

The Effect of Dust Storms on the Morphological Characteristics of Sunflower Leaves in the Field Environment

¹ Mohammed Ridha Abbass hassoon

- Maha Ali Abd Alameer²

Biology Department - Science College - Al-Qadisiyah University - Iraq^{1 2}

sci.bio.phd.22.10@qu.edu.iq

Maha.ali@edu.qu.iq

Abstract

This study examined the effect of dust storms on the physiological and morphological growth of sunflower plants. The results demonstrated that the accumulation of dust particles on the leaf surface caused a significant reduction in key growth indicators. Plants exposed to dust storms showed a clear decline in stem length, number of leaves, and total leaf area compared to unexposed plants. This indicates that dust accumulation disrupts gas exchange and reduces photosynthetic activity, which ultimately limits normal plant growth. It was observed that a thin layer of dust, particularly on leaves with dense trichomes, intensifies these effects by covering the leaf surface, decreasing the amount of incident light, and partially blocking the stomatal pores. This blockage restricts gas movement between the atmosphere and the leaf interior, leading to stomatal closure and water stress. As a result, leaf tissues exhibit contraction or shrinkage in growth, accompanied by a noticeable decrease in both leaf length and width, which reduces the total leaf area. In conclusion, the spread of dust particles on the surfaces of plant leaves imposes physical stress manifested through mechanical isolation and cellular coverage. This stress is associated with increased leaf temperature, reduced photosynthetic efficiency, and a general decline in vegetative growth and productivity of sunflower plants

Keywords: Dust storms, Sunflower, Environmental adaptation

Introduction

This study addresses dust and sand storms as natural phenomena occurring widely around the world. Some storms contain microscopic and nano-sized dust particles carried by air and added to the atmospheric envelope as a result of natural processes or human activities. These fine particles can significantly impair visibility and pose serious health risks, including respiratory problems and potential loss of life [4].

Iraq, particularly Baghdad, experienced a series of intense dust storms in the spring of 2022. Although these storms are considered natural climatic events due to Iraq's location within a vast desert belt, they are distinguished by their severity, causing harmful health impacts, aviation disruptions, and airport closures. The increased intensity of these storms is linked to reduced rainfall in Iraq and

neighboring countries in recent years. Their frequency has risen during the spring and summer seasons, with an occurrence rate ranging from 2 to 11 hours. Satellite image analysis identified the primary source areas of these storms as northern Syria, eastern Jordan, and northern Saudi Arabia [17].

One of the major impacts of dust storms is on the agricultural sector, which plays a vital role in economic stability and food security. Previous research indicated a 1.1% decrease in the value of crop production as a result of each additional dust and sand storm event, equivalent to about 0.045% of Iraq's total GDP, or approximately 0.1 billion dollars. Crop yields were also shown to decline significantly by 0.9–3% per day during storm events [2].

Dust storms strip the soil of its finest and most nutrient-rich organic particles, negatively

affecting soil fertility and crop productivity. They also cover plant surfaces, interfering with vital physiological processes such as transpiration and photosynthesis. Beyond agriculture, dust accumulation on homes, streets, and public facilities imposes additional burdens on municipal services and citizens through increased cleaning and maintenance efforts [26].

Helianthus annuus L. (sunflower) is considered one of the most important strategic oilseed crops. It is valued for its nutritional and health benefits due to its high content of unsaturated fatty acids, vitamins B and C, minerals, and dietary fiber. The plant also contains active compounds including flavonoids, phytic acid, tannins, phenols, essential oils, and alkaloids, which contribute to its therapeutic properties such as anti-inflammatory, antibacterial, antiviral, and anti-gout effects. These properties have supported its use in traditional medicine systems [3].

Sunflower belongs to the Compositae family and has an oil content ranging from 39% to 49%. Its oil is considered healthy due to its richness in omega-3 fatty acids and unsaturated fats. Sunflower seeds are widely used in cooking oil production and in various industrial applications such as soap and dye manufacturing. They are also an important source of minerals including calcium, copper, iron, magnesium, and phosphorus [15].

Research Aim

The present study aims to evaluate the impact of natural dust storms on the vegetative growth, physiological responses, and chemical composition of sunflower (*Helianthus annuus* L.) plants under field conditions in central Iraq. The research also seeks to analyze the physical, chemical, and biological characteristics of dust particles and their potential effects on plant performance and soil properties

Materials and Methods

Soil Preparation and Cultivation

The experiment began with the preparation of agricultural soil to ensure an optimal growth environment for sunflower plants, with careful control of all environmental factors to achieve homogeneity between treatments. First, harmful weeds and plant residues were removed from the soil surface. Then, primary plowing was performed to an average depth ranging between 25 and 30 cm using a disc plow, with the aim of loosening the soil, improving its aeration, and facilitating the absorption of water and nutrients [7].

Certified sunflower seeds were obtained from the Agricultural Research Center to ensure high quality and genetic purity. The seeds were inspected before planting to confirm they were free of diseases and pests [3].

A mixture of clay and sand soil in a 1:1 ratio was used, and the soil was sterilized thermally at 80 °C for 24 hours to eliminate pests and microorganisms [7].

A drip irrigation system was installed to precisely control the amount of water supplied to the plants. Soil moisture was maintained at 70 % of field capacity to ensure optimal growth conditions [12]. Urea fertilizer was used as the main nitrogen source, which plays a critical role in stimulating vegetative growth and enhancing protein formation. Fertilization was carried out in two doses:

First dose: 500 mg of urea applied directly before planting and thoroughly mixed with the soil during the second plowing to ensure homogeneous nutrient distribution.

