Egypt. J. Agron. **Vol. 47**, No. 2, pp: 211 - 224 (2025)

Egyptian Journal of Agronomy
http://agro.journals.ekb.eg/

Enhancing Sunflower growth, yield, and Oil Production by foliar spring of selenium under localized irrigation systems

Elham A. Badr[a]*, Gehan A. Amin[a] and **Saied El Sayed[b]**

[a] Field Crops Research Department, [b] Plant Nutrition Department, Agricultural and Biological Research Institute, National Research Centre, 33 El Behouth St. Giza, Egypt. P.O. 12622

A Drought is a persistent and devastating obstacle to crop production. Selenium (Se) mitigates various types of abiotic stress and promotes growth and crop production under unfavorable conditions. Two field experiments were conducted at Nubaria research station to evaluate the effects of Selenium on yield and oil production of Sunflower under different irrigation levels as 100, 75 and 50% of water requirement (WR) during seasons of 2020 and 2021. The results showed that low irrigation rates(50%WR) reduced the chlorophyll content, growth parameters (head diameter, head dry weight, number of seeds/head, 100 seed weight), Seed and Straw yield, oil content, oil yield and macro-micronutrient content. While increased the application of selenium (20ppm) resulted in an increases in all the above measurements. Results showed that the interaction of selenium was more effective in increasing chlorophyll content and growth parameters compared to the control under water stress conditions. Foliar application of selenium had a positive effect on Oil content and Oil production to increasing by(8.6&52.1%), nutrient content and water use efficiency, particularly at (20 ppm Se) comparable with the control under deficit irrigation regimes. The most effective way to improve the growth, yield and quality of sunflower plants under deficient irrigation systems is to use selenium (Se), which increases the plant's resistance to weather and water stress. Therefore, it is recommended that gardeners in arid and semi-arid regions fertilize sunflowers with selenium (20 ppm) to reduce the negative effects of drought and maintain crop yield and quality.

Keywords: Water stress; Selenium; Seed yield, Oil yield; Nutrient contents.

1. Introduction

Sunflower (*Helianthus annuus. L.*) is the major source of edible vegetable oil, with a worldwide seed production of 33.3 million ton allocated nearly entirely to oil extraction, accounting for 8.5% of total global volume **(FAO, 2018).** Growing sunflowers requires a variety of conditions, including healthy seeds, moderate rainfall, and rich soil. Sunflower is one of the three main oilseed crops and a substantial source of edible oil of superior quality, especially for use in cooking **Pal and associates, (2015).** Sunflower's ability to withstand a variety of climatic conditions makes it an important oilseed crop. Due to its short growing season and decreased watering needs, sunflowers have drawn more attention from plant breeders in various areas **(Forleo *et al.*, 2018).**

Increasing crop yield with the least amount of water is one of the largest challenges facing agriculture as a result of current climate change and its aftereffects, which include a decrease in water availability and an increase in temperature, especially in areas where rainfall is unreliable or limited **(Iqbal *et al.*, 2020).** Environmental changes alter the physiological mechanisms that plants use to grow, develop, and generate agricultural goods **(Araújo *et al.*, 2019; Ozturk *et al.*, 2020).** One of the main factors influencing plant growth is water stress. Water makes about 85–95% of live plant cells on average. There are three different kinds of water relationships in plants. Bound water

* Corresponding author: elhamnrc @yahoo.com Orcid ID:0000-0002-0166-0313
Received: 25/12/2024; Accepted: 12/05/2025
DOI: 10.21608/agro.2025.347523.1587

molecules, which are chemically connected to complexes like salts and organic materials, are the primary form of water. When the plant is stressed or needed, this water is difficult to move **(Zafar *et al*., 2023).** All of the plant's physiological processes are impacted by its water condition, both directly and indirectly **(Farid *et al*., 2021).** Cell turgidity, which is linked to photosynthesis and the growth of tissues, organs, and cells, requires water. It is believed that water stress is the primary factor limiting sunflower photosynthetic yield and efficiency. In addition to regulating the plants' metabolic processes, adequate moisture availability at critical stages of plant growth also improves the crop's capacity to absorb fertilizer **(Muhammad *et al*., 2021).**

Even in drought-prone environments, selenium can control water levels; even trace amounts of this element have been demonstrated to boost lettuce's selenium content and quicken the plant's typical development rate **(Hossain *et al*., 2021).** Enhancing drought resilience and lowering agricultural losses due to water-restricting variables can be achieved at a low cost with selenium. Due to its physiological and antioxidant properties, selenium has attracted the attention of several agricultural specialists in recent decades **(Sarkar *et al*., 2023).** Despite having no direct effect on plant metabolic systems, selenium lowers agricultural losses under a variety of physiological situations **(Kamran *et al*., 2020).**

However, little study has been done on how Se helps plants become more drought-resistant **(Ghorai *et al*., 2022).** During drought stress, Se can control water balance and increase biomass output by activating plants' antioxidant systems. Selenium may boost growth, raise leaf carotenoids and chlorophyll, control water availability, accumulate appropriate solutes, activate the antioxidant mechanism, and improve plant resilience to drought even at very low concentrations **(Zahedi *et al*., 2023).** This research demonstrates that applying selenium can improve sesame's resistance to drought stress **Le Vinh *et al.* (2021).** Selenate and selenite are commercial types of selenium-enriched fertilizers. It was recently shown by **Deng *et al*. (2017)** that the use of fertilizers based on selenium enhanced the buildup of Se. Additionally, it was shown that foliar spraying Se was a more economical and effective method than incorporating it into the soil **(Wang *et al*., 2017).** The purpose of this experiment is to ascertain how foliar selenium affects a few agro physiological characteristics of sunflowers during drought stress. The premise of the experiment is that foliar selenium may be able to mitigate the limiting effects of drought stress.

2. Materials and methods

2.1 Experimental design

During the summer seasons of 2020–2021 and 2021–2022, two field experiments were carried out at the Research and Production Station, National Research Centre, Nubaria Province, Behera Governorate, Egypt, to examine the impact of foliar selenium application on sunflower productivity when grown in newly reclaimed soil under water stress conditions. Seeds of sunflower (*Helianthus annuus L.)* Sakha 53 cultivar was obtained from Agricultural Research Centre Giza, Egypt. The split plot design with three replicates was used of (100, 75 and 50 %) from irrigation water requirements were distributed in the main plots while foliar application treatment (0, 5, 10 and 20 ppm) was randomly distributed in the sub plots to equal doss after 30 day and 45 day. sunflower seeds were sown on May in both two seasons. The plot area was 12.0 m^2 and all plots received, the experimental soil received the recommended fertilizer dose according to the Ministry of Agriculture recommendations (Nitrogen fertilizer (as the form of urea 46% N), 100 Kg fed^{-1} Super phosphate “15.50% P_2O_5” and 50 Kg fed^{-1} Potassium sulphate “48% K_2O”). Soil was directly irrigated after sowing to provide suitable moisture. The initial soil analysis for the experimental area was: sandy loam in texture (75.3% sand, 5.18% silt, 17.12% clay), OM (0.57%), $CaCO_3$ (1.36%), pH (7.34); EC (0.96 dSm^{-1}) and available N, P and K were 33.6, 7.14 and 13.8 mg kg^{-1} soil, respectively. Soil analysis executed according to technique of **Rebecca, (2004).** Seed of sunflower cultivar Sakha 53 were sown during the first week of May of the two seasons. At harvest; plants were taken at random from the inner area of each experimental plot to estimate the following characters.

