of the MeOH has been removed, the resultant aqueous extract was cleared of low polarity contaminants such as fats, terpenes, chlorophylls and xanthophylls by extraction (in a separating funnel) with hexane or chloroform, this was repeated several times and the extracts obtained were concentrated.

Reagents

1. Vanillin reagent -1% vanillin in 70% conc.H2SO4.
2. Catechin standard 110 μg/ml.

Procedure

An aliquot of the extract was pipetted into a test tube and evaporated to dryness.

Then 4 ml of vanillin reagent was added and it was heated for 15 min in a boiling water bath. A standard was also treated in the same manner. Then the optical density was read at 340 or 360 nm.

3.3.8 Determination of Ascorbic acid

Vitamin - C content as ascorbic acid (mg) was estimated in leaves fresh weight, according to (HELRICH, A.O.A.C., 1990). as follow:

Ascorbate is converted to dehydroascorbate by treatment with activated charcoal or bromine. Dehydro ascorbic acid then reacts with 2,4- dinitrophenyl hydrazine to form osazones, which dissolve in sulphuric acid to give an orange colored solution, whose absorbance can be measured spectrophotometrically at 540nm.

Reagents

1. Trichloroacetic acid (4%)
2. Sulphuric acid (9N)
3. 2,4-dinitrophenylhydrazine reagent (2% in 9N sulphuric acid)
4. Thiourea solution (10%)
5. Sulphuric acid (85%)
6. Standard Ascorbate solution: 10 mg ascorbate in 100ml of 4% TCA.

Procedure

Ascorbate was extracted into 4% TCA by homogenizing 1g of sample in it and the volume was made up to 10 ml with 4% TCA. The supernatant obtained after centrifugation at 2000 rpm for 10 mins was treated with a pinch of activated charcoal, shaken well and kept for 10 mins. Centrifugation was repeated once again to remove the charcoal residue. The volumes of the clear supernatants obtained were noted. Two different aliquots of the supernatant were taken for the assay (0.5 ml and 1.0 ml). The assay volumes were made up to 2.0 ml with 4% TCA. 0.2 to 1.0 ml of the working standard solution containing 20-100 g of ascorbate respectively were pipetted into clean dry test tubes, the volumes of which were also made up to 2.0 ml with 4% TCA. DNPH reagent (0.5ml) was added to all the tubes, followed by two drops of 10% thiourea solution. The osazones formed after incubation at 37°C for 3 hours were dissolved in 2.5 ml of 85% H_2SO_4, in cold, with no appreciable rise in temperature. To the blank alone, DNPH reagent and thiourea were added after the addition of H_2SO_4. After incubation for 30 minutes at room temperature, the samples were read at 540 nm and the levels of ascorbic acid in the samples were determined using the standard graph constructed on an electronic calculator.

4. Results and Discussion

4.1 Growth Parameters

As shown in Table (4.9) plant growth significantly decreased in response to drought stress. At severe drought conditions (30% FC), shoot FW and DW decreased by about (31.57%) and (33.32%), respectively lower than their corresponding comparing with unstressed treatment (controls) (Table 9). However, a foliar spraying with the studied concentrations of NSi (10, 5 and 3 PPM) significantly increased plant growth under drought Conditions.

Fresh and dry weight of shoot and of root significantly enhanced by increasing NSi concentration under mild (70% FC) drought condition (Tables. 4.1, 4.2 and 4.4). The most pronounced enhanced achieved under mild drought conditions (70% FC by applying 5 ppm (NSi) where shoot fresh weight increased by about 38.29 %, dry weight of shoot increased by 29.41% more than untreated stressed control) (Tables. 4.1-4.4). At severe drought conditions (30% FC) by adding 5 PPM of NSi showed significantly enhanced in shoot fresh weight by 20.68 %, shoot dry weight by 21.05% respectively than untreated stressed (control) (Table. 4.9).

Pooled data for levels of silicon under irrigation levels were used for correlation heat map of plant hormones, macro elements, and micro elements have shown in Fig 1. All trait showed a positive significant ($p \leq 0.01$) correlation with all studied traits except ABA, and total phenols which had a negative correlation with all studied traits.

4.2 Statistical analysis

The dataset of studied traits was collected and subjected to statistical analysis. The analysis of variance (ANOVA) for testing the significant differences within treatments was performed according to Gomez and Gomez (1984) was done using XLSTAT (Addin soft, New York, USA) statistical package. Duncan's Multiple Range Test was used to do mean comparisons for main effects and interaction. Pooled data for traits was used for correlation analysis using Origin Pro 2021(Origin Lab, Northampton, MA, USA) computer software program.

Table 4.1: Means and standard error for plant hormones (content) in Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		GA3 (µg/g F.W)	ABA (µg/g F.W)	Ascorbic Acid (g/100 g)
Irrigation (I)	100 % (I1)	55.45 ± 5.76 a	14.23 ± 0.86 c	17.02 ± 0.73 a
	70% (I2)	36.50 ± 3.10 b	16.81 ± 0.50 b	14.93 ± 0.43 b
	30 % (I3)	20.97 ± 3.93 c	19.41 ± 0.61 a	12.67 ± 0.52 c
	Sig.	**	**	**
Silicon (S)	Control (S0)	33.11 ± 5.24 b	17.45 ± 0.84 a	13.13 ± 0.85 b
	5 ppm (S1)	39.61 ± 2.97 a	16.52 ± 0.43 b	15.96 ± 0.45 a
	10 ppm (S2)	40.20 ± 3.67 a	16.47 ± 0.56 b	15.52 ± 0.57 a
	Sig.	**	**	**
Irrigation × Silicon (I × S)	I1 × S0	48.95 ± 2.48 c	14.81 ± 0.35 f	15.80 ± 1.01 bc
	I1 × S1	54.18 ± 0.63 b	14.30 ± 0.18 f	16.20 ± 0.92 bc
	I1 × S2	63.21 ± 0.52 a	13.57 ± 0.32 g	19.05 ± 0.14 a
	I2 × S0	32.85 ± 0.43 f	17.72 ± 0.30 c	12.90 ± 0.12 d
	I2 × S1	40.29 ± 1.25 d	15.77 ± 0.12 e	16.83 ± 0.20 b
	I2 × S2	36.37 ± 0.57 e	16.96 ± 0.06 d	15.07 ± 0.47 c
	I3 × S0	17.53 ± 0.66 i	19.82 ± 0.03 a	10.70 ± 0.23 e
	I3× S1	24.37 ± 0.33 g	19.50 ± 0.11 ab	14.85 ± 0.09 c
	I3 × S2	21.02 ± 0.31 h	18.90 ± 0.07 b	12.45 ± 0.03 d
	Sig.	**	**	**

* and **: statistically significant differences at p ≤ 0.05 and p ≤ 0.01, respectively.

Table (4.1) presents the means and standard errors for plant hormone content, specifically GA3, ABA, and Ascorbic Acid, in Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for GA3, ABA, and Ascorbic Acid content are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, all three hormones showed significant differences among the irrigation levels at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for GA3, ABA, and Ascorbic Acid content under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01. In this case, all three hormones showed significant differences among the silicon treatments at p ≤ 0.01.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for GA3, ABA, and Ascorbic Acid content under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$. In this case, all three hormones showed significant differences at various combinations of irrigation and silicon levels at $p \leq 0.01$.

The results suggest that both irrigation and silicon treatments have significant effects on the GA3, ABA, and Ascorbic Acid content in Coriandrum sativum plants. Different levels of irrigation and silicon treatments can lead to variations in hormone levels, indicating their influence on plant physiological processes and responses.

Gibberellic acid (GA3) is a plant hormone involved in promoting stem elongation, seed germination, and flowering. Abscisic acid (ABA) is a hormone associated with plant stress responses, dormancy, and regulation of stomatal closure. Ascorbic Acid, or vitamin C, is an antioxidant that plays a crucial role in plant defense mechanisms and stress tolerance.

The findings indicate that variations in irrigation levels and silicon treatments can affect the levels of GA3, ABA, and Ascorbic Acid in Coriandrum sativum plants. These changes in hormone levels may have implications for plant growth, development, and responses to environmental stresses.