Second dose: 500 mg of urea applied one month after planting, immediately after irrigation to allow gradual nitrogen absorption and minimize loss through volatilization or leaching [3].

This fertilization method followed recommendations from the internationally recognized fertilization guide for field crops [7]. After fertilization, the soil surface was leveled using traditional equipment to achieve a smooth and uniform surface, ensuring homogeneous moisture distribution. The soil

was then divided into agricultural basins of equal dimensions to guarantee uniform plant distribution.

On February 14th, G3-75 hybrid sunflower seeds were planted. This genetically improved variety is characterized by high growth homogeneity and strong adaptability to environmental conditions, ensuring consistent results and accurate measurement of physiological variables during the experimental stages.[15 The experiment began with the preparation of agricultural soil to ensure an optimal growth environment for sunflower plants, with careful control of all environmental factors to achieve homogeneity between treatments. First, harmful weeds and plant residues were removed from the soil surface. Then, primary plowing was performed to an average depth ranging between 25 and 30 cm using a disc plow, with the aim of loosening the soil, improving its aeration, and facilitating the absorption of water and nutrients [7].

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Soil Analysis and Determination of Physical and Chemical Components and pH

To ensure the accuracy and reliability of the experimental results, a comprehensive analysis of the soil used for sunflower cultivation was conducted prior to planting. This step aimed to identify the physical and chemical characteristics of the soil and to confirm its suitability for the experiment.[7]

Sample Collection:

Soil samples were collected before planting from a depth of 0–30 cm at several random points across the experimental field to represent the root zone. The collected samples were thoroughly mixed to obtain a composite sample representative of the entire field soil. The composite sample was then air-dried in a shaded area, followed by sieving through a 2 mm mesh sieve to remove debris and coarse particles.[10]

Physical and Chemical Analysis:

The prepared soil samples were analyzed in the Soil and Environmental Materials

Laboratory for their key physicochemical indicators. The following parameters were determined:

Organic Matter (%)

Total Nitrogen (%)

Available Phosphorus (mg/kg)

Exchangeable Potassium (mg/kg)

Electrical Conductivity (EC, dS/m)

Soil texture analysis was conducted using the hydrometer method to determine particle-size distribution [10].

An X-ray Fluorescence (XRF) spectrometer was used to determine the mineral composition of the soil with high accuracy, as it provides rapid and non-destructive elemental analysis [29].

pH Measurement:

Soil pH was measured using a Hanna Instruments HI 5221 pH meter following the standard 1:2.5 soil-to-water suspension

The field design is summarized in Table 2, which ensures uniform conditions across groups except for the dust storm factor.

Treatment	Treatment Details	Location in the Field
Exposed Group	Fully exposed, uncovered, directly exposed to the artificial dust storm	Southern half
Unexposed Group	Covered with transparent plastic houses for complete protection from the dust storm	Northern half

Measurement of Vegetative Traits

Timing of Measurements:

Vegetative traits were measured twice during the growing season.

The first measurement was conducted eight weeks after planting, representing the advanced vegetative growth stage [14].

The second measurement occurred eleven weeks after planting, immediately following the dust storm exposure [14].

Measurement Methodology:

All vegetative traits were measured using a flexible plastic measuring tape with an accuracy of ± 0.1 cm following standardized field measurement procedures [12].

method. The suspension was stirred thoroughly and allowed to settle for 30 minutes before taking the readings [12].

Experimental Groups and Seed Distribution

To ensure valid results and accurate statistical analysis, plants were divided into two equal experimental groups in the same field [13]:

1. First Group (Exposed to Dust Storm)

Placed in the southern half of the field and left unprotected to allow direct impact of the dust storm

2. Second Group (Not Exposed – Covered):

Placed in the northern half of the field and protected using small transparent plastic micro-greenhouses, which transmit 90 % of light while blocking dust. Side ventilation prevented excess moisture accumulation, and a separating distance prevented dust transfer between groups [13]

Leaf Length: Measured from the petiole base to the leaf apex; averages were calculated from 2–3 leaves per plant [12].

Leaf Width: Determined at the widest point of each leaf used in length measurements [12].

Stem Height: Measured from the soil surface to the apical bud or growing point [12].

To ensure accuracy, each plant was measured multiple times and the average was used to represent the final value.

Replicates:

Five plants per treatment group were randomly selected as biological replicates, with internal measurements averaged to reduce variability [13].

Recording and Documentation:

All vegetative measurements were tabulated immediately after collection and stored for statistical processing and comparison between treatments [13].

Photographs were taken to support morphological documentation and illustrate differences between the exposed and control groups.

Dust Storm Documentation and Sample Collection

The dust storm event was documented using satellite imagery provided by NASA and ESA platforms, which were analyzed to track storm formation, movement, and arrival time over the study area [17].

Meteorological data from local weather stations were also used to confirm wind speed, visibility levels, and dust intensity during the event [17].

Dust samples were collected immediately after the storm using standardized dust traps installed at multiple points within the experimental field to ensure spatial representation [26].

All collected samples were stored in sealed, sterile containers and transported to the laboratory for subsequent physical and chemical analysis [26].

Dust Analysis Procedures

Particle Size Distribution

Particle size distribution of dust samples was determined using laser diffraction, which provides accurate quantitative assessment of micron-scale particle fractions [10].