2.2 Growth characters:

Head diameter (cm), Head dry weight (g), number of seeds per head, 100 seed weight (g), Seed yield (ton fed^{-1}), Straw yield (ton fed^{-1}), Oil yield (kg fad^{-1}) was determined by multiplying seed yield (kg fed^{-1}) by seed oil percentage.

2.3 Biological yield

The total biomass of the harvested plants (kg $plot^{-1}$), then it was transformed into ton per ha. Grain yield: It was obtained as the weight of clean grains of the plot after threshing, and then it was transformed into ton ha^{-1}.

Harvest index HI: $\frac{\textbf{Grain yield (ton fed−1)}}{\textbf{Biological yield (ton fed−1)}} X100$

2.4 Irrigation treatments

Three drip irrigation regimes, applied as a percentage of the crop evapotranspiration (ETc), employed computations according to **Allen *et al.* (1998),** as follows:

$$\boldsymbol{ETc = ETo\ x\ Kc}$$

Where: Kc = crop coefficient, ETc is the crop water needs (mm day^{-1}), and ETo is the reference evapotranspiration (mm day^{-1}). ETo calculations used the technique of **Allen *et al.* (1998)**, as follows:

$$\boldsymbol{ETo = Epan\ x\ Kp}$$

Where: Epan is the evaporation from class A and Kp is the pan coefficient. The plants in all plots incurred irrigation at 10-day intervals with different amounts of water. Irrigation water quantities approximation used the following equation:

$$\boldsymbol{IWR = \frac{A\ x\ ETc\ X\ Ii}{Ea\ X\ 1000}}$$

Where: A = plot size (m2), ETc is the reference evapotranspiration (mm day^{-1}), IWA is the irrigation water application (m3), Ii is the irrigation intervals (day), and Ea is the application efficiency (%). An irrigation water application (IWA) controller was a 50 mm diameter plastic pipe (spiles). Each plot had a single spile to transport water. The pumped volume of water via a plastic pipe attained identification using **Israelsen and Hansen, (1962).**

2.5 Chemical constituents:

Chlorophyll a, b and total carotenoids in leaves were determined using the method described by **Lichtenthaler, (1987).** Seed oil percentage was determined using soxhlet apparatus according to **A.O.A.C., (1980)**, protein content was calculated as Total N x 6.25. Iodine value of the oil was determined using ABBE-refract meter instrument at 20°C. Photosynthetic pigments of fresh leaves were determined as described by **Lichtenthaler and Buchmann, (2001)**. Nitrogen (N), phosphorus (P) and potassium (K) contents were determined by method of **Cottenie *et al.* (1982).** Irrigation water use efficiency (WUE) was estimated according to **Jensen, (1980)** by equation: **WUE =**Seed yield (kg/fed)/Applied water (m^3/fed).

2.6 Statistical analysis

Using the **MSTAT-C, (1988)** computer software package, a combined analysis of the data for the two seasons was statistically examined using the analysis of variance (ANOVA) approach for the split-plot design. The differences between treatment means were tested at the 5% level of probability using the Least Significant Difference (LSD) technique, as outlined by **Snedecor and Cochran, (1990).**

3. Results and Discussion

Sunflowers are grown in tropical and subtropical regions, where drought and high temperatures have historically required irrigation **(Arshad *et al.*, 2020).** It contains 20%–27% protein and 25%–48% oil. It can easily adjust to changes in soil composition, temperature, moisture content, and farming methods. The growing season's dryness and lack of water significantly diminish seed production and cut sunflower yield by 41%. Climate change and rapid population increase pose serious challenges to global food security and production **(Ameen *et al.*, 2023a)**.

3.1 photosynthetic pigments content

Foliar application of selenium under water stress conditions on the chlorophyll content in the growth stages of the sunflower plant. The results shown in Figure (1) make it evident that the amount of chlorophyll This increase is observed when the quantity of Se increases in sunflower and the data indicated that the highest values in chlorophyll content induced by the combination between 100% WR with the foliar application of selenium at a rate (20 ppm Se) as comparable with the control (0 ppm Se). According to data in fig. (1), applying selenium to flowers increased the amount of chlorophyll in plants. This could be because exogenous selenium has a positive effect on chlorophyll synthesis and prevents chlorophyll degradation when there is a water deficit (**Shahzadi *et al.*, 2017).** Selenium aids plants in delaying the deterioration of their pigments. These outcomes mirrored how the okra plant responded to dryness when 3 mg/L of selenium was added **(Ali *et al.*, 2020).** In tropical and subtropical areas, plant development and performance are significantly harmed by water shortages and high temperatures **(Dietz *et al.*, 2021).**

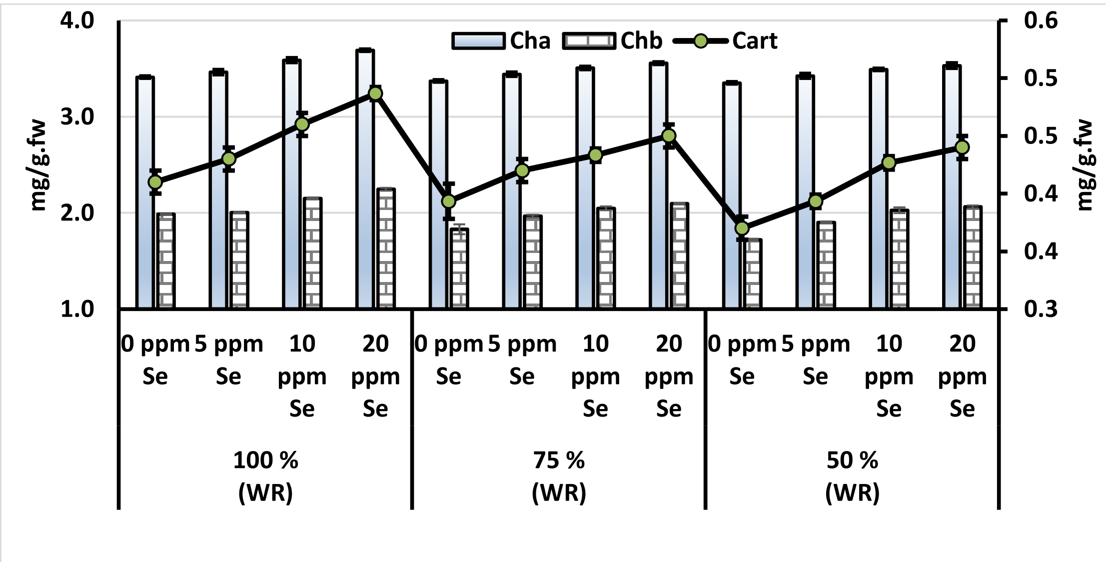


Fig. 1. Effect of selenium foliar spray on Cha, Chb and Carotien of sunflower under water stress condations.