Table 4.2: Means and standard errors for the secondary products in Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon, and interactions.

Treatment		Total alkaloids	Total phenols	Total Flavonoids
		(μg/g D.W)	(μg CE/g)	(μg CE/g)
Irrigation (I)	100 % (I1)	1.68 ± 0.07 a	7.95 ± 0.19 c	35.72 ± 1.84 a
	70% (I2)	1.50 ± 0.04 b	8.63 ± 0.10 b	29.23 ± 0.93 b
	30 % (I3)	1.26 ± 0.05 c	9.11 ± 0.13 b	24.74 ± 1.22 c
	Sig.	**	**	**
Silicon (S)	Control (S0)	1.05 ± 0.09 b	8.79 ± 0.14 a	27.04 ± 1.86 b
	5 ppm (S1)	1.70 ± 0.04 a	8.53 ± 0.06 b	32.00 ± 1.01 a
	10 ppm (S2)	1.70 ± 0.06 a	8.37 ± 0.08 b	30.65 ± 1.27 a
	Sig.	**	**	**
Irrigation × Silicon (I × S)	I1 × S0	1.34 ± 0.22 c	8.32 ± 0.23 cd	32.78 ± 0.45 b
	I1 × S1	1.76 ± 0.01 ab	8.10 ± 0.01 d	35.77 ± 0.37 ab
	I1 × S2	1.93 ± 0.01 a	7.47 ± 0.01 e	38.61 ± 0.27 a
	I2 × S0	1.00 ± 0.02 d	8.90 ± 0.01 ab	26.69 ± 0.69 d
	I2 × S1	1.77 ± 0.03 ab	8.42 ± 0.24 cd	32.29 ± 3.05 bc
	I2 × S2	1.73 ± 0.03 ab	8.58 ± 0.15 bc	28.71 ± 2.69 cd
	I3 × S0	0.80 ± 0.01 d	9.15 ± 0.00 a	21.64 ± 0.31 e
	I3× S1	1.56 ± 0.00 bc	9.07 ± 0.00 a	27.96 ± 0.17 d
	I3 × S2	1.43 ± 0.01 c	9.11 ± 0.01 a	24.63 ± 0.30 de
	Sig.	**	**	**

* and **: statistically significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table (4.2) presents the means and standard errors for secondary products, specifically Total Alkaloids, Total Phenols, and Total Flavonoids, in Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for Total Alkaloids, Total Phenols, and Total Flavonoids are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, all three secondary products showed significant differences among the irrigation levels at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for Total Alkaloids, Total Phenols, and Total Flavonoids under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01. In this case, all three secondary products showed significant differences among the silicon treatments at p ≤ 0.01.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for Total Alkaloids, Total Phenols, and Total Flavonoids under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, all three secondary products showed significant differences at various combinations of irrigation and silicon levels at p ≤ 0.01.

The results suggest that both irrigation and silicon treatments have significant effects on the Total Alkaloids, Total Phenols, and Total Flavonoids content in Coriandrum sativum plants. Different levels of irrigation and silicon treatments can lead to variations in the production of these secondary metabolites, indicating their influence on the plant's biochemical composition and potential medicinal properties.

Total Alkaloids are organic compounds with various physiological effects, including antimicrobial and anti-inflammatory properties. Total Phenols are a diverse group of compounds known for their antioxidant activity and potential health benefits. Total Flavonoids are a subclass of phenolic compounds that possess antioxidant, anti-inflammatory, and anticancer properties.

The results indicate that variations in irrigation levels and silicon treatments can affect the levels of Total Alkaloids, Total Phenols, and Total Flavonoids in Coriandrum sativum plants. These changes in secondary product content may have implications for the plant's nutritional value, flavor, and potential medicinal properties.

Table 4.3: Means and standard error for the carbohydrates in Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon, and interaction.

Treatment		Total fatty acids (μg/g D.W of seeds)	Total Carbohydrates (%)
Irrigation (I)	100 % (I1)	54.80 ± 3.57 a	23.31 ± 0.96 c
	70% (I2)	41.86 ± 1.77 b	21.13 ± 0.64 b
	30 % (I3)	33.52 ± 2.33 c	17.62 ± 0.72 b
	Sig.	**	**
Silicon (S)	Control (S0)	40.29 ± 3.59 b	19.02 ± 1.14 b
	5 ppm (S1)	45.32 ± 1.79 a	21.59 ± 0.86 a
	10 ppm (S2)	44.56 ± 2.35 a	21.44 ± 0.90 a
	Sig.	**	**
Irrigation × Silicon (I × S)	I1 × S0	51.73 ± 0.63 c	21.77 ± 0.94 bc
	I1 × S1	54.15 ± 0.57 b	20.90 ± 0.35 bc
	I1 × S2	58.52 ± 0.41 a	27.25 ± 0.49 a
	I2 × S0	38.82 ± 0.23 f	20.10 ± 0.17 c
	I2 × S1	45.86 ± 1.56 d	22.83 ± 0.75 b
	I2 × S2	40.90 ± 0.27 e	20.47 ± 1.39 bc
	I3 × S0	30.32 ± 0.35 h	15.20 ± 0.17 d

Treatment		Total fatty acids (μg/g D.W of seeds)	Total Carbohydrates (%)
	I3× S1	35.95 ± 0.13 g	21.05 ± 1.41 bc
	I3 × S2	34.28 ± 0.31 g	16.60 ± 0.12 d
	Sig.	**	**

* and **: statistically significant differences at p ≤ 0.05 and p ≤ 0.01, respectively.

Table (4.3) provides the means and standard errors for two variables, Total Fatty Acids and Total Carbohydrates, in Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for Total Fatty Acids and Total Carbohydrates are given, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, both Total Fatty Acids and Total Carbohydrates showed significant differences among the irrigation levels at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for Total Fatty Acids and Total Carbohydrates under each silicon level are provided, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01. In this case, both Total Fatty Acids and Total Carbohydrates showed significant differences among the silicon treatments at p ≤ 0.01.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for Total Fatty Acids and Total Carbohydrates under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, both Total Fatty Acids and Total Carbohydrates showed significant differences at various combinations of irrigation and silicon levels at p ≤ 0.01.

Total Fatty Acids are organic compounds that serve as a major energy source in organisms and play essential roles in cell structure and function. Total Carbohydrates are a group of macronutrients that serve as a primary source of energy in plants and animals.

The results suggest that variations in irrigation levels and silicon treatments can influence the levels of Total Fatty Acids and Total Carbohydrates in Coriandrum sativum plants. These changes in biochemical composition may have implications for the plant's nutritional value and potential applications in food and pharmaceutical industries.

Table 4.4: Means and standard error for N and P elements in shoot and root of Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		N %		P%	
		Shoot	Root	Shoot	Root
Irrigation (I)	100 % (I1)	2.91 ± 0.09 a	0.90 ± 0.10 a	0.09 ± 0.01 a	0.29 ± 0.02 a
	70% (I2)	2.52 ± 0.03 b	0.78 ± 0.07 a	0.27 ± 0.01 a	0.21 ± 0.01 b
	30 % (I3)	2.41 ± 0.05 c	0.36 ± 0.08 b	0.21 ± 0.01 b	0.18 ± 0.01 c
	Sig.	**	**	**	**
Silicon (S)	Control (S0)	2.51 ± 0.06 c	0.65 ± 0.10 a	0.25 ± 0.02 b	0.19 ± 0.02 c
	5 ppm (S1)	2.61 ± 0.03 b	0.69 ± 0.09 a	0.26 ± 0.01 ab	0.22 ± 0.01 b
	10 ppm (S2)	2.72 ± 0.04 a	0.69 ± 0.08 a	0.27 ± 0.01 a	0.27 ± 0.01 a
	Sig.	**	ns	**	