Chemical Composition

The chemical composition of dust was analyzed via X-ray Fluorescence (XRF), enabling non-destructive identification of major mineral elements and trace metals [29]

Morphological Analysis (SEM)

Scanning Electron Microscopy (SEM) was used to characterize particle morphology, including shape, surface roughness, and aggregation behavior. This technique allowed

visualization of micro- and nano-scale structures relevant to plant–dust interactions [26].

Sample Preparation

Dust samples were oven-dried at 40 °C for 24 hours to eliminate moisture without altering chemical properties.

Dried particles were mounted on aluminum stubs using conductive carbon tape and coated with a 10–20 nm gold layer using a sputter coater to enhance conductivity required for SEM imaging [26].

Analysis Techniques

SEM Imaging: Conducted using a JEOL JSM-6510LV at 15 kV, with magnifications ranging from 500× to 5000× to visualize particle geometry and surface texture [26].

Energy Dispersive X-ray Spectroscopy (EDX): Performed directly after SEM imaging to determine the elemental composition of dust particles, focusing on major mineral constituents such as Si, Al, Fe, Ca, Mg, and K [26].

Objectives of Dust Analysis

The analytical procedures aimed to

Characterize dust particle size, morphology, and chemical composition under natural storm conditions.

Link dust deposition to subsequent physiological and biochemical responses in sunflower plants.

Provide essential environmental context for interpreting growth, pigment, and stress-related outcomes observed in the experiment [17].

Results and Discussion

1. Soil Analysis

Chemical Composition

= 155.3 (good), Ca = 812.7 (high), Mg = 106.5 (suitable), Fe = 23.2 (normal), and Zn = 3.7 (relatively low) (Table 3).

Table 3. Chemical composition of the experimental soil (mg kg⁻¹) before planting

The topsoil before planting contained (mg kg^{-1}): N = 72.6 (moderate), P = 18.4 (sufficient), K

Element	Symbol	Concentration (mg/kg)	General Assessment (Soil Chemistry)
Total Nitrogen	N	72.6	Moderate
Phosphorus Available	P	18.4	Sufficient
Exchangeable Potassium	K	155.3	Good
Calcium	Ca	812.7	High
Magnesium	Mg	106.5	Suitable
Iron	Fe	23.2	Normal
Zinc	Zn	3.7	Relatively Low

Discussion

Moderate nitrogen supports vegetative growth, while adequate phosphorus enhances root formation. Elevated potassium and calcium reinforce cell-wall strength and improve stress resistance. In contrast, low zinc content coupled with alkaline pH (≈ 7.5) may restrict

micronutrient availability and enzyme activity, reducing vegetative performance [7].

Physical Properties

Soil texture was classified as loamy sand (72 % sand, 18 % silt, 10 % clay) with 11.3 % moisture, bulk density 1.49 g cm^{-3} , EC 1.37 dS m^{-1} , and organic matter 1.6 % (Table 4).

Table 4. Physical properties of the experimental soil (texture, moisture, bulk density, EC, organic matter).

Physical Property	Measured Value	Scientific Interpretation
Soil Texture	Loamy Sand	Excellent aeration and good drainage
Sand (%)	72	High
Silt (%)	18	Low
Clay (%)	10	Very Low
Relative Moisture	11.3%	Suitable for sunflower plant
Bulk Density	1.49 mg/cm^3	Moderate density
Electrical Conductivity (EC)	1.37 dS/m	Low and non-influential salinity
Organic Matter	1.6%	Relatively low

Discussion.

Loamy-sand soil ensures good aeration and drainage but limits water and nutrient retention, increasing plant sensitivity to dust-storm stress. Low organic matter further constrains microbial activity and nutrient cycling [10].

Dust Sample Analysis (Morphology (SEM

Dust particles ($1.4\text{--}6.4 \mu\text{m}$) displayed spherical, oval, and irregular crystalline forms;

several carried microbial-like structures resembling spores or cocci.

Scanning Electron Microscopy (SEM) was employed to characterize the morphology, particle size, and surface texture of the settled dust collected after the storm. The images revealed a wide range of particle sizes and geometries, confirming the heterogeneous mineral nature of the dust composition. Figures (1–5) illustrate the progressive

magnifications and structural variations observed among dust particles.