3.2 Growth analysis and Growth attributes:

Results of this study presented in Table (1) showed that increasing irrigation water requirement (100%WR slightly increased the studied growth indices (head diameter (cm), head dry weight (g), number of seeds per head, and weight of 100 seeds (g) of sunflower plant, as compared with those plants grown under water stress conditions (50%WR) water deficit (75% and 50% WR) resulted in significant decreases in growth attributes. Meanwhile foliar spray of Selenium (Se 20 ppm) increased significant in the diameter of head (cm), dry weight of head (g), number of seeds per head, and the weight of 100 seeds, by 18.08, 19.8, 10.54, and 26.5%, respectively, compared to the control treatment. Selenium is an element whose deficiency causes the decrease in defense mechanisms of living organisms and maintains antioxidative defense systems and enhances sugar and starch accumulation. This led to an increase in growth characteristics. Although foliar selenium administration can enhance plant development and productivity, **(Karimi *et al*., 2020).** Despite not being a necessary component for plant development, selenium has been shown to increase crop resistance to drought **(Andradea *et al*., 2018)**. The goal of modern agriculture is to provide foods that are high in vitamins and nutrients so that humans, animals, and plants can withstand the oxidation process **(Dwivedi *et al*., 2023)** humans, animals, and plants can withstand the oxidation process **(Dwivedi *et al*., 2023)**. The results in Table (2) also showed that the interaction between (100% WR and (20 ppm) of selenium gave a significant increase on the abovementioned parameters at different irrigation water requirements compared with plants grown without selenium. It is observed from Table (1&2). Dry head weight is the best indicator for estimating oil and seed production due to the strength of the relationship. Head diameter and 100-seed weight also have a significant effect on productivity, especially oil production. The relationship between variables and productivity is generally strong, indicating that these variables can be used to predict productivity especially oil production. The relationship between variables and productivity is generally strong, indicating that these variables can be used to predict productivity. In addition to addressing soil nutrient deficiencies, nutrient supplementation enhanced crop quality and yield **(Oyetunji *et al*., 2022).**

Table 1. Growth parameters affected by selenium foliar application under water stress conditions

Treatments		Head diameter (cm)	Head dry weight (gm)	No. of seeds/ deal	100 seed weight (gm)
WR	Selenium				
100 % (WR)	0 ppm Se	15.67	89.50	724.52	6.07
	5 ppm Se	15.93	91.46	731.00	6.18
	10 ppm Se	18.66	108.59	842.60	8.24
	20 ppm Se	20.94	121.81	873.49	8.86
75 % (WR)	0 ppm Se	14.97	86.67	712.40	5.60
	5 ppm Se	15.48	88.87	722.06	6.00
	10 ppm Se	16.57	97.33	747.77	6.62
	20 ppm Se	17.57	106.53	770.04	7.65
50 % (WR)	0 ppm Se	14.39	85.00	701.73	5.13
	5 ppm Se	15.27	88.17	717.67	5.80
	10 ppm Se	16.30	95.49	743.90	6.33
	20 ppm Se	16.72	101.07	755.33	6.73
Mean of WR	100% WR	17.80	102.84	792.90	7.34
	75% WR	16.14	94.85	738.07	6.47
	50% WR	15.67	92.43	729.66	6.00
Mean of Se	0 ppm Se	15.01	87.06	712.88	5.60
	5 ppm Se	15.56	89.50	723.58	5.99
	10 ppm Se	17.18	100.47	778.09	7.06
	20 ppm Se	18.41	109.80	799.62	7.75
LSD 0.05	WR	*0.231*	*1.061*	*2.182*	*0.117*
	Selenium	*0.267*	*1.225*	*2.520*	*0.135*
	Interaction	*0.472*	*2.165*	*4.452*	*0.238*

WR: Water Requirements

3.3 Yield and yield it's compounded:

Results presented in Table (2) clearly stated that, yield and its aspects expressed by (seeds, stove and biological (ton/fed) addition to harvest index (%) were greatly affected by irrigation water requirement (WR. Findings, the 50% WR treatment produced the highest harvest index at 41%, while the 100% WR treatment produced the maximum yield for (seeds, stove, biological (ton/fed). The Table also shows that utilizing a rate of 75% WR produced excellent outcomes; specifically, the yield of (seeds, stove, biological, and oil) reduced by 3.9, 8.66, 12.15, and 13.9 as compared to the 100% WR treatment. Also.Table (3) show that (oil yield (kg/fed), oil and protein content (%) were greatly affected by irrigation water requirement (WR. The maximum oil (yield &content) and protein (747.6 (kg/fed), 36.51% and 18.27%) of sunflower were recorded under 100%WR compared with 50% WR. Foliar treatment of selenium concentration induced significant increments in yield criteria in comparison with controls. Data clearly show that (20 ppm se) caused more significant increases in all the studied yield characters (Table 2 & 3) compared with untreated controls. It could be noted that 100% WR with 20 ppm Se produced the highest amount of in all studied characters in yield.

LSD shows significant differences at 5% level between selenium levels and irrigation levels. The combined effects of selenium and irrigation were significant in all parameter conclusions from mean values, at 20 ppm Se, the highest seed (1.89 ton/fed) and straw (2.82 ton/fed) yields were achieved. At 10 ppm Se, a significant but relatively lower improvement was achieved compared to 20 ppm Se. Mean effect of irrigation (WR): With 100% WR, the highest values were achieved in all parameters, reflecting the positive effect of full irrigation.

Results recorded in Table (3) stated that foliar application of selenium levels and water requirements on yield such as oil yield, oil content, protein content, and water use efficiency (WUE). Effect of Selenium Levels. (Oil yield, oil content and protein content) increases with increasing selenium levels from 0 to 20 ppm, regardless of water level. The highest values were (oil yield, oil and protein content (622.2 kg/fed, 35.30% and 17.51%) at 20ppm Se. Water use efficiency increases gradually with increasing selenium levels, where it recorded the highest value (3.37 kg/m³) at 20 ppm. Oil Yield decreased with water reduction from 100% to 50% WR). At 100% WR, the average yield was highest (534.8 kg/fed). Oil Content decreased slightly with water reduction, but remained higher with high selenium levels. Protein Content decreased with water reduction. At 100% WR, the average was 16.47%, while it decreased to 13.15% at 50% WR. Water Use Efficiency (WUE) improved with water reduction, with the highest value recorded at 50% WR (4.03 kg/m³). The supply of irrigation water is the sufficient amounts. Selenate and selenite are the forms of selenium that plants may bio accumulate. The application of foliar selenium may serve as an effective approach to mitigate the negative impacts of drought stress, thereby promoting sustainable agricultural practices. sufficient amounts. Selenate and selenite are the forms of selenium that plants may bio accumulate. The application of foliar selenium may serve as an effective approach to mitigate the negative impacts of drought stress, thereby promoting sustainable agricultural practices.

Table 2. Yield parameters affected by selenium foliar application under water stress conditions.