Treatment		N %		P%	
		Shoot	Root	Shoot	Root
Irrigation × Silicon (I × S)	I1 × S0	2.69 ± 0.09 c	0.82 ± 0.12 b	0.29 ± 0.01 b	0.24 ± 0.02 b
	I1 × S1	2.81 ± 0.02 b	0.81 ± 0.02 b	0.25 ± 0.02 cd	0.20 ± 0.02 cde
	I1 × S2	3.23 ± 0.05 a	1.07 ± 0.01 a	0.32 ± 0.01 a	0.42 ± 0.00 a
	I2 × S0	2.49 ± 0.02 de	0.84 ± 0.02 b	0.26 ± 0.01 bcd	0.18 ± 0.02 de
	I2 × S1	2.57 ± 0.01 d	0.83 ± 0.08 b	0.28 ± 0.00 bc	0.24 ± 0.01 b
	I2 × S2	2.52 ± 0.03 de	0.67 ± 0.17 b	0.28 ± 0.01 bc	0.22 ± 0.01 bc
	I3 × S0	2.35 ± 0.02 f	0.31 ± 0.03 c	0.20 ± 0.01 e	0.16 ± 0.01 e
	I3× S1	2.45 ± 0.01def	0.43 ± 0.01 c	0.24 ± 0.01 d	0.22 ± 0.01 bcd
	I3 × S2	2.42 ± 0.01 ef	0.33 ± 0.01 c	0.21 ± 0.00 e	0.17 ± 0.00 e
	Sig.	**	**	**	**

* and **: statistically significant differences at p ≤ 0.05 and p ≤ 0.01, respectively. ns: non-significant

Table (4.4) presents the means and standard errors for the N and P elements in the shoot and root of Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for N and P percentages in the shoot and root are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, all comparisons among the irrigation levels for N and P percentages in both shoot and root showed significant differences at p ≤ 0.01, except for the N percentage in the root, which was not significant (ns).

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for N and P percentages in the shoot and root under each silicon level are provided, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01. In this case, all comparisons among the silicon treatments for N and P percentages in the shoot and root showed significant differences at p ≤ 0.01, except for the P percentage in the shoot, which was not significant (ns).

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for N and P percentages in the shoot and root under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01. In this case, all comparisons among the combinations of irrigation and silicon levels for N and P percentages in the shoot and root showed significant differences at p ≤ 0.01.

N and P are essential elements for plant growth and development. N is a major component of proteins, nucleic acids, and other important molecules, while P is involved in energy transfer, nucleic acid synthesis, and cell signaling.

The results suggest that variations in irrigation levels and silicon treatments can affect the levels of N and P percentages in the shoot and root of Coriandrum sativum plants. These changes in nutrient composition may have implications for plant growth, nutrient uptake, and overall plant health.

Table 4.5: Means and standard error for K and Mg elements in shoot and root of Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		K %		Mg %	
		Shoot	Root	Shoot	Root
Irrigation (I)	100 % (I1)	3.31 ± 0.17 a	2.35 ± 0.14 a	0.35 ± 0.02 a	0.07 ± 0.00 a
	70% (I2)	3.33 ± 0.15 a	2.20 ± 0.11 b	0.25 ± 0.01 b	0.06 ± 0.00 a
	30 % (I3)	2.46 ± 0.14 b	1.55 ± 0.11 c	0.21 ± 0.01 c	0.04 ± 0.00 b
	Sig.	**	**	**	*

Treatment		K %		Mg %	
		Shoot	Root	Shoot	Root
Silicon (S)	Control (S0)	2.79 ± 0.22 c	1.74 ± 0.21 b	0.25 ± 0.03 b	0.04 ± 0.01 b
	5 ppm (S1)	3.11 ± 0.17 b	2.14 ± 0.17 a	0.28 ± 0.01 a	0.06 ± 0.00 a
	10 ppm (S2)	3.21 ± 0.17 a	2.21 ± 0.17 a	0.29 ± 0.02 a	0.06 ± 0.00 a
	Sig.	**	*	**	*
Irrigation × Silicon (I × S)	I1 × S0	3.27 ± 0.07 b	2.20 ± 0.18 c	0.34 ± 0.02 b	0.06 ± 0.01 ab
	I1 × S1	3.13 ± 0.02 c	2.13 ± 0.02 c	0.32 ± 0.02 b	0.05 ± 0.02 bc
	I1 × S2	3.55 ± 0.04 a	2.72 ± 0.03 a	0.39 ± 0.01 a	0.09 ± 0.00 a
	I2 × S0	3.04 ± 0.02 c	2.00 ± 0.06 cd	0.22 ± 0.02 d	0.04 ± 0.01 bc
	I2 × S1	3.49 ± 0.03 a	2.41 ± 0.01 b	0.27 ± 0.01 c	0.08 ± 0.01 a
	I2 × S2	3.46 ± 0.02 a	2.19 ± 0.05 c	0.27 ± 0.01 c	0.06 ± 0.01 ab
	I3 × S0	2.05 ± 0.03 e	1.04 ± 0.03 f	0.18 ± 0.01 e	0.02 ± 0.01 c
	I3× S1	2.71 ± 0.01 d	1.89 ± 0.05 de	0.23 ± 0.01 d	0.06 ± 0.01 ab
	I3 × S2	2.62 ± 0.01 d	1.72 ± 0.01 e	0.21 ± 0.01 de	0.04 ± 0.010 bc
	Sig.	**	**	**	*

* and **: statistically significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table (4.5) presents the means and standard errors for the K (potassium) and Mg (magnesium) elements in the shoot and root of Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for K and Mg in both shoot and root are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for K and Mg in both shoot and root under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at $p \leq 0.05$ and ** representing a significant difference at $p \leq 0.01$.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for K and Mg in shoot and root under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$.

The significance row at the bottom of each section and the Irrigation × Silicon (I × S) section indicates the overall statistical significance of the effects. The presence of * or ** in the Sig. row suggests significant differences between the treatments in most comparisons.

Based on the table, it can be observed that both irrigation and silicon treatments have significant effects on the K and Mg content in the shoot and root of Coriandrum sativum plants. The means of K and Mg content vary across different irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

Furthermore, the interaction between irrigation and silicon treatments (I × S) also shows significant effects on K and Mg content. The means of K and Mg content differ among the various combinations of irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

The results suggest that variations in irrigation levels and silicon treatments can influence the uptake and accumulation of potassium and magnesium in different plant parts, specifically the shoot and root of Coriandrum sativum. These findings highlight the importance of appropriate irrigation management and the potential role of silicon supplementation in influencing the nutrient status of the plant.

The statistical analysis presented in Table 4.5 indicates significant differences between treatments in terms of potassium and magnesium content in the shoot and root of Coriandrum sativum plants. The findings suggest that irrigation, silicon supplementation, and their interaction play a role in modulating these nutrient levels in the plant. However, further research is required to fully understand the underlying mechanisms and practical implications of these findings.

Table 4.6: Means and standard error for Ca element in shoot and root of Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		Ca %	
		Shoot	Root
Irrigation (I)	100 % (I1)	1.56 ± 0.03 a	1.16 ± 0.11 a
	70% (I2)	1.52 ± 0.02 b	1.09 ± 0.09 b
	30 % (I3)	1.36 ± 0.03 c	0.58 ± 0.09 c
	Sig.	**	**
Silicon (S)	Control (S0)	1.41 ± 0.03 b	0.75 ± 0.18 c
	5 ppm (S1)	1.51 ± 0.03 a	1.06 ± 0.15 b
	10 ppm (S2)	1.51 ± 0.03 a	1.02 ± 0.15 a
	Sig.	**	**
Irrigation × Silicon (I × S)	I1 × S0	1.48 ± 0.04 cd	1.11 ± 0.04 c
	I1 × S1	1.54 ± 0.02 b	1.15 ± 0.02 c
	I1 × S2	1.65 ± 0.01 a	1.22 ± 0.00 a
	I2 × S0	1.46 ± 0.01 cd	1.01 ± 0.01 cd
	I2 × S1	1.57 ± 0.02 b	1.15 ± 0.00 b
	I2 × S2	1.52 ± 0.01 bc	1.12 ± 0.01 c
	I3 × S0	1.29 ± 0.01 f	0.12 ± 0.01 f
	I3× S1	1.42 ± 0.01 de	0.89 ± 0.01 de
	I3 × S2	1.38 ± 0.00 e	0.73 ± 0.01 e
	Sig.	**	**

* and **: statistically significant differences at p ≤ 0.05 and p ≤ 0.01, respectively.