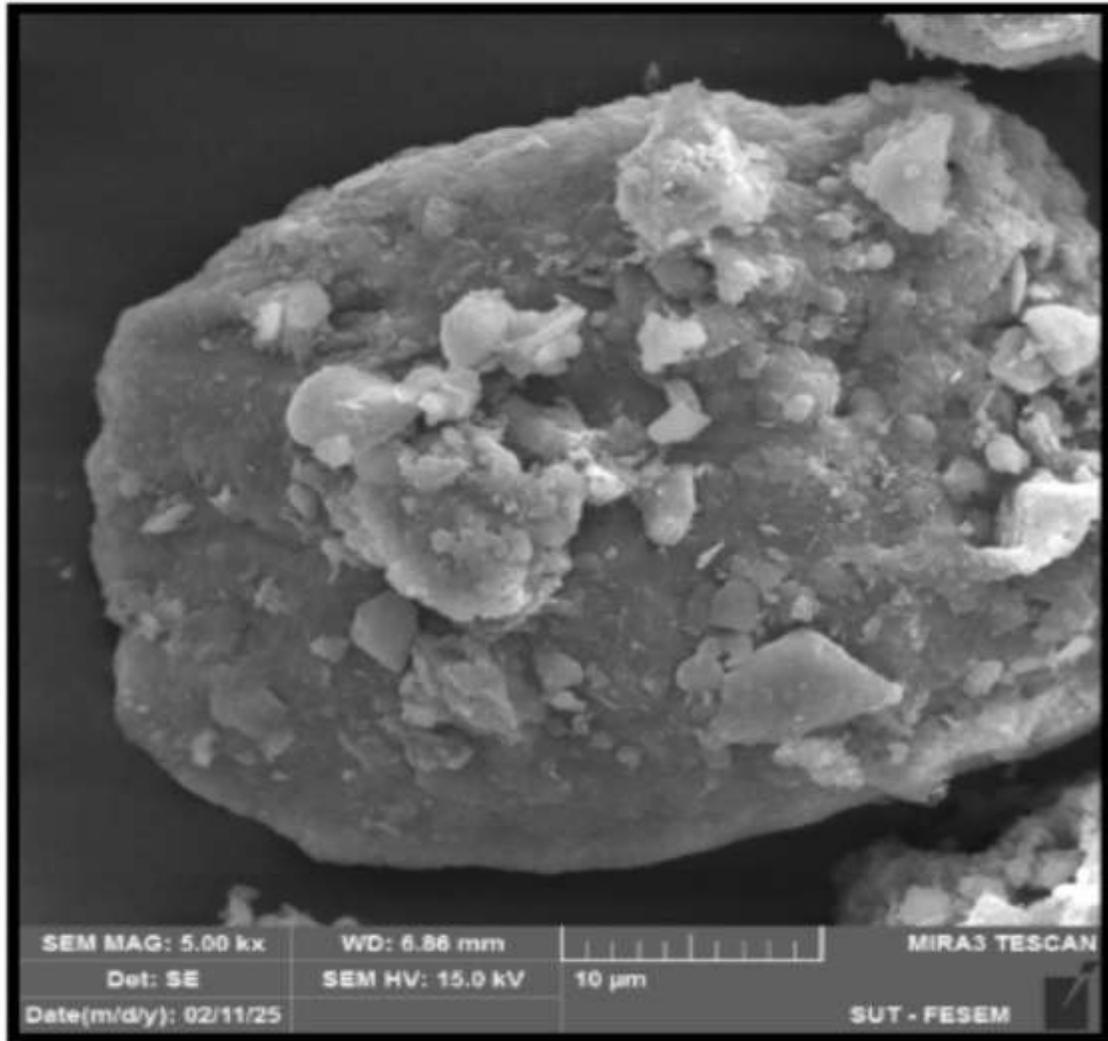


Figure 1.

Scanning electron micrograph of a coarse dust particle (magnification $\times 5.0k$). The particle exhibits an irregular and rough surface with multiple crystalline protrusions and small adhering fragments. The heterogeneous texture and granular surface indicate mechanical abrasion and mineral aggregation during atmospheric transport. Such coarse particles represent the fraction primarily responsible for initial mechanical injury to plant leaves