Treatments		Seed yield (ton/fed)	Straw yield (ton/fed)	Biological yield (ton/fed)	Harvest Index (%)
WR	Selenium				
100 % (WR)	0 ppm Se	1.56	2.43	3.98	39.07
	5 ppm Se	1.65	2.46	4.11	40.11
	10 ppm Se	1.87	2.77	4.64	40.38
	20 ppm Se	2.04	3.11	5.15	39.62
75 % (WR)	0 ppm Se	1.48	2.24	3.72	39.80
	5 ppm Se	1.53	2.33	3.86	39.58
	10 ppm Se	1.76	2.60	4.36	40.39
	20 ppm Se	1.84	2.71	4.55	40.40
50 % (WR)	0 ppm Se	1.44	2.18	3.62	39.80
	5 ppm Se	1.50	2.29	3.79	39.54
	10 ppm Se	1.70	2.54	4.24	40.06
	20 ppm Se	1.80	2.63	4.44	40.62
Mean of WR	100% WR	1.78	2.69	4.47	39.80
	75% WR	1.65	2.47	4.12	40.04
	50% WR	1.61	2.41	4.02	40.01
Mean of Se	0 ppm Se	1.49	2.28	3.77	39.56
	5 ppm Se	1.56	2.36	3.92	39.75
	10 ppm Se	1.78	2.64	4.42	40.28
	20 ppm Se	1.89	2.82	4.71	40.21
LSD 0.05	WR	*0.022*	*0.027*	*0.042*	
	Selenium	*0.025*	*0.032*	*0.049*	
	Interaction	*0.045*	*0.056*	*0.086*	

WR: Water Requirements

Table 3. Oil yield, Oil content, protein and water using efficiency as affected by selenium foliar application under water stress conditions.

Treatments		Oil yield (kg/fed)	Oil Content (%)	Protein Content (%)	WUE Kg/m^3
WR	Selenium				
100 % (WR)	0 ppm Se	358.0	33.34	14.79	1.95
	5 ppm Se	400.8	34.63	15.42	2.06
	10 ppm Se	633.0	35.40	17.40	2.34
	20 ppm Se	747.6	36.51	18.27	2.55
75 % (WR)	0 ppm Se	338.4	32.36	8.94	2.46
	5 ppm Se	352.9	33.21	11.46	2.54
	10 ppm Se	416.4	34.32	16.75	2.94
	20 ppm Se	603.4	34.85	17.25	3.06
50 % (WR)	0 ppm Se	331.1	31.70	8.65	3.60
	5 ppm Se	344.5	33.17	10.67	3.75
	10 ppm Se	409.8	34.13	16.29	4.25
	20 ppm Se	515.7	34.54	17.00	4.50
Mean of WR	100% WR	534.8	34.97	16.47	2.22
	75% WR	427.8	33.68	13.60	2.75
	50% WR	400.3	33.39	13.15	4.03
Mean of Se	0 ppm Se	342.5	32.47	10.79	2.67
	5 ppm Se	366.1	33.67	12.51	2.79
	10 ppm Se	486.4	34.62	16.81	3.18
	20 ppm Se	622.2	35.30	17.51	3.37
LSD 0.05	WR	*3.481*	*0.374*	*0.467*	
	Selenium	*4.020*	*0.432*	*0.539*	
	Interaction	*7.102*	*0.763*	*0.953*	

3.4 The nutritional contents of the yielded sunflower

Presented in Table (4). It is clear nutrient content and uptake affected by selenium foliar application under water stress conditions, Nitrogen increases with increasing selenium levels at all water requirement levels (WR). the highest value for nitrogen was at 20 ppm Se with 100% WR (2.92%), Phosphorus its effect is limited compared to nitrogen and potassium, but it increases slightly at higher selenium levels. values are almost constant at 0.32-0.35, Potassium follows the same trend as nitrogen, with an increase with higher selenium levels. Nutrient Uptake (N, P, K Uptake). all nutrient uptake values (N, P, K) increase significantly with increasing selenium levels. The most significant effect was on N Uptake, which increased from 36.81 (kg/fed) at 0 ppm Se with 100% WR to 59.63(kg/fed) at 20 ppm Se with 100% WR. The highest performance was observed at 100% WR, where the highest values were for N and K and their uptake. At 75% and 50% WR, the values gradually decreased with water reduction. Selenium plays a crucial role in enhancing the nutrient content of leaves, primarily by promoting vegetative growth and expanding leaf area. This improvement in leaf development subsequently fosters the growth of the root system, thereby increasing the surface area available for the absorption of essential nutrients reduced, which in turn caused a drop in the net absorption rate. Additionally, a lack of water leads to nutritional imbalance (**Abd–Elrahman *et al*., 2022**). In order to increase crop output in the face of water stress conditions, it is crucial and challenging to use more efficient irrigation techniques (**Ramadan *et al*., 2023**). These advancements boosted adaptive mechanisms, such as maintaining appropriate cellular turgor alongside physiological processes (**Awad *et al*., 2021**), which raise plant stress tolerance and provide satisfactory growth and seed output. Although it is not a necessary element for plants, selenium (Se) supports the antioxidant system of plants and increases crop yield and development when it is present in sufficient amounts. Selenate and selenite are the forms of selenium that plants may bio accumulate. The application of foliar selenium may serve as an effective approach to mitigate the negative impacts of drought stress, thereby promoting sustainable agricultural practices.

Table 4. Nutrient content and uptake affected by selenium foliar application under water conditions.

Treatments		N%	P%	K%	N uptake (kg/fed)	P uptake (kg/fed)	K uptake (kg/fed)
WR	Selenium						
100 % (WR)	0 ppm Se	2.37	0.32	2.20	36.81	5.01	34.25
	5 ppm Se	2.47	0.33	2.22	40.68	5.39	36.68
	10 ppm Se	2.78	0.35	2.69	52.15	6.58	50.35
	20 ppm Se	2.92	0.35	2.88	59.63	7.21	58.81
75 % (WR)	0 ppm Se	1.43	0.31	2.03	21.15	4.65	29.97
	5 ppm Se	1.83	0.32	2.17	27.99	4.89	33.09
	10 ppm Se	2.68	0.33	2.40	47.24	5.88	42.25
	20 ppm Se	2.76	0.35	2.62	50.74	6.37	48.10
50 % (WR)	0 ppm Se	1.38	0.31	2.02	19.92	4.47	29.09
	5 ppm Se	1.71	0.32	2.10	25.62	4.78	31.55
	10 ppm Se	2.61	0.33	2.32	44.30	5.60	39.49
	20 ppm Se	2.72	0.34	2.49	49.00	6.14	44.86
Mean of WR	100% WR	2.64	0.34	2.50	47.32	6.05	45.02
	75% WR	2.18	0.33	2.30	36.78	5.45	38.35
	50% WR	2.10	0.32	2.23	34.71	5.25	36.25
Mean of Se	0 ppm Se	1.73	0.32	2.08	25.96	4.71	31.10
	5 ppm Se	2.00	0.32	2.16	31.43	5.02	33.77
	10 ppm Se	2.69	0.34	2.47	47.90	6.02	44.03
	20 ppm Se	2.80	0.35	2.66	53.12	6.57	50.59
LSD 0.05	WR	*0.075*	*0.003*	*0.042*	*1.275*	*0.100*	*0.977*
	Selenium	*0.086*	*0.004*	*0.048*	*1.472*	*0.115*	*1.128*
	Interaction	*0.152*	*0.007*	*0.085*	*2.601*	*0.204*	*1.993*

WR: Water Requirements.