Table (4.6) provides the means and standard errors for the Ca (calcium) element in the shoot and root of Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for Ca in both shoot and root are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for Ca in both shoot and root under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for Ca in shoot and root under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01.

The significance row at the bottom of each section and the Irrigation × Silicon (I × S) section indicates the overall statistical significance of the effects. The presence of * or ** in the Sig. row suggests significant differences between the treatments in most comparisons.

Based on the results, it can be observed that both irrigation and silicon treatments have significant effects on the Ca content in the shoot and root of Coriandrum sativum plants. The means of Ca content vary across different irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

Furthermore, the interaction between irrigation and silicon treatments (I × S) also shows significant effects on Ca content. The means of Ca content differ among the various combinations of irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

The results suggest that variations in irrigation levels and silicon treatments can influence the uptake and accumulation of calcium in different plant parts, specifically the shoot and root of Coriandrum sativum. Calcium is an essential nutrient for plant growth and development, playing a crucial role in cell wall formation, enzyme activation, and various physiological processes.

Table 4.7: Means and standard error for micro elements in shoot Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		Fe	Zn	Mn
		ppm	ppm	ppm
Irrigation (I)	100 % (I1)	191.9 ± 6.86 a	58.9 ± 3.12 a	13.9 ± 1.00 a
	70% (I2)	174.9 ± 4.40 b	52.9 ± 2.20 b	11.1 ± 0.59 b
	30 % (I3)	150.9 ± 5.10 c	40.6 ± 2.41 c	8.1 ± 0.71 c
	Sig.	**	**	**
Silicon (S)	Control (S0)	167.5 ± 8.92 b	48.8 ± 3.75 c	10.1 ± 0.93 b
	5 ppm (S1)	176.4 ± 6.96 a	53.1 ± 2.38 a	11.4 ± 0.59 a
	10 ppm (S2)	173.7 ± 7.14 ab	50.7 ± 2.77 b	11.7 ± 0.69 a
	Sig.	**	**	**
Irrigation × Silicon (I × S)	I1 × S0	188.0 ± 0.93 ab	59.4 ± 0.50 a	12.7 ± 0.30 c
	I1 × S1	189.5 ± 0.55 a	58.1 ± 0.43 b	13.7 ± 0.29 b
	I1 × S2	198.2 ± 0.38 a	59.5 ± 0.46 a	15.6 ± 0.52 a
	I2 × S0	177.3 ± 0.89 bc	49.9 ± 0.14 e	10.3 ± 0.26 e
	I2 × S1	177.5 ± 3.54 bc	56.6 ± 0.53 c	11.8 ± 0.26 d
	I2 × S2	169.8 ± 8.66 cd	52.4 ± 0.64 d	11.2 ± 0.17 d
	I3 × S0	137.3 ± 4.04 f	37.3 ± 0.24 h	7.2 ± 0.04 g
	I3× S1	162.3 ± 0.76 de	44.8 ± 0.23 f	8.7 ± 0.36 f
	I3 × S2	153.3 ± 0.87 e	40.1 ± 0.24 g	8.3 ± 0.07 f
	Sig.	**	**	**
C.V%		3.54	1.48	4.53

* and **: statistically significant differences at p ≤ 0.05 and p ≤ 0.01, respectively.

Table (4.7) presents the means and standard errors for three microelements (Fe, Zn, and Mn) in the shoot of Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for Fe, Zn, and Mn in the shoot are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for Fe, Zn, and Mn in the shoot under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at $p \leq 0.05$ and ** representing a significant difference at $p \leq 0.01$.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for Fe, Zn, and Mn in the shoot under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$.

The coefficient of variation (C.V%) is also provided for each microelement, indicating the variability of the measurements.

Based on the table, it can be observed that both irrigation and silicon treatments have significant effects on the content of Fe, Zn, and Mn in the shoot of Coriandrum sativum plants. The means of these microelements vary across different irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

Furthermore, the interaction between irrigation and silicon treatments (I × S) also shows significant effects on the microelement content in the shoot. The means of Fe, Zn, and Mn differ among the various combinations of irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

The results suggest that variations in irrigation levels and silicon treatments can influence the uptake and accumulation of microelements in the shoot of Coriandrum sativum. Microelements such as Fe, Zn, and Mn play essential roles as cofactors for various enzymes and are involved in important metabolic processes in plants.

Table 4.8: Means and standard error for micro elements in root Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon and interaction.

Treatment		Fe	Zn	Mn
		ppm	ppm	ppm
Irrigation (I)	100 % (I1)	83.31 ± 6.13 a	20.86 ± 1.36 a	10.29 ± 1.14 a
	70% (I2)	73.73 ± 4.56 b	17.38 ± 0.86 b	6.89 ± 0.67 b
	30 % (I3)	47.76 ± 4.83 c	12.72 ± 1.01 c	3.42 ± 0.81 c
	Sig.	**	**	**
Silicon (S)	Control (S0)	62.77 ± 6.15 c	15.49 ± 1.37 b	5.74 ± 1.15 b
	5 ppm (S1)	71.87 ± 4.46 b	17.87 ± 0.92 a	7.34 ± 0.57 a
	10 ppm (S2)	70.16 ± 4.80 a	17.60 ± 1.04 a	7.53 ± 0.75 a
	Sig.	**	**	**
Irrigation × Silicon (I × S)	I1 × S0	78.30 ± 2.17 c	19.20 ± 0.32 c	9.43 ± 0.18 c
	I1 × S1	82.33 ± 0.49 b	21.18 ± 0.17 b	10.03 ± 0.15 b
	I1 × S2	89.30 ± 0.46 a	22.20 ± 0.23 a	11.40 ± 0.06 a
	I2 × S0	67.62 ± 0.56 d	16.18 ± 0.19 e	5.22 ± 0.06 f
	I2 × S1	78.23 ± 0.27 c	18.63 ± 0.43 c	8.20 ± 0.21 d
	I2 × S2	75.33 ± 0.84 c	17.33 ± 0.09 d	7.27 ± 0.33 e
	I3 × S0	42.40 ± 0.60 g	11.10 ± 0.20 g	2.56 ± 0.07 h
	I3× S1	55.04 ± 1.17 e	13.81 ± 0.10 f	3.77 ± 0.16 g
	I3 × S2	45.84 ± 0.73 f	13.27 ± 0.24 f	3.94 ± 0.03 g
	Sig.	**	**	**

* and **: statistically significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table (4.8) presents the means and standard errors for three microelements (Fe, Zn, and Mn) in the root of Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for Fe, Zn, and Mn in the root are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for Fe, Zn, and Mn in the root under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at p ≤ 0.05 and ** representing a significant difference at p ≤ 0.01.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for Fe, Zn, and Mn in the root under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at p ≤ 0.05 and ** indicating a significant difference at p ≤ 0.01.

The coefficient of variation (C.V%) is also provided for each microelement, indicating the variability of the measurements.

Based on the table, it can be observed that both irrigation and silicon treatments have significant effects on the content of Fe, Zn, and Mn in the root of Coriandrum sativum plants. The means of these microelements vary across different irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

Furthermore, the interaction between irrigation and silicon treatments (I × S) also shows significant effects on the microelement content in the root. The means of Fe, Zn, and Mn differ among the various combinations of irrigation and silicon levels, and the significance values indicate that these differences are statistically significant.

The results suggest that variations in irrigation levels and silicon treatments can influence the uptake and accumulation of microelements in the root of Coriandrum sativum. Microelements such as Fe, Zn, and Mn are essential for various physiological and biochemical processes in plants, including enzyme activities and metabolic pathways.

The findings from this study highlight the importance of appropriate irrigation management and the potential role of silicon supplementation in modulating the microelement status of the plant's root system.