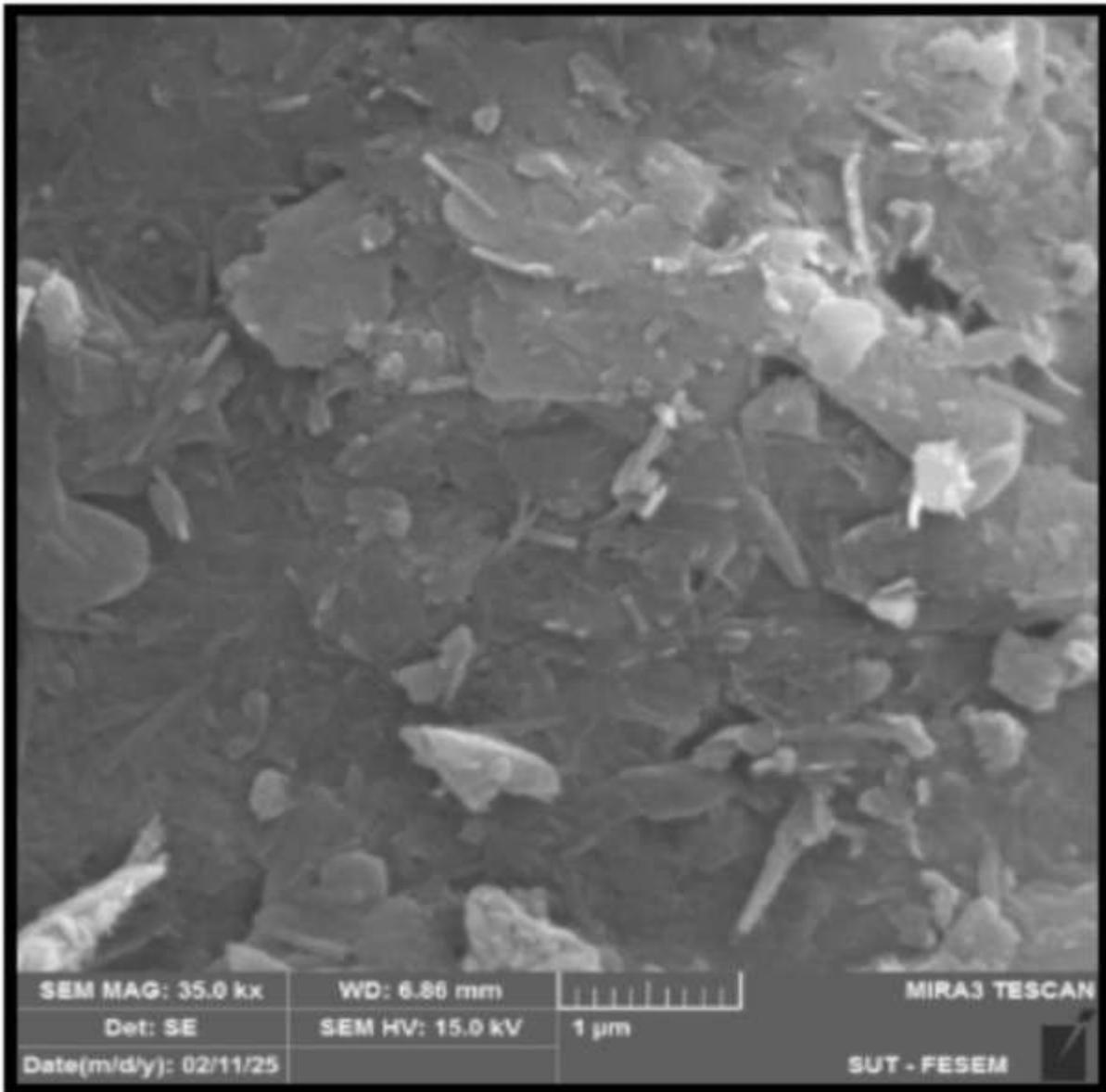


Figure 2.

. High-magnification SEM image ($\times 35.0k$) showing flake-like and elongated micro-particles distributed on the surface of a larger aggregate. These layered structures suggest the presence of silicate and clay minerals derived from arid soils. The uneven surface texture reflects natural weathering and erosion processes associated with storm turbulence

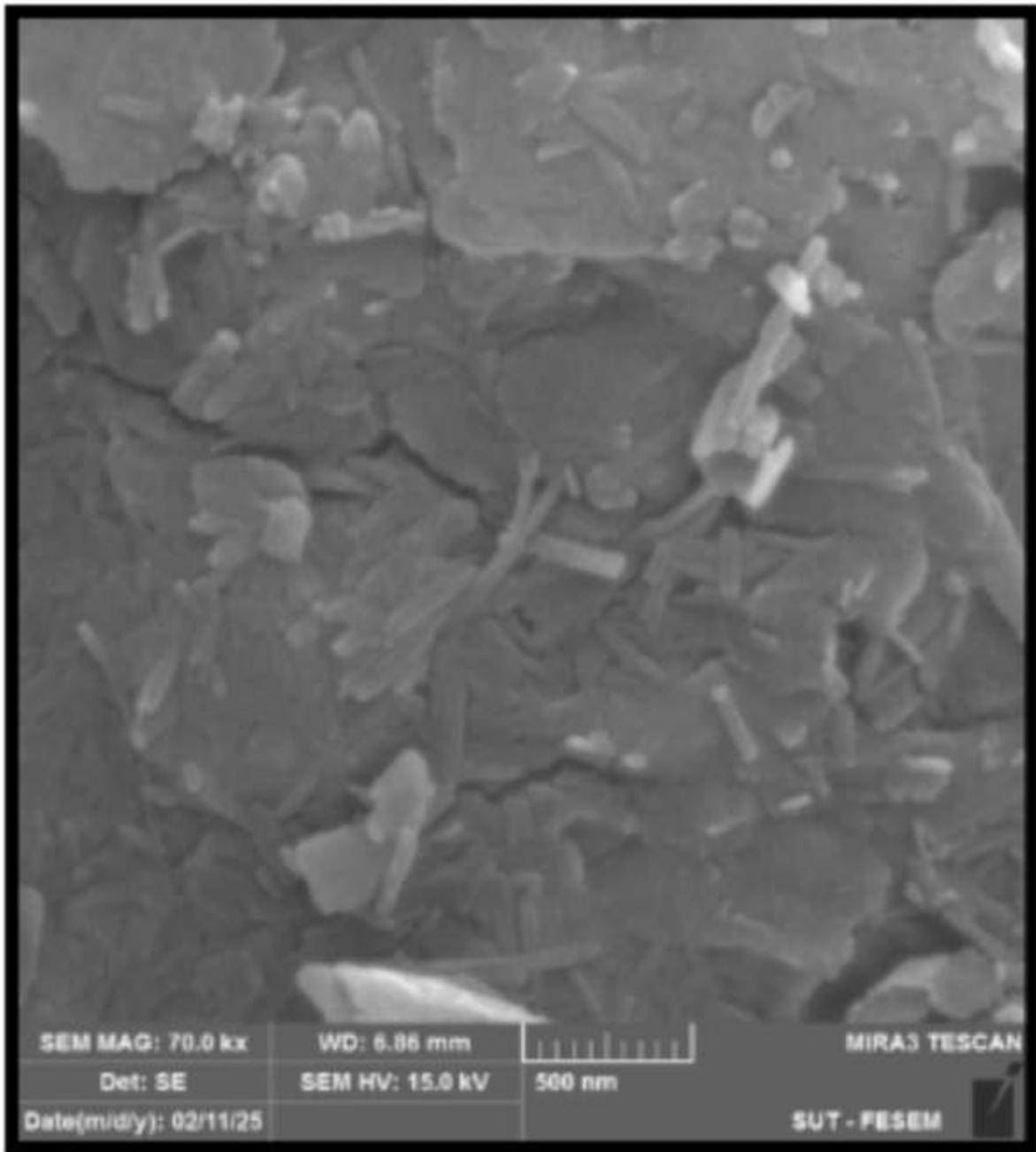


Figure 3.