3.5 Micronutrient contents:

Data presented in Table (5) showed that affected by selenium foliar application under water stress conditions on sunflower. With decreasing water requirement from 100% to 50%. Iron (Fe) ppm total values decrease (385.1 → 363.6 ppm). Zn ppm also decreases gradually (32.55 →8.83 ppm). Mn ppm decreases clearly (20.33 → 17.64 ppm).

All decrease with decreasing irrigation. Full water requirement (100% WR) consistently leads to the highest concentrations and uptakes for Fe, Zn, and Mn compared to water-stressed conditions (75% WR and 50% WR) with increasing Se concentration (0 → 20 ppm). Fe ppm increases (302.01 → 417.37). Zn ppm increases (25.64 → 32.74). Mn ppm increases (16.11 → 21.12). All show significant increases with increasing selenium. Increasing Se generally improves Fe, Zn, and Mn uptake across all WR levels. Higher Se levels (10 ppm and 20 ppm) show notable increases in both concentration and uptake. Interaction between WR and Se to influence the uptake of these micronutrients significantly. 100% WR shows the highest average Fe, Zn, and Mn levels and uptakes. Se at 20 ppm achieves the maximum uptake values for Fe, Zn, and Mn. LSD values suggest that Se, WR, and their interaction have statistically significant effects on the measured parameters, with notable distinctions at $p \leq 0.05$.

Table 5. Micronutrient content and uptake affected by selenium foliar application under water stress conditions.

Treatments		Fe ppm	Zn ppm	Mn ppm	Fe uptake (kg/fed)	Zn uptake (kg/fed)	Mn uptake (kg/fed)
WR	Selenium						
100 % (WR)	0 ppm Se	312.5	28.49	16.90	486.5	44.36	26.31
	5 ppm Se	389.6	32.41	19.82	642.8	53.47	32.71
	10 ppm Se	404.0	33.46	20.70	756.9	62.68	38.79
	20 ppm Se	434.2	35.83	23.90	885.6	73.07	48.75
75 % (WR)	0 ppm Se	299.1	24.52	16.07	442.3	36.26	23.76
	5 ppm Se	314.5	29.94	17.71	480.1	45.71	27.04
	10 ppm Se	402.0	33.44	21.65	708.7	58.96	38.16
	20 ppm Se	410.3	34.50	22.65	754.2	63.41	41.63
50 % (WR)	0 ppm Se	294.4	23.91	15.35	423.9	34.44	22.11
	5 ppm Se	368.0	31.03	18.81	551.9	46.54	28.22
	10 ppm Se	384.3	32.48	19.57	653.1	55.19	33.26
	20 ppm Se	407.6	27.89	16.80	734.4	50.25	30.27
Mean of WR	100% WR	385.1	32.55	20.33	693.0	58.39	36.64
	75% WR	356.5	30.60	19.52	596.3	51.08	32.65
	50% WR	363.6	28.83	17.64	590.9	46.61	28.46
Mean of Se	0 ppm Se	302.01	25.64	16.11	450.9	38.3	24.1
	5 ppm Se	357.34	31.12	18.78	558.3	48.6	29.3
	10 ppm Se	396.78	33.13	20.64	706.3	58.9	36.7
	20 ppm Se	417.37	32.74	21.12	791.4	62.2	40.2
LSD 0.05	WR	*1.402*	*1.431*	*1.496*	*0.424*	*0.378*	*0.635*
	Selenium	*1.063*	*1.438*	*1.528*	*0.281*	*0.232*	*0.316*
	Interaction	*2.378*	*2.751*	*2.899*	*0.682*	*0.591*	*0.925*

WR: Water Requirements

3.6 Correlation:

The Tables (6) presented contain correlation coefficients between different sunflower plant characteristics (such as head diameter, head dry weight, number of seeds, 100-seed weight, etc.) and productivity outcomes (such as oil and protein yield). Correlation Coefficient (r): Indicates the strength of the relationship between the two variables. If the value is close to +1, the relationship is strong positive.

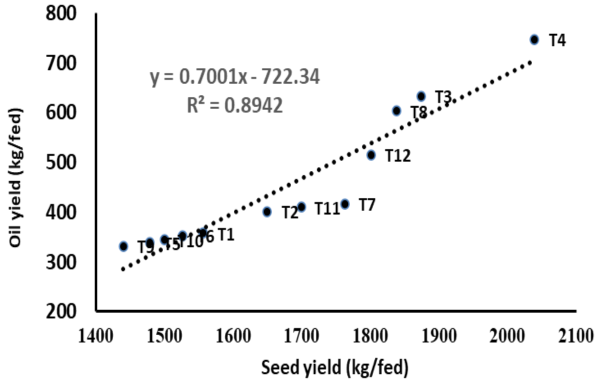
If it is close to -1, the relationship is strong negative, If it is close to 0, there is no significant relationship between the two variables. Notes on the results. Strong relationships: Head diameter is strongly correlated with most variables such as head dry weight (r = 0.986), and oil yield (r = 0.965). Head dry weight (Head dry wt.) is strongly correlated with most variables such as 100-seed weight (r = 0.980) and biological yield (r = 0.981). Yield (seed Y, straw, and Bio .Y): Total yield (Bio.Y) has a strong correlation with all productivity parameters, especially straw yield (r = 0.998). Oil yield (Oil yield): is strongly correlated with most variables, especially 100-seed weight (r = 0.976). Protein and nitrogen relationships. Protein (%) is well correlated with total yield (Bio.Y, r = 0.893) and nitrogen (N%, r = 0.899). Nutrients (N%, P% and K%). Phosphorus (P %) and potassium (K%) show strong correlation with productivity (e.g. seed. Y, straw. Y and Bio.Y). There is a strong relationship between increasing macronutrients and increasing straw and grain yields, as increasing nitrogen leads to increased protein content and increased seed quality and productivity.

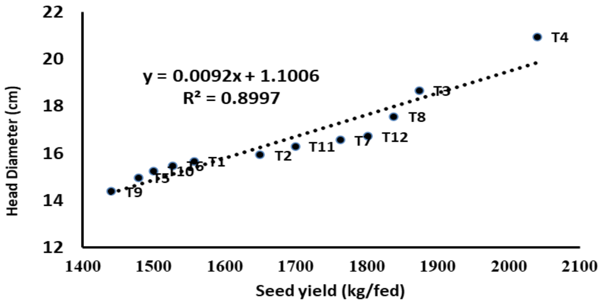
Table 6. correlation coefficients between different sunflower plant characteristics.