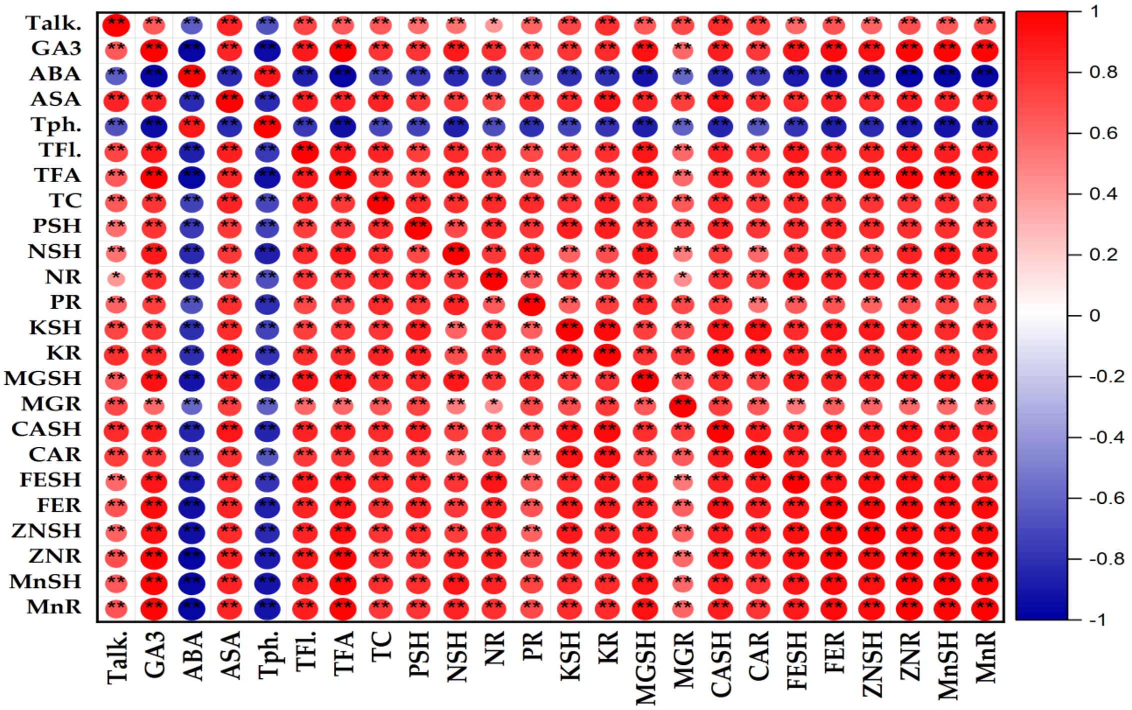

Figure 4.1. Correlation heat map for studied traits. * and ** present the significantly of correlation coefficient at 0.05 and 0.01 in respective.

Pooled data for levels of silicon under irrigation levels were used for correlation heat map of plant hormones, macro elements, and micro elements have shown in Fig 4.1. All trait showed a positive significant (p ≤ 0.01) correlation with all studied traits except ABA, and total phenols which had a negative correlation with all studied traits.

Table 4.9: Means and standard error for root length, shoot length, fresh weight, and dry weight in Coriandrum sativum plant under three levels of irrigation, foliar spray with nano-silicon, and interaction.

Treatment	Root Length	Shoot Length	Fre		
h Weight		Dry Weight			
		(cm)	(cm)	(gm)	(gm)
Irrigation (I)	100 % (I1)	6.64 ± 0.12 a	5.60 ± 0.21 ab	0.19 ± 0.02 a	0.09 ± 0.02 a
	70% (I				
)	6.92 ± 0.12 a	6.49 ± 0.20 a	0.29 ± 0.02 a	0.12 ± 0.02 a	
	30 % (I3)	6.20 ± 0.09 a	5.27 ± 0.12 b	0.13 ± 0.01 a	0.06 ± 0.01 a
	Sig.	ns	*	ns	ns
Silicon (S)	Control (S0				
	6.28 ± 0.12 a	6.30 ± 0.04 a	0.23 ± 0.01 a	0.15 ± 0.04 a	
	5 ppm (S1)	6.86 ± 0.09 a	6.1		
± 0.04 a	0.29 ± 0.01 a	0.19 ± 0.04 a			
	10 ppm (S2)	6.63 ± 0.03 a	4.91 ± 0.02 b	0.18 ± 0.01 a	0.0
± 0.02 a					
	Sig.	ns	*	ns	**
Irrigation × Silicon (I × S)	I1 × S0	6.00 ± 0.29 a	6.33 ± 1.11 ab	0.26 ± 0.09 b	0.12 ± 0.05 ab
	I1 × S1	6.40 ± 0.47 a	4.77 ± 0.41 bc	0.10 ± 0.01 b	0.04 ± 0.00 b
	I1 × S2	7.53 ± 0.69 a	5.70 ± 0.47 b	0.22 ± 0.06 b	0.11 ± 0.03 ab
	I2 × S0	6.67 ± 0.41 a	6.17 ± 0.41 b	0.19 ± 0.01 b	0.32 ± 0.23 a
	I2 × S1	7.23 ± 1.27 a	8.03 ± 0.92 a	0.47 ± 0.09 a	0.17 ± 0.04 ab
	I2 × S2	6.87 ± 1.48 a	5.27 ± 0.63 bc	0.21 ± 0.01 b	0.10 ± 0.01 ab
	I3 × S0	6.17 ± 0.12 a	6.40 ± 0.44 ab	0.26 ± 0.10 b	0.08 ± 0.04 ab
	I3× S1	6.93 ± 0.38 a	5.63 ± 0.15 bc	0.21 ± 0.04 b	0.10 ± 0.01 ab
	I3 × S2	5.50 ± 0.29 a	3.77 ± 0.26 c	0.11 ± 0.01 b	0.04 ± 0.01 b
	Sig.	ns	*	*	*

* and **: statistically significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively. ns: non-significant

Table (4.9) presents the means and standard errors for root length, shoot length, fresh weight, and dry weight in Coriandrum sativum plants. The analysis focuses on the effects of three factors: irrigation, foliar spray with nano-silicon, and their interaction.

Under the Irrigation (I) factor, three levels of irrigation are compared: 100% (I1), 70% (I2), and 30% (I3). The mean values for root length, shoot length, fresh weight, and dry weight are provided, along with their respective standard errors. The statistical significance of the differences between the means is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$. In this case, no significant differences were observed for root length, fresh weight, and dry weight, while shoot length showed a significant difference at $p \leq 0.05$.

Similarly, under the Silicon (S) factor, three levels of silicon treatment are compared: Control (S0), 5 ppm (S1), and 10 ppm (S2). The mean values for root length, shoot length, fresh weight, and dry weight under each silicon level are given, along with the standard errors. The significance of the differences is indicated by asterisks (* and **), with * representing a significant difference at $p \leq 0.05$ and ** representing a significant difference at $p \leq 0.01$. In this case, shoot length and dry weight showed significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while root length and fresh weight did not show significant differences.

The Irrigation × Silicon (I × S) section represents the interaction between irrigation and silicon treatments. It includes multiple sub-sections corresponding to different combinations of irrigation and silicon levels. The mean values for root length, shoot length, fresh weight, and dry weight under each combination are provided, along with their standard errors. The statistical significance of the differences is denoted by asterisks (* and **), with * indicating a significant difference at $p \leq 0.05$ and ** indicating a significant difference at $p \leq 0.01$. In this case, shoot length, fresh weight, and dry weight showed significant differences at various combinations of irrigation and silicon levels, while root length did not show significant differences.

The results suggest that irrigation and silicon treatments can have significant effects on the shoot length, fresh weight, and dry weight of Coriandrum sativum plants. However, no significant differences were observed for root length under the tested conditions.

The findings indicate that variations in irrigation levels and silicon treatments can influence the growth and biomass accumulation of Coriandrum sativum plants. Shoot length, fresh weight, and dry weight are important parameters that reflect plant development, biomass production, and overall plant performance.

Overall, the statistical analysis presented in Table 4.9 suggests that the interaction between irrigation and silicon treatments can have significant effects on shoot length, fresh weight, and dry weight in Coriandrum sativum plants, with irrigation and silicon treatments individually influencing some of these parameters as well. However, root length did not show significant differences under the tested conditions.

4.3 Conclusion

The study investigated the effects of different levels of irrigation (100%, 70%, 30%) and silicon spray treatments (control, 5 ppm, 10 ppm), as well as their interaction, on key plant hormones (GA3, ABA, ascorbic acid) and secondary metabolites (total alkaloids, total phenols, total flavonoids) in Coriandrum sativum plants.