SEM image at $\times 70.0k$ revealing nano-scale crystalline rods and plate-like structures (~ 500 nm) interlocked within the matrix. The compact arrangement and high surface area of these particles imply strong adhesion potential to plant epidermal tissues, facilitating stomatal blockage and micro-abrasion. Such particles are typically associated with calcium carbonate and sodium sulfate crystals formed under saline dust conditions.

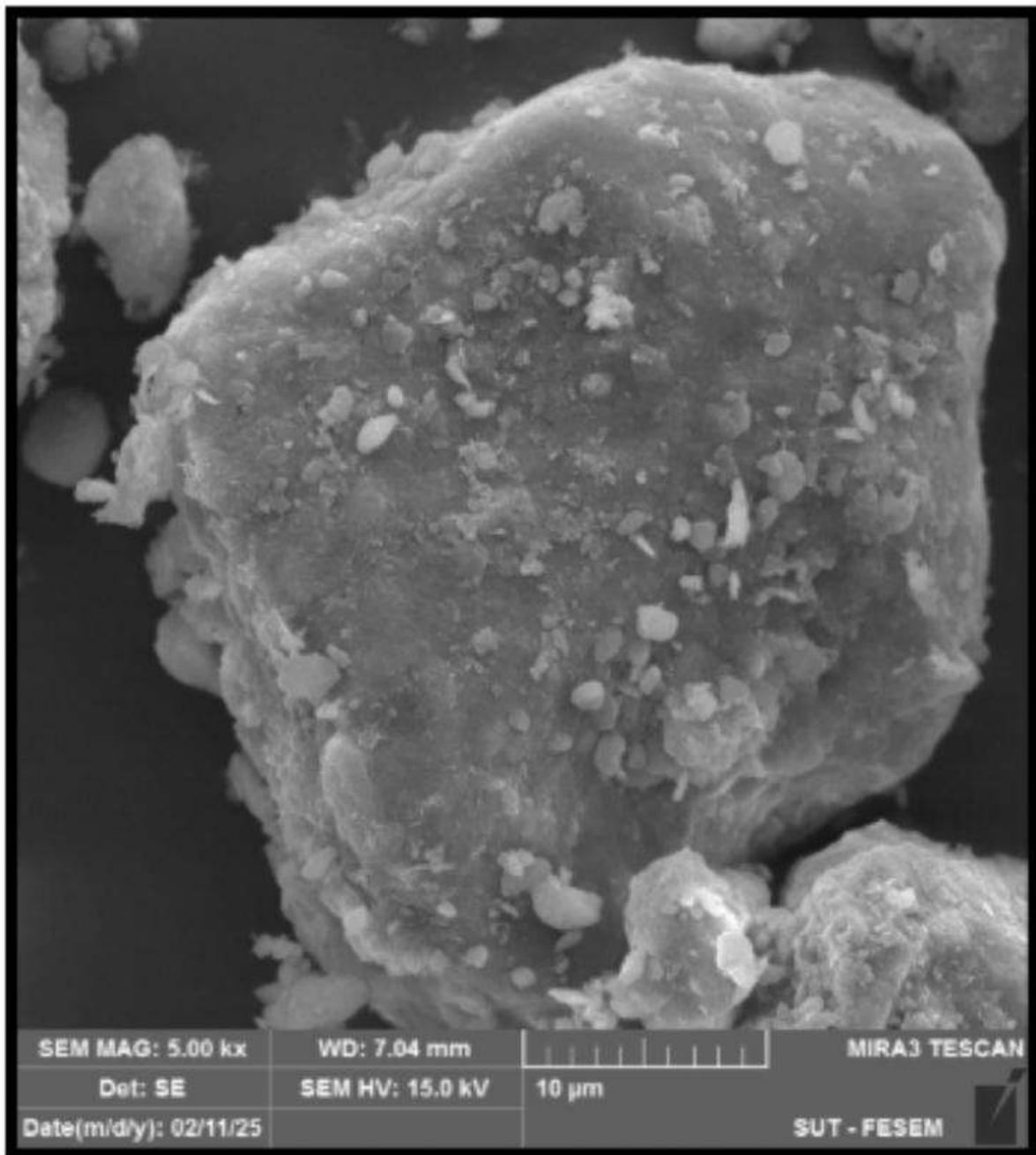


Figure 4

Scanning electron micrograph ($\times 5.0k$) displaying a rounded dust particle densely covered with fine micro-aggregates and fused debris. Smooth zones alternate with rough patches, indicating repeated mechanical collisions and partial fusion during atmospheric suspension. These characteristics enhance the dust's ability to adhere to moist leaf surfaces after deposition.