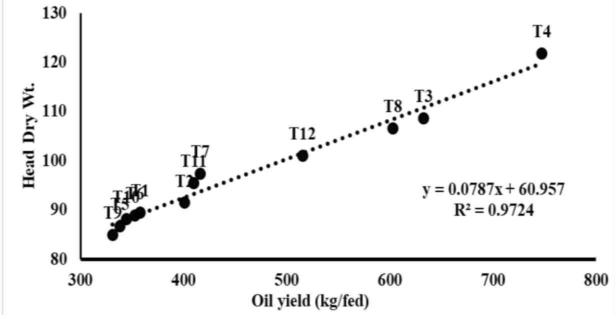
	Head diameter	Head dry wt. (g)	No. Seed/head	100 wt. seed	Seed yield	Straw Yield	Bio. Y	HI	Oil yield	Oil %	Protein %	N%	P%
Head DW.	0.986												
No. Seed/head	0.980	0.958											
100 wt. seed	0.981	0.980	0.970										
G.Y	0.949	0.972	0.910	0.952									
S.Y	0.978	0.982	0.934	0.964	0.986								
Bio. Y	0.969	0.981	0.927	0.962	0.995	0.998							
HI	0.237	0.348	0.246	0.324	0.483	0.332	0.396						
Oil yield	0.965	0.986	0.953	0.976	0.946	0.948	0.950	0.374					
Oil %	0.958	0.958	0.920	0.963	0.976	0.982	0.982	0.362	0.924				
Protein %	0.780	0.801	0.721	0.807	0.903	0.881	0.893	0.475	0.759	0.899			
N%	0.780	0.801	0.721	0.807	0.903	0.881	0.893	0.475	0.759	0.899	1.000		
P%	0.926	0.956	0.907	0.966	0.977	0.954	0.966	0.512	0.955	0.966	0.889	0.889	
K%	0.966	0.987	0.940	0.981	0.985	0.982	0.987	0.415	0.975	0.974	0.866	0.866	0.986

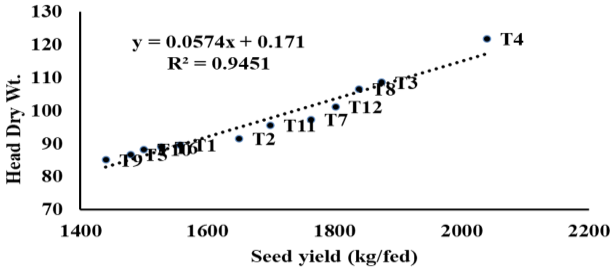
Table 7. Determination coefficient r2.

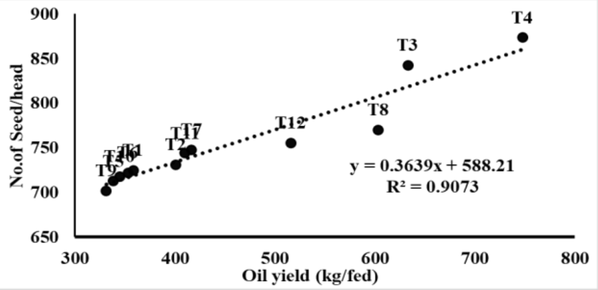
Traits	Seed yield/fed. (kg)	Oil yield /fed. (kg)
Head diameter cm	0.8997	0.9307
Head dry wt. (g)	0.9451	0.9724
No. of seed/head	0.8272	0.9073
100 seed wt. (g)	0.8272	.0.9524
Seed yield (kg/fed)	0	0.8942
Oil yield (kg/fed)	0.8942	0

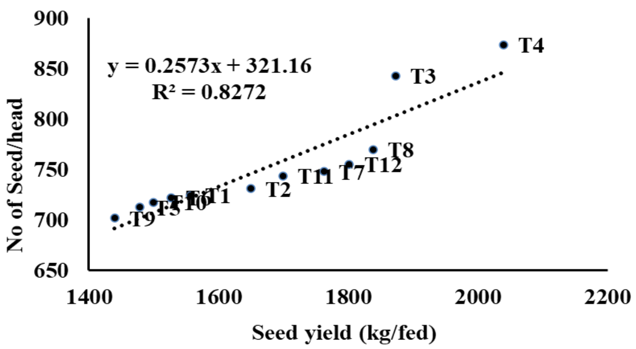


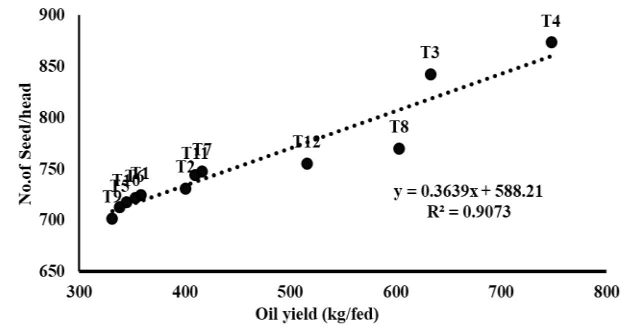


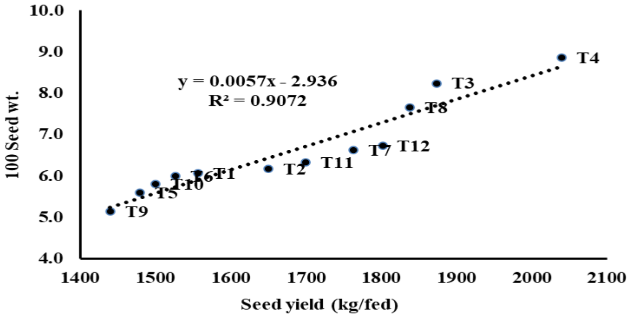


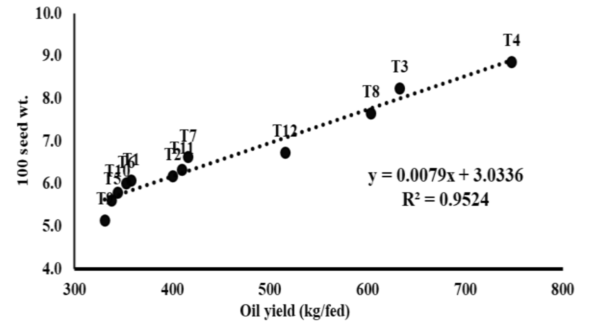












4. Conclusion

In times of stress, plants have evolved or adapted defenses (such as antioxidants, osmoprotectants, etc.) to cope with water deficiency stress or even to endure it. The exogenous use of certain adjuvants (such as selenium) is crucial to assist plants effectively tolerate water deficit stress since these endogenous anti-drought chemicals are insufficient to allow stressed plants to endure extended drought periods. This study aimed to investigate how selenium could reduce drought stress and improve crop resilience and productivity under the adverse effects of climate change and aggravation of drought conditions. This could be through its role in increasing antioxidant levels in plants. Since Egyptian soils are selenium deficient, it should be supplied to plants through foliar application. Previous studies have reported that foliar selenium treatment was important to improve drought tolerance.

Funding

This work was supported and funded by National Research Centre, Egypt.

Declaration of competing interest

Regarding the publication of this manuscript, all authors declare that there are no conflict of interest related this manuscript.

Acknowledgments

The authors would like to express their gratitude to the whole team at the Research and Production Station in El-Nubira for their help in conducting this study.