The results showed that both irrigation levels and silicon treatments significantly impacted the levels of all hormones and secondary products measured. Varying the irrigation amount and silicon application resulted in changes to the plant's hormone concentrations and biochemical composition.

Specifically, deficiencies in watering (30% irrigation) or lack of silicon treatment were found to decrease the levels of growth-promoting GA3, stress-response ABA, and antioxidant ascorbic acid compared to optimal conditions. Secondary metabolites involved in medicinal properties like antimicrobial activity were also reduced under stressed conditions.

In conclusion, this study demonstrated that irrigation management and silicon supplementation can influence important physiological and chemical processes in Coriandrum sativum by altering the production and balance of key plant hormones and secondary metabolites. This has implications for growth, development, environmental responses, nutritional value and potential medicinal uses of the crop.

This study demonstrated that irrigation management and silicon supplementation can influence important physiological, chemical, nutritional, and elemental processes in Coriandrum sativum by altering the production and balance of key plant hormones, secondary metabolites, and macronutrients. Specifically, deficiencies decreased hormones, metabolites, fatty acids, carbohydrates, and nutrient levels compared to optimal conditions. This has implications for growth, development, environmental responses, nutritional value, potential medicinal uses, and overall health of the crop. Variations in irrigation and silicon treatments were shown to impact the levels of hormones, secondary products, fatty acids, carbohydrates, nitrogen, and phosphorus in both the shoots and roots of the plants. The changes in biochemical composition may have further implications for the plant's applications in food and pharmaceutical industries. Therefore, precise control of irrigation and silicon supplements can optimize the cultivation of coriander.

This study evaluated the effects of different irrigation levels (100%, 70%, 30%), silicon spray treatments (0, 5, 10 ppm), and their interaction on growth parameters and nutrient status of Coriandrum sativum plants.

The results found that irrigation, silicon application, and their combined interaction significantly impacted the content of various macronutrients, micronutrients and minerals in both the shoots and roots. This included N, P, K, Mg, Ca, Fe, Zn and Mn. The treatment factors also influenced phytohormone and secondary metabolite levels in the plants.

Significant differences were observed in the shoot length, fresh weight and dry weight of C. sativum under varying irrigation and silicon regimes, indicating effects on growth and biomass accumulation. However, root length was not significantly impacted.

5.1 Findings

Recently, researchers and agricultural experts are interested in using NPs for alleviating plant responses to stress conditions in order to provide a secure and long-term future for agriculture around the world (Saxena et al., 2016). Since of their increased surface area and the ability to tailor specific features through coatings and/or functionalization to improve nutrition delivery, nanoparticles are more reactive than their bulk scale counterparts (Dimkpa *et al.,*2019 and Ahmad and Kalra, 2020). Drought is one of the most significant restrictions in irrigated agriculture, limiting crop output and consequently posing a danger to food security (Abdelkhalik et al.,2019). Increased drought occurrences in arid places intensify these concerns to food production sustainability. Drought stress can inhibit plant growth by interfering with a variety of physio-biochemical processes and generating nutritional shortages. As a result, these stresses may result in severe yield reductions.

Due to eco-friendliness, economic opportunities and sustainability the "green" route for NPs synthesis is of great interest. It is a new and evolving research area in the scientific world, where regular advances are noted to guarantee a promising future for this field that can be used to reduce the negative effects of abiotic stresses on plants (Younes *et al.*, 2020). Plant extracts could be used as reducing and stabilizing agents for green synthesis of NPs (Ahmad and Kalra, 2020).

The dry fruits of *C. sativum* are known as coriander seeds, and the word “coriander” often refers to the fruits (as a spice), rather than to the plant. The top producers of *C. sativum* fruits in the world today are India, Russia, Morocco, Canada, Romania, and Ukraine, with smaller producers including Iran, Turkey, Israel, Egypt, China, the United States, Argentina, and Mexico (**Nadeem *et al.,* 2013**). In 2008, global trade in coriander was around 100 million kg (around US$ 134 million) **(Sharma MM *et al.,* 2008)** The odor of the fruits of *C. sativum* has been described as sweet, candy-like, and aromatically spicy **(kerolla *at al.,* 1993).** The dried fruits are used in curries, curry powder, pickles, sausages, soups, stews, and ratatouille **(Sharma MM *et al.,* 2008).** The fruit essential oils of *C. sativum* are typically dominated by linalool (60%-80%), with lesser concentrations of α-pinene (up to 9.5%), γ-terpinene (1%-10%), camphor (up to 4.9%), and geranyl acetate (up to 4.7%) **(Zheljazkov & mandal *et al.,* 2015)** The International Organization of Standards (ISO) standard for coriander essential oil is α-pinene (3.0%-7.0%), myrcene (0.5%-1.5%), limonene (2.0%-5.0%), γ-terpinene (2.0%-7.0%), linalool (65.0%-78.0%), camphor (4.0%-6.0%), α-terpineol (0.5%-1.5%), geraniol (0.5%-3.0%), and geranyl acetate (1.0%-3.5%). Data collected from ISO *ISO3516*

The commercially available *C. sativum* essential oils from this study, either the fruit (coriander) essential oil or the herb (cilantro) essential oil, have similar chemical compositions. Thus, unless adulteration is a problem, the chemical qualities of the essential oils are very consistent. Commercial coriander essential oil is dominated by linalool (62.2%-76.7%) with lesser quantities of α-pinene (0.3%-11.4%), γ-terpinene (0.6%-11.6%), and camphor (0.0%-5.5%). Commercial cilantro essential oil is composed largely of (2*E*)-decenal (16.0%-46.6%), linalool (11.8%-29.8%), (2*E*)-decen-1-ol (0.0%-24.7%), decanal (5.2%-18.7%), (2*E*)-dodecenal (4.1%-8.7%), and 1-decanol (0.0%-9.5%). Nevertheless, there are likely other chemotypes of *C. sativum* essential oils that may be considered for cultivation and commercialization **(Prabodh *et al.,* 2020).** The enantiomeric distribution of linalool was 87% (+)-linalool:13% (−)-linalool in both coriander and cilantro essential oils, while α-pinene was 93% (+):7% (−) in coriander, 90% (+):10% (−) in cilantro; and (+)-camphor:(−)-camphor was 13%:87% in both essential oils. Chiral GC–MS analysis was able to detect an adulterated coriander essential oil sample. Coriander essential oil has apparently shown no human toxicity **(Mandal S *et al.,* 2015)** There are no published reports on any adverse effects of cilantro essential oil. Both coriander and cilantro essential oils can be considered safe for use in human foods. **(Prabodh *et al.,* 2020).**

References

- Abhilash PC, Tripathi V, Adil Edrisi S, Kant Dubey R, Bakshi M, Dubey PK, Singh HB, Ebbs SD (2016) Sustainability of crop production from polluted lands. Energ Ecol Environ 1(1):54–65.
- Abobatta W.F., (2019). Drought adaptive mechanisms of plants – a review. Advancesin Agriculture and Environmental Science ,2(1):62–65.
- Ahmad Z., Anjum S., Waraich E.A., Ayub M.A., Ahmad T., Tariq R.M.S., Ahmad R.and Iqbal M.A. (2018). Growth, physiology, and biochemical activities of plant responses with foliar potassium application under drought stress—A review. *Journal of Plant Nutrition*, 41:1734-1743.
- Alaei S.H., Melikyan A., Kobraee S. and Mahna N., (2013). Effect of different soil moisture levels on morphological and physiological characteristics of Dracocephalum moldavica. Agricultural Communications, 1:23-26.
- Allakhverdiev S.I., Kinoshita M., Inaba M., Suzuki I., Murata N. (2001): Unsaturated fatty acids in membrane lipids protect the photosynthetic machinery against salt-induced damage in Synechococcus. Plant Physiology, 125: 1842–1853.