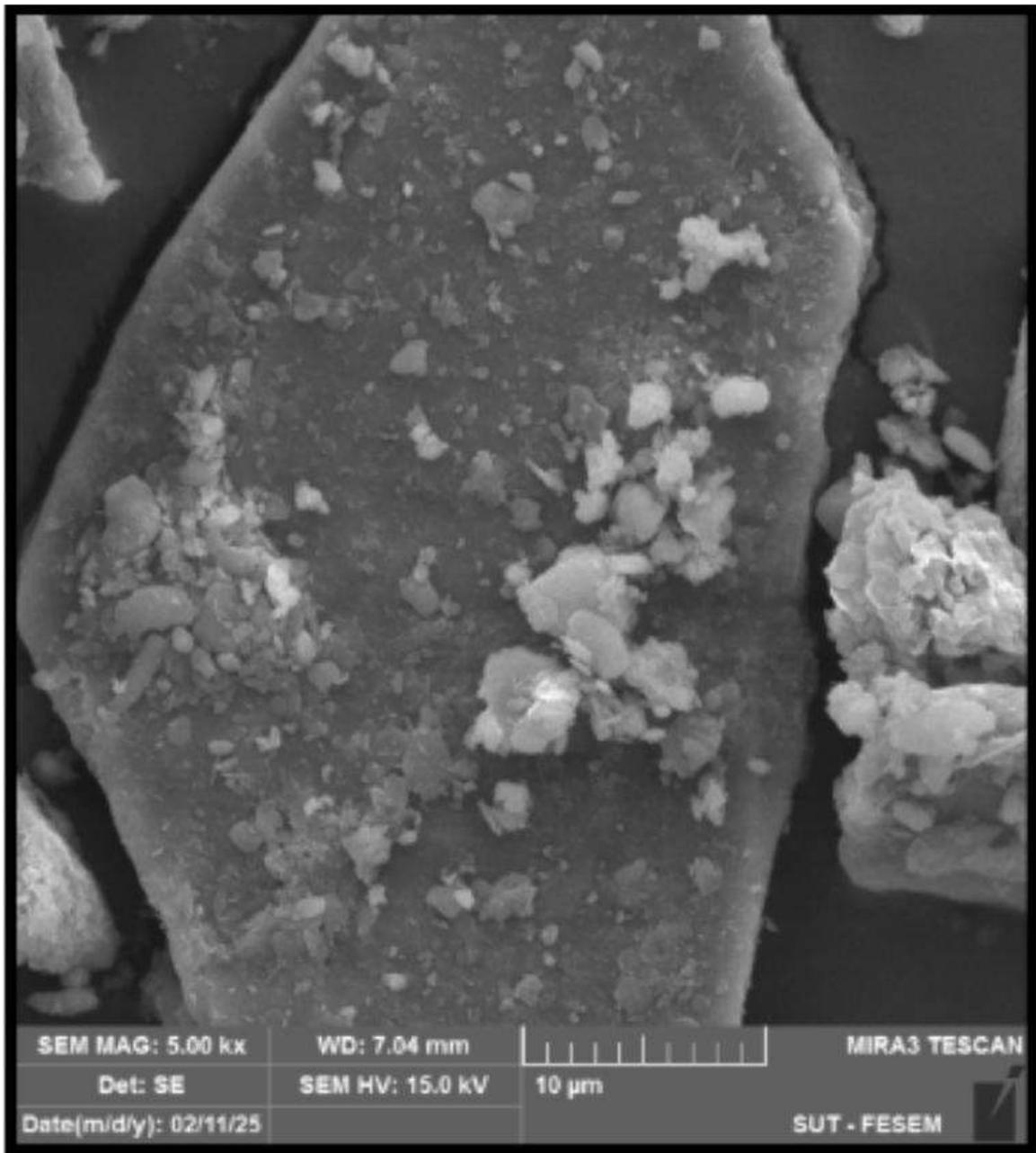


Figure 5.

SEM image (×5.0k) depicting a flat crystalline plate surrounded by numerous adhering granules and sharp-edged fragments. The compact texture and irregular edges suggest a mineral origin dominated by calcium-rich silicates. The angular geometry of such particles increases their potential to cause epidermal micro-lesions and alter leaf surface micro-topography upon impact.

Discussion of SEM Results

The sequential SEM images confirm that the storm-borne dust possesses a complex mixture of mineral fractions ranging from coarse aggregates to fine crystalline sub-particles. This morphological diversity directly correlates with the dust's mechanical and physiological impacts on sunflower plants.

Coarse, angular particles can abrade the leaf cuticle and epidermis, while finer particles (<1 µm) may adhere tightly to the leaf surface and obstruct stomatal pores, thereby restricting transpiration and limiting CO₂ exchange. The pronounced surface roughness and high granule density observed in the micrographs further enhance particle adhesion, prolonging the duration of physiological stress on the leaves.

These observations are consistent with reports describing mineral dust behavior in arid environments, where micro- and nano-sized particles reduce leaf surface integrity, impair stomatal function, and promote stress-related

biochemical responses in plants [26,13]. Additionally, the elemental signatures revealed by SEM-EDX and XRF analysis indicate the presence of mineral components capable of influencing nutrient uptake and photosynthetic stability, reinforcing the role of dust as a combined mechanical and chemical stress factor [29].

Together, these characteristics explain the significant influence of storm-derived dust on photosynthetic performance, nutrient acquisition, and the activation of protective secondary metabolites such as phytoalexins in sunflower plants

Heavy Metal Content (AAS)

Comparison of dust before and after the storm showed notable variation (Table 5):

Increased elements: As (+13.4 %), Hg (+104.9 %)

Decreased elements: Cd (-19.6 %), Co (-20.4 %), Cr (-33.6 %), Ni (-41.9 %), Pb (-66.5 %), Sb (-45.6 %)

Table 5. Concentrations of heavy metals (ppm) in dust samples before and after the storm

Heavy Metal	Symbol	Before Storm (Farm)	After Storm (Storm)	Difference (%)
Arsenic	As	7.17	8.13	+13.4
Cadmium	Cd	141.20	113.58	-19.6
Cobalt	Co	16.57	13.19	-20.4
Chromium	Cr	125.22	83.10	-33.6
Mercury	Hg	0.107	0.219	+104.9
Nickel	Ni	131.14	76.14	-41.9
Lead	Pb	453.14	151.86	- 66.5
Antimony	Sb	5.39	2.93	-45.6

. Discussion

The increase in arsenic and mercury suggests anthropogenic contamination transported by the storm, while the decrease in other metals indicates dilution with natural desert-derived

dust. Elevated As and Hg are known to interfere with nutrient absorption and photosynthetic stability, particularly through disruption of Fe/Mg-dependent enzymatic pathways [27,16].