References:

A.O.A.C., 1980. Official methods of analysis (4th Ed.) Association of official Agricultural Chemists Washington D.C., U.S.A. AOAC: Official Methods of Analysis (Volume 1)

Abd El Mageed, T.A., Semida, W., Hemida, K.A., Gyushi, M.A.H., Rady, M.M,, Abdelkhalik, A., Abdelhamid, T., 2023. Glutathione-mediated changes in productivity, photosynthetic efficiency, osmolytes, and antioxidant capacity of common beans (Phaseolus vulgaris) grown under water deficit. Peer J 11: e15343. https://doi.org/10.7717/peerj.15343

Abd El-Mageed, T. A., A bd El-Mageed, S.A., El-Saadony, M.T, Abdelaziz, S., Abdou, N.M., 2022a. Plant growth-promoting rhizobacteria improve growth, morph-physiological responses, water productivity, and yield of rice plants under full and deficit drip irrigation. Rice 15: 6. https://doi.org/10.1186/s12284-022-00564-6

Abd–Elrahman, Sh. H., Saudy, H. S., Abd El–Fattah, D. A., Hashem, F.A., 2022. Effect of irrigation water and organic fertilizer on reducing nitrate accumulation and boosting lettuce productivity. Journal of Soil Science and Plant Nutrition 22:2144-2155. https://doi.org/10.1007/s42729-022-00799-8

Abou-Sreea, A. I., Kamal, M., El Sowfy, D. M., Rady, M. M., Mohamed, G. F., Al-Dhumri, S. A., Al-Harbi, M.S, Abdou NM 2022. Small-sized nanophosphorus has a positive impact on the performance of fenugreek plants under soil-water deficit stress: A case study under field conditions. Biology 11:115. https://doi.org/10.3390/biology11010115

Ali, J., Jan, I. U., Ullah, H., 2020. Selenium supplementation affects vegetative and yield attributes to escalate drought tolerance in Okra. Sarhad J Agri. 36(1):120–9. https://doi: 10.17582//2020/36.1.120.129.

Allen, L. H. J. R., Valle, R. R., Jones, J. W., Jones, P. H., 1998. Soybean leaf water potential responses to carbon dioxide and drought. Agron. J. 90:375-383. https://doi.org/10.2134/agronj1998.00021962009000030010x

Ameen, M., Mahmood, A., Ahmad, M., Mansoor Javaid, M., Nadeem, M. A., Asif, M., 2023a. "Impacts of climate change on fruit physiology and quality," in Climate-resilient agriculture, vol 1: crop responses and agroecological perspectives. Ed. M. Hasanuzzaman (Springer International Publishing, Cham), 93–124. https://doi.org/10.1007/978-3-031-37424-1_5

Andradea, F. R., Silvab, G. N., Guimarãesc, K. C., Barretod, H. P. F., Souzae, K. R. D., Guilhermea, L. R. G., 2018. Selenium protects rice plants from water deficit stress. Ecotox Environ Safe. 164:562–70. https://doi: 10.1016/j.ecoenv.2018.08.022.

Araújo Júnior, G., Gomes, F. T., Silva, M. J. da., Jardin, A. M. da. RF., Simões, V. J. L. P., Izidro, J. L. P. S., 2019. Estresse hídrico em plantas forrageiras: Uma revisão Pubvet 13 (1), 1–10. https://doi.org/10.31533/pubvet.v13n01a241.1-10

Arshad, A., Ghani, M. U., Hassan, M.U., Qamar, H., and Zubair, M., 2020. "Sunflower modelling: A review," in Systems modeling. Ed. M. Ahmed (Springer, Singapore), 307–326. http://dx.doi.org/10.1007/978-981-15-4728-7_11

Awad, A. A., Sweed, A. A., Rady, M. M., Majrashi, A., Ali, E. F., 2021. Rebalance the nutritional status and the productivity of high CaCO3-stressed sweet potato plants by foliar nourishment with zinc oxide nanoparticles and ascorbic acid. Agronomy 11:1443. https://doi.org/10.3390/agronomy11071443

Christoforidou, M., Borghuis, G., Seijger, C., Van Halsema, G. E., Hellegers, P., 2023. Food security under water scarcity: a comparative analysis of Egypt and Jordan. Food Security 15: 171–185. https://doi.org/10.1007/s12571-022-01310-y

Cottenie, A., Verlo, M., Kjekens, L., Camerlynch, R. A., 1982. Chemical analysis of plant and soil. Laboratory of Analytical Agro Chemistry. State Univ of Gent. 4, pp. 280-284. https://lib.ugent.be/catalog/rug01:000239299

Deng, X., Liu K, Li, M., Zhang, W., Zhao, X., Zhao, Z., & Liu, X., 2017. Difference of selenium uptake and distribution in the plant and selenium form in the grains of rice with foliar spray of selenite or selenate at different stages. *Field Crops Research* 211: 165-171. https://doi.org/10.1016/j.fcr.2017.06.008

Dietz, K. J., Zörb, C., and Geilfus, C. M., 2021. Drought and crop yield. Plant Biol. 23, 881–893. https://doi:10.1111/plb.13304

Dwivedi, S. L., Garcia-Oliveira, A. L., Govindaraj, M., Ortiz, R., 2023. Biofortification to avoid malnutrition in humans in a changing climate: Enhancing micronutrient bioavailability in seed, tuber, and storage roots. Frontiers in Plant Science 14:1119148. https://doi.org/10.3389/fpls.2023.1119148

FAO., 2018. Food and Agriculture Organization of the United Nations (FAO). (2018). Statistical Databases. Available at: http://www.fao.org/faostat/en/#data/QC/visualize. Access 22 12 2020.

Farid, H., Saied, E., Hani, M., Abdel-Hady, M., 2021. Effects of micronutrient mixture foliar spraying on sunflower yield under water deficit and its evaluation by Aqua Crop model. Vol. 23, No.2. AgricEngInt: CIGR Journal Open access at http://www.cigrjournal.org

Forleo, M. B., Palmieri, N., Suardi, A., Coaloa, D., Pari, L., 2018. The eco-efficiency of rapeseed and sunflower cultivation in Italy. Joining environmental and economic assessment. *Journal of Cleaner Production*, *172*, 3138–3153. https://doi.org/10.1016/j.jclepro.2017.11.094.

Ghorai, M., Kumar, V., Kumar, V., Al-Tawaha, A. R., Shekhawat, M. S., Pandey, D. K., 2022. Beneficial role of selenium (Se) biofortification in developing resilience against potentially toxic metal and metalloid stress in crops: recent trends in genetic engineering and omics approaches. J. Soil Sci. Plant Nutr. 22, 2347–2377. https://doi:10.1007/s42729-022-00814-y

Hossain, A., Skalicky, M., Brestic, M., Maitra, S., Sarkar, S., Ahmad, Z., 2021. Selenium biofortification: roles, mechanisms, responses and prospects. Molecules 26, 881. https://doi:10.3390/molecules26040881

Iqbal, Q., Noor Hazlina, A., Adeel N., Syed A. R. K., 2020. A moderated-mediation analysis of psychological empowerment: Sustainable leadership and sustainable performance. Journal of Cleaner Production 262(6). https://doi.org/10.1016/j.jclepro.2020.121429.

Israelsen, W., Hansen, V. E., 1962. Irrigation Principles and Practices. 3rd Ed. New York, London.