- Amiripour A, Jahromi MG, Soori M.K, mohammadi Torkashvand A. Changes in essential oil composition and fatty acid profile of coriander (*Coriandrum sativum* L.) leaves under salinity and foliar-applied silicon. Ind. Crop Prod. 2021;168, 113599
- Arora A., Sairam R.K. and Srivastava G.C., (2002). Oxidative stress and antioxidativesystem in plants. *Current Science*, 82:10-25.
- Bao-shan l., chun-hui l., li-jun F., Shu-chun Q., Min y. 2004. Effect of TMS (nanostructured silicon dioxide) on growth of changbai larch seedlings. Journal of Forestry Research 15: 138–140.
- Baozhu Li et al., (Flavonoids improve drought tolerance of maize seedlings by regulating the homeostasis of reactive oxygen species)
- Bassett c.l. 2013. water use and Drought response in cultivated and wild apples, in: abiotic Stress - plant responses and applications in agriculture (ed. k. Vahdati, ch.leslie). inTech, 249–276. Doi: 10.5772/55537.
- Batsmanova L.M., Gonchar L.M., Taran N.Y. and Okanenko A.A., (2013). Using a colloidal solution of metal nanoparticles as micronutrient fertilizer for cereals. *Proceedings of the International Conference Nanomaterials: Applications and Properties*, 2(4):42-58.
- Belal E, El-Ramady H (2016) Nanoparticles in water, soils and agriculture. In: Ranjan S et al (eds) Nanoscience in food and agriculture 2, Sustainable agriculture reviews 21. Springer, Cham. https://doi.org/10.1007/978-3-319-39306-3_10
- Beyzi E, Karaman K, Gunes A, Beyzi, S.B. Change in some biochemical and bioactive properties and essential oil composition of coriander seed (Coriandrum sativum L.) varieties from Turkey. Ind Crop Prod. 2017; 109: 74-78.
- Bigler c. , Bräker o.u. , Bugmann H. , Dobbertin M., rigling a. 2006. Drought as an inciting mortality factor in Scots pine stands of the Valais, Switzerland. Ecosystems 9: 330–343.
- Botir Khaitov et al., 2021, Licorice (Glycyrrhiza glabra)—Growth and Phytochemical Compound Secretion in Degraded Lands under Drought Stress
- Bukhari MA, Ahmad Z, Ashraf MY, Afzal M, Nawaz F, Nafees M, Manan A (2020) Silicon Mitigates Drought Stress in Wheat (Triticum aestivum L.) Through Improving Photosynthetic Pigments, Biochemical and Yield Characters. Silicon. 2020;1-16.
- Bukhari MA, Ahmad Z, Ashraf MY, Afzal M, Nawaz F, Nafees M, Manan A (2020) Silicon Mitigates Drought Stress in Wheat (Triticum aestivum L.) Through Improving Photosynthetic Pigments, Biochemical and Yield Characters. Silicon. 2020;1-16.
- Burman U, Saini M, Praveen K., (2013). Effect of zinc oxide nanoparticles on growthand antioxidant system of chickpea seedlings. *Toxicological and Environmental Chemistry*, 95(4):605–612.
- Cakmak I., (2008). Enrichment of cereal grains with zinc, "Agronomic or genetic biofortification". *Plant and Soil*, 30 (2):1-17.
- Cui G., Zhao X., Liu S., Sun F., Zhang C., Xi Y., (2017). Beneficial effects of melatonin in overcoming drought stress in wheat seedlings. *Plant Physiology and Biochemistry*, 118:138–149.
- Diana salem 2021 (Nanobiotechnological Approaches to Enhance Drought Tolerance in Catharanthus roseus Plants Using Salicylic Acid in Bulk and Nanoform)
- Diederichsen, A. (1996). Coriander, Coriandrum sativum L. International Plant Genetic Resources Institute (IPGRI), Rome, Italy, 83 p.
- Elgayyar, M.; Draughon, F.A.; Golden, D.A. and Mount, J.A. (2001). Antimicrobial activity of essential oils from plants against selected pathogenic and saprophytic microorganisms. J. Food Protect, 64:1019–1024.
- Esmail S.M., Omara R.I., Abdelaal K.A.A. and Hafez M., (2019). Histological and biochemical aspects of compatible and incompatible wheat-Puccinia striiformis interactions. *Physiological and Molecular Plant Pathology*, 106:120-128.
- FAO World Food and Agriculture. Statistical Yearbook. (2019). Available online: http://www.fao.org/3/i3107e/i3107e
- Feizi H., Rezvani Moghaddam P., Shahtahmassebi N., and Fotovat A., (2012). Impactof bulk and nanosized titanium dioxide (TiO2) on wheat seed germination and seedling growth. *Biological Trace Element Research*, 146:101-106.
- Foroutan L., Solouki M., Abdossi V., Fakheri B.A., Mahdinezhad N., Gholzmipourfard K. and Safarzaei A., 2019 The effects of Zinc Oxide Nanoparticles on Drought Stress in Moringa peregrine Populations. International journal of research in applied and basic medical sciences 4(3): 119-127.
- Gharibi S., Tabatabaei B.E.S., Tabatabaei S. and Matkowski A., (2019). The effect ofdrought stress on polyphenolic compounds and expression of flavonoidbiosynthesis related genes in *Achillea pachycephala* Rech.f. *Phytochemistry*,162:90-98.
- Ghorbanpour et al., 2013 Two Main Tropane Alkaloids Variations of Black Henbane (Hyoscyamus niger) Under PGPRs Inoculation and Water Deficit Stress Induction at Flowering Stage
- Hammad S.A. and Ali O.A., (2014). Physiological and biochemical studies on droughttolerance of wheat plants by application of amino acids and yeast extract. *Annalsof Agricultural Sciences*, 59:133-145.
- Hannah R., Alison K., Glen F., Jerome F., Andrew B. and Lee H., (2018). Root architectural traits and yield: exploring the relationship in barley breeding trials. *Euphytica*, 214:151.