Plant Growth Response

Vegetative Measurements

Ten days after the storm, sunflower plants showed significant reductions compared with controls (Tables 6 to 8):

Parameter	Control (cm) \pm SD	Treated (cm) \pm SD	Reduction (%)
Stem length	0.43 \pm 71.30	0.64 \pm 61.18	% 14.2-
Leaf length	0.15 \pm 13.20	0.19 \pm 10.78	% 18.3-
Leaf width	* 0.25 \pm 22.08	*0.21 \pm 18.22	% 17.5-

Table 6. Average vegetative measurements of the control group.

Plant No.	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)
1	71.2	13.4	22.1
2	70.8	13.0	21.7
3	72.0	13.2	22.5
4	71.5	13.3	21.9
5	71.0	13.1	22.2
Average \pm SD	71.3 \pm 0.43	13.2 \pm 0.15	22.08 \pm

Table 7. Average vegetative measurements of the treated group

Plant No.	Stem Length (cm)	Leaf Length (cm)	Leaf Width (cm)
1	61.5	10.9	18.2
2	60.2	10.5	17.9
3	62.0	11.0	18.5
4	61.0	10.8	18.1
5	61.2	10.7	18.4
Average \pm SD	61.18 \pm 0.64	10.78 \pm 0.19	18.22 \pm

Table 8. Independent-samples t-test comparing control and treated plant.

Variable	Control Mean (cm)	Treated Mean (cm)	Difference (cm)	T-Value	P-Value
Leaf Length	22.08	18.22	3.86	22.360	0.0000
Leaf Width	13.20	10.78	2.42	21.732	0.0000
Stem Length	71.30	61.18	10.12	27.812	0.0000

Discussion

All vegetative traits declined significantly ($P < 0.01$), confirming a strong inhibitory effect of dust deposition on sunflower growth. These reductions are attributed to stomatal blockage, decreased chlorophyll content, mechanical

abrasion of leaf surfaces, and disruption of nutrient assimilation. Comparable physiological constraints under dust exposure were previously described in studies addressing dust-induced stress in arid agricultural environments [23,18,27].

Functional Physiology and Pigments

Dust-exposed leaves exhibited marked reductions in photosynthetic rate, stomatal conductance, and total chlorophyll (a + b) and carotenoids, accompanied by elevated leaf-surface temperature and partial stomatal blockage as confirmed by SEM observations.

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Pathogen Carriage in Dust

SEM observations revealed spore-like particles attached to mineral dust grains, indicating that airborne dust may function as a biological carrier for fungal and bacterial propagules.

Discussion

Sharp-edged mineral particles can create micro-lesions on the leaf epidermis, facilitating microbial colonization. When combined with the ability of dust storms to transport biological particles across long distances, these factors increase the likelihood of infection following storm events. Such interactions between mineral particulates and microbial agents align with dust transport behavior described in semi-arid systems [23,18,20].

Integrated Interpretation

Baseline soil conditions—characterized by loamy sand texture, low organic matter, limited zinc availability, and moderately alkaline pH—already imposed mild physiological constraints on sunflower plants. The dust storm superimposed additional mechanical, chemical, and biological stressors, including abrasive particle deposition, stomatal blockage, trace-metal accumulation, and microbial load. These combined factors contributed to the significant reductions

observed in vegetative growth parameters and pigment concentration.

The integrated physiological response indicates systemic disruption of photosynthesis, water balance, and nutrient uptake. Such stress conditions are known to activate protective biochemical pathways in plants, including antioxidant enzymes and the biosynthesis of defensive secondary metabolites. These mechanisms are consistent with plant responses to dust-induced stress documented in arid environmental conditions [23,18,27].

Conclusions

The results of this study confirm that dust storms constitute a complex environmental stress combining mechanical, chemical, and biological effects that markedly influence the growth and physiology of sunflower plants (*Helianthus annuus* L.). The loamy sand soil used was slightly alkaline and relatively low in organic matter and zinc, predisposing plants to stress. Morphological and chemical analyses showed that the storm-borne dust was heterogeneous in composition, dominated by calcium carbonate, silicates, and sodium sulfate, with traces of arsenic and mercury of partly anthropogenic origin. SEM examination revealed particles (1.4 -- 6.4 μm) of irregular and crystalline forms capable of abrading leaf surfaces and clogging stomata, while some carried microbial-like structures, confirming dust's role as both a physical and biological stressor. Heavy-metal analysis indicated an increase in As and Hg after the storm, whereas Cd, Cr, and Pb declined, reflecting mainly natural desert dust mixed with minor industrial residues. Ten days post-storm, exposed sunflower plants showed significant reductions in stem length, leaf length, and leaf width (14–18%) compared with controls, associated with stomatal blockage, reduced photosynthesis, and epidermal damage. Overall, dust deposition disrupted physiological activity and likely induced

defense responses such as phytoalexin production. The study concludes that dust storms substantially impair sunflower performance and soil quality, emphasizing the

need for adaptive management through tolerant cultivars, balanced fertilization, and the establishment of vegetative barriers to reduce dust impact

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