Jensen, M. E., 1980. Design and operation of farm irrigation systems, American Society of Agricultural Engineers St. Joseph, MI, USA.

Kamran, M., Parveen, A., Ahmar, S., Malik, Z., Hussain, S., Chattha, M. S., 2020. An overview of hazardous impacts of soil salinity in crops, tolerance mechanisms, and amelioration through selenium supplementation. Int. J. Mol. Sci. 21, 148. https://doi:10.3390/ijms21010148

Karimi, R., Ghabooli, M., Rahimi, J., Amerian, M., 2020. Effects of foliar selenium application on some physiological and phytochemical parameters of Vitis vinifera L. cv. Sultana under salt stress. J Plant Nutr. 43 (14) :2226–42. https://doi:10.1080/01904167.2020.1766072.

Langstroff, A., Heuermann, M. C., Stahl, A., Junker, A., 2022. Opportunities and limits of controlled-environment plant phenotyping for climate response traits. Theoretical and Applied Genetics 135: 1–16. https://doi.org/10.1007/s00122-021-03892-1

Le Vinh, T., Jun-Ichim S., Le Thanh, H., Tran Ngoc, H., Nguyen, Q. K., Le Ly, V. V., 2021. Foliar selenium application for improving drought tolerance of sesame (Sesamum indicum L.). Open Agriculture 2021; 6: 93–101. https://doi.org/10.1515.

Lichtenthaler H. K., Buschmann, C., 2001. Chlorophyll and carotenoids: measurement and characterization by UV–VIS spectroscopy. In: Wrolstad RE, Acree TE, An H, Decker EA, Penner MH, Reid DS, Schwartz SJ, Shoemaker CF, Sporns P (eds) Current protocols in food analytical chemistry (CPFA). Wiley, New York, pp F4.3.1– F4.3.8. https://www.scirp.org/(S(351jmbntvnsjt

Lichtenthaler, H. K., 1987. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. Methods in Enzymology 148: 350-382. https://doi.org/10.1016/0076-6879(87)48036-1

MSTAT-C, 1988. A Microcomputer Program for the Design. Arrangement and Analysis of Agronomic Research. Michigan State University, East Lansing. https://doi.org/ 10.4236/ce.2017.812125

Muhammad, N. K., Zulfiqar, A. A., Aijaz, A. S., Naimatullah, L., Muhammad, I. K., Ahmed, N. Sh., Ghulam, M. J., Nadia, M., Shazia, P. T., 2021. Evaluation of Irrigation Frequencies and Seed Priming with Plant Nutrients on Growth and Yield of Sunflower (*Helianthus annuus* L.) Genotypes. Pakistan Journal of Agricultural Research. Volume 34 | Issue 1 | Page 58-69. http://dx.doi.org/10.17582/journal.pjar/2021/34.1.58.69 .

Oliveira, V. C. D., Faquin, V., Guimarães, K. C., Andrade, F. R., Pereira, J., Guilherme, L. R. G. 2018. Agronomic biofortification of carrot with selenium. Ciência e Agrotecnologia, v. 42, n. 2, p. 138-147. https://doi.org/10.1590/1413-70542018422031217 .

Oyetunji, O., Bolan, N., Hancock, G., 2022. A comprehensive review on enhancing nutrient use efficiency and productivity of broadacre (arable) crops with the combined utilization of compost and fertilizers. Journal of Environmental Management

317: 115395. https://doi.org/10.1016/j.jenvman.2022.115395 .

Ozturk, M., TurkyilmazUnal, B., GarcíaCaparr´os, P., Khursheed, A., Gul, A., Hasanuzzaman, M., 2020. Osmoregulation and its actions during the drought stress in plants. *PhysiologiaPlantarum,* Special Issue Article 1–15. https://doi.org/10.1111/ppl.13297.

Pal, U., Patra, R., Sahoo, N., Bakhara, C., Panda, M., 2015. Effect of refining on quality and composition of sunflower oil. *Journal of FoodScience and Technology*, *52*(7), 4613–4618.https://doi.org/10.1007/s13197-014-1461-0.

Ramadan, K. M. A., El-Beltagi, H. S., El-Mageed, T. A. A., Saudy, H. S., Al-Otaibi, H. H., Mahmoud, M. A. A., 2023. The changes in various physio-biochemical parameters and yield traits of faba bean due to humic acid plus 6-benzylaminopurine application under deficit irrigation. Agronomy 13:1227. https://doi.org/10.3390/agronomy13051227.

Rebecca, B., 2004. Soil Survey Methods Manual. Soil Survey Investigations Report No. Natural Resources Conservation Services, USDA, USA.

Sarkar, J., Mridha, D., Davoodbasha, M. A., Banerjee, J., Chanda, S., Ray, K., 2023. A state-of-the-art systemic review on selenium nanoparticles: mechanisms and factors influencing biogenesis and its potential applications. Biol. Trace Elem. Res. 201, 5000–5036. https://doi:10.1007/s12011-022-03549-0.

Saudy, H. S., El-Bially, M. A., Hashem, F. A., Shahin, M. G., El–Gabry, Y. A., 2023. The changes in yield response factor, water use efficiency, and physiology of sunflower owing to ascorbic and citric acids application under mild deficit irrigation. Gesunde Pflanzen 75:899-909. https://doi.org/10.1007/s10343-022-00736-w .

Shahzadi, I., Iqbal, M., Rasheed, R., Ashraf, M. A., Perveen, S., Hussain, M., 2017. Foliar application of selenium increases fertility and grain yield in bread wheat under contrasting water availability regimes. Acta Physiol Plant. 39 (173) :1–11. https://doi:10.1007/s11738017-24777.

Snedecor, G.W., Cochran, W.G., 1990. Statistical Methods, eighth ed., vol. 609. Iowa State Univ Press Ames, Iowa USA (PRILIMINERY AND CONTENTS.pdf). Microsoft Word - Final6formated2.doc

Stefîrţă, A., Botnari, V., Brânză, L., Bulhac, I., Chilinciuc, A., 2016. Agronomical biofortification of garlic plant (Allium sativum L.) in aspect of increasing selenium content and antioxidant properties. Advances in Medicinal Plants Research 4:99-105. 16-023.pdf

Wang, Q., Yu, Y., Li, J., Wan, Y., Huang, Q., Guo, Y., Li, H., 2017. Effects of different forms of selenium fertilizers on Se accumulation, distribution, and residual effect in winter wheat–Summer maize rotation system. *Journal of Agricultural and Food Chemistry* 65 (6): 1116-1123. DOI: 10.1021/acs.jafc.6b05149.

Zafar, S., Afzal, H., Ijaz, A., Mahmood, A., Ayub, A., Nayab, A., 2023. Cotton and drought stress: An updated overview for improving stress tolerance. S. Afr. J. Bot. 161, 258–268. https://doi:10.1016/j.sajb.2023.08.029.

Zahedi, S. M., Hosseini, M. S., Fahadi Hoveizeh, N., Kadkhodaei, S., Vaculík, M., 2023. Comparative morphological, physiological and molecular analyses of drought stressed strawberry plants affected by SiO2 and SiO2-NPs foliar spray. Sci. Hortic. 309, 111686. https://doi:10.1016/j.scienta.2022.111686.