- Hasanuzzaman M., Borhannuddin M.H.M.B. , Zulfiqar F. , Raza A. , Mohsin S.M. , Al Mahmud J. , Fujita M. and Fotopoulos V.,(2020). Reactive Oxygen Species and Antioxidant Defense in Plants under Abiotic Stress: Revisiting the Crucial Role of a Universal Defense Regulator. *Antioxidants*, 9:681.
- Hui Liu 2021 Secondary Metabolism and Hormone Response Reveal the Molecular Mechanism of Triploid Mulberry (Morus Alba L.) Trees Against Drought.
- Jeliazkova, E.A.; Craker, L.E. and Zheljazkov, V.D. (1997). Irradiation of seeds and productivity of coriander, Coriandrum sativum L. J. Herbs Spices Med. Plants, 5:73–79.
- joshan et al., 2019. Effect of drought stress on oil content and fatty acids composition of some safflower genotypes.
- Jun L.v., Zong X.f., Ahmad A. S., Wu X., Wu C., Li Y.p. and Wang S.G., (2020). Alteration in morpho-physiological attributes of *Leymus chinensis* (Trin.) Tzvelevby exogenous application of brassinolide under varying levels of drought stress. *Chilean journal of agricultural research*, 80(1).
- Karunakaran G., Suriyaprabha R., Manivasakan P., Yuvakkumar R., Rajendran V., Prabu P., Kannan N., 2013: Effect of nanosilica and silicon sources on plant growth promoting rhizobacteria, soil nutrients and maize seed germination. – IET nanobiotechnology, 7(3): 70–77.
- Li F., Chen X., Yu X., Chen M., Lu W., Wu Y. and Xiong F., (2020). Novel insights into the effect of drought stress on the development of root and caryopsis in barley.*Peer Jornals*, 8:8469.
- liang y., Sun w., Zhu y.g., christie p. 2007. Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: a review. Environmental Pollution 147: 422–428.
- Ma J.F. 2004. role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Science and Plant Nutrition 50:11–18.
- Ma J.F., yamaji n. 2006. Silicon uptake and accumulation in higher plants. Trends in Plant Science 11: 392–397.
- Machado, A.S.R.; De Azevedo, E.G.; Da Ponte, M.N. and Sardinha, R.M.A. (1993). High pressure carbon dioxide extraction from coriander plants/headspace analysis. J. Essent. Oil Res., 5:645-649.
- Mahajan S. and Tuteja N. (2005). Cold, salinity and drought stresses: an overview. Archives of Biochemistry and Biophysics, 44(4):139-158.
- Mahajan S., Tuteja n. 2005. cold, salinity and drought stresses: an overview. Archives of Biochemistry and Biophysics 444:139–158.
- Martínez-Vilalta J., piñol J. 2002. Drought-induced mortality and hydraulic architecture in pine populations of the nE iberian peninsula. Forest Ecology and Management 161: 247–256.
- Mmbulaheni Happiness Netshimbupfe 1,* , Jacques Berner 1 , Frank Van Der Kooy 2, Olakunle Oladimeji 2 and Chrisna Gouws (Influence of Drought and Heat Stress on Mineral Content, Antioxidant Activity and Bioactive Compound Accumulation in Four African Amaranthus Species)
- Mohammadi H., Esmailpour M. and Gheranpaye A., (2016). Effects of TiO2 nanoparticles and water-deficit stress on morpho-physiological characteristics of dragonhead (*Dracocephalum moldavica* L.) plants. *Acta agriculturae Slovenica*, 107:43-5, 2.
- Mohammadi H., Esmailpour M. and Gheranpaye A., (2016). Effects of TiO2 nanoparticles and water-deficit stress on morpho-physiological characteristics of dragonhead (Dracocephalum moldavica L.) plants. Acta agriculturae Slovenica, 107:43-5, 2.
- Monica r.c., cremonini r. 2009. nanoparticles and higher plants. caryologia. 62:161–165.
- Nair r., Varghese S.H., nair B.g., Maekawa T., yoshida y., kumar D.S. 2010. nanoparticulate material delivery to plants. Plant Science 179: 54–163.
- Nawaz F., Ahmad R., Ashraf M.Y., Waraich E.A. and Khan S.Z., (2015). Effect of selenium foliar spray on physiological and biochemical processes and chemical constituents of wheat under drought stress. Ecotoxicology and Environmental Safety, 113:191-200.
- Nazarian-Firouzabadi F. and Visser R.G.F., (2017). Potato starch synthases: functions and relationships. *Biochemistry and Biophysics Reports,*10:7-16.
- Osorio S., Ruan Y. L. and Fernie A.R., (2014). An update on source-to-sink carbon partitioning in tomato. *Frontiers in Plant Science*, 5:516.
- Outoukarte I., El Keroumi A., Dihazi A. and Naamani K., (2019). Use of morpho- physiological parameters and biochemical markers to select drought tolerant genotypes of durum wheat. *Journal of Plant Stress Physiology*, 5:1-7.
- Paongpetch et al., 2012 Impact of Drought Stress on the Accumulation of Capsaicinoids in Capsicum Cultivars with Different Initial Capsaicinoid Levels
- Pazirandeh M.S., Hasanloo T., Niknam V., Shahbazi M., Mabood H.E. and Ghaffari A., (2013). Effects of drought and methyl jasmonate on antioxidant activities of selected barley genotypes. *Journal of Agriculture and Biology*,30:71-82.
- Pino, J.A.; Rosado, A. and Fuentes, V. (1996). Chemical composition of the seed oil of Coriandrum sativum L. from Cuba. J. Essent. Oil Res., 8: 97–98.
- Prasad T.N., Sudhakar P., Sreenivasulu Y., Latha P., Munaswamy V., Reddy K.R., Sreeprasad T.S., Sajanlal P.R., Pradeep T., 2012: Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. – Journal of Plant Nutrition, 35(6): 905–927.

- Semida W.M., Abdelkhalik A., Mohamed G.F., Abd El-Mageed T.A., Abd El-MageedS.A., Rady M.M. and Ali E.F.,(2021). Foliar Application of Zinc Oxide Nanoparticles Promotes Drought Stress Tolerance in Eggplant (Solanum melongena L.). *Plants*, 10:421.
- Seyed basir et al., 2021 Effect of auxin foliar application on seed yield and fatty acids composition of two safflower genotypes under late-season drought.
- Sharma A. and Zheng B., (2019). Melatonin Mediated Regulation of Drought Stress: Physiological and Molecular Aspects. *Plants*, 8:190.
- Siddiqui M.H., al-whaibi M.H., 2014. role of nano-Sio2 in germination of tomato (Lycopersicum esculentum seeds Mill.). Saudi Journal of Biological Sciences 21:13–17.
- Smaoui A., Chérif A. (2000): Changes in molecular species of triacylglycerols in developing cotton seeds under salt stress. Biochemical Society Transactions, 28: 902–905. Yeilaghi H., Arzani A., Ghaderian M., Fotovat R., Feizi M., Pourdad
- Soliman A.S., El-feky S.A. and Darwish E., (2015). Alleviation of salt stress on Moringa peregrina using foliar application of nanofertilizers. *Journal of Horticulture and forestry*,7(2):36-47.
- Suriyaprabha r., karunakaran g., yuvakkumar r., rajendran V., kannan n. 2012a. Silica nanoparticles for increased silica availability in maize (Zea mays l.) seeds under hydroponic conditions. Current Nanoscience 8:902–908.
- Suriyaprabha r., karunakaran g., yuvakkumar r., rajendran V., kannan n. 2012b. Silica nanoparticles for increased silica availability in maize (Zea mays l.) seeds under hydroponic conditions. Current Nanoscience 8:902–908.
- Vasanthi n., Saleena l.M., raj S.a. 2012. Silicon in day today life. World Applied Sciences Journal 17:1425–1440
- Wainwright M., 1997: The neglected microbiology of silicon – from the origin of life to an explanation for what Henry Charlton Bastian saw. – Society of General Microbiology Quarterly, 24(3): 83–85.
- Wang R., Gao M., Ji S., Wang S., Meng Y. and Zhou Z., (2016). Carbon allocation, osmotic adjustment, antioxidant capacity and growth in cotton under long-term soil drought during flowering and boll-forming period. *Plant Physiology and Biochemistry*,107:137-146.
- Wang R., Gao M., Ji S., Wang S., Meng Y. and Zhou Z., (2016). Carbon allocation, osmotic adjustment, antioxidant capacity and growth in cotton under long-term soil drought during flowering and boll-forming period. *Plant Physiology and Biochemistry*,107:137-146.
- Watson J-L, Fang T, Dimkpa CO, Britt DW, McLean JE, Jacobson A, Anderson AJ (2015) The phytotoxicity of ZnO nanoparticles on wheat varies
- Xie Y., Li B., Zhang Q., Zhang C., 2012: Effects of nano-silicon dioxide on photosynthetic fluorescence characteristics of Indocalamus barbatus McClure. – Journal of Nanjing Forestry University (Natural Science Edition), 2: 59–63.
- Xiong SJ, Xu WH, Xie WW, Chen R, Chen YQ, Chi SL, Chen X, Zhang JZ, Xiong ZT, Wang ZY, Xie DT (2015) Effect of nano zeolite on chemical fractions of Cd in soil and its uptake by cabbage. Huan Jing Ke Xue 36(12):4630–4641. (Article in Chinese)
- Xiyue Wang et al., 2022. Physiological Response of Soybean Plants to Water Deficit
- Zanella M., Borghi G.L., Pirone C., Thalmann M., Pazmino D., Costa A., Santelia D.,Trost P. and Sparla F., (2016). β-amylase 1 (BAM1) degrades transitory starch tosustain proline biosynthesis during drought stress. *Journal of Experimental Botany*, 67:1819-1826.
- Zarafshar M., akbarinia M., askari H., Hosseini S.M., rahaie M., Struve D. 2015. Toxicity assessment of Sio2 nanoparticles to pear seedlings. International Journal of Nanoscience and Nanotechnology 11(1)
- Zhong C., Cao X., Bai Z., Zhang J., Zhu L., Huang J. and Jin Q., (2018). Nitrogen metabolism correlates with the acclimation of photosynthesis to short-term waterstress in rice (*Oryza sativa* L.). *Plant Physiology and Biochemistry,*125:52–62.
- Zong X., Yang A., Anjum S.A., Lv J., Li N. and He X., (2018). Effects of brassinolide application on antioxidant characteristic and endogenous hormones of *Leymus chinensis* (Trin.) Tzvelev under different light intensity regimes. *Chilean Journalof Agricultural Research*, 78:539-548.