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Mitigating salinity stress and improving growth and productivity of anise (*Pimpinella anisum* L.) through soil and foliar applications of potassium silicate and potassium humate

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Abstract
Soil salinity is a major abiotic stress limiting the growth, productivity, and quality of medicinal and aromatic plants. This study evaluated the effects of potassium silicate (PS) and potassium humate (PH), applied as soil and foliar treatments, on the growth, yield, mineral composition, biochemical characteristics, and essential oil production of anise (*Pimpinella anisum* L.) grown under saline soil conditions at Farm of Wadi El-Netron El-Bahyra Governorate, Egypt. Located on GPS (30º 42 802 N, 30º 26 316 E), during two successive seasons winter 2024 and winter 2025. Nine treatments, including an untreated control, were arranged in a completely randomized design with three replicates. Potassium silicate was applied at 3 and 5 kg fed^{-1} as soil application and 2 and 4 g L^{-1} as foliar spray, whereas potassium humate was applied at 3 and 5 kg fed^{-1} as soil application and 3 and 5 g L^{-1} as foliar spray every 30 days after planting respectively, until harvest**.** Potassium humate and potassium silicate are widely utilized as soil conditioners, facilitating improved soil structure and increased water retention capacity. Humates have also been employed to supply nutritional to plants deficiency in calcareous. So the incorporation of humic acid enhances various soil nutrient contents, including total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, and organic matter, with the most substantial effects observed in the second year., as a soil conditioner, These results showed that all treatments significantly ($P \leq 0.05$) improved vegetative growth, yield components, leaf and seed N, P, and K contents, antioxidant activity, total carbohydrates, essential oil percentage, and reduced proline and total phenolic contents compared with the control. Soil application was generally more effective than foliar spraying. Potassium silicate at 5 kg fed^{-1} produced the highest values for most measured traits, followed by potassium humate at 5 kg fed^{-1}, whereas foliar application of potassium silicate at 4 g L^{-1} was the best foliar treatment. Overall, potassium silicate was more effective than potassium humate in mitigating salinity stress and improving the productivity and quality of anise under saline soil conditions**.**

Keywords: *Pimpinella anisum* L., potassium silicate, potassium humate, salinity stress, biostimulants, essential oil, nutrient uptake, sustainable agriculture

Introduction
Soil salinity is considered one of the most destructive environmental constraints limiting agricultural productivity and sustainability worldwide, according to the Food and Agriculture Organization, more than 850 million hectares of land are affected by salinity, accounting for approximately 21% of the world's cultivated land and nearly one-third of irrigated agricultural areas (FAO, 2021) [52]. The continuous expansion of salt-affected soils, resulting from climate change, inappropriate irrigation practices, seawater intrusion, and poor soil management, has become a serious challenge to global food security (Hopmans *et al.*, 2021) [24]. Excessive accumulation of soluble salts, particularly sodium (Na^+) and chloride (Cl^-) ions, adversely affects soil physicochemical properties, reduces nutrient availability, and significantly limits crop growth and productivity (Zaman *et al.*, 2018) [54]. Consequently, improving crop performance under saline conditions has become a major objective of modern sustainable agriculture (Munns and Tester, 2008[39]*)*

Salinity affects plant growth through a complex combination of osmotic, ionic, and oxidative stresses. Initially, high salt concentrations decrease soil water potential, thereby restricting water absorption by roots and inducing physiological drought (Munns and Gilliham, 2015) [38]. Subsequently, excessive accumulation of Na^+ and Cl^- ions disrupts cellular ion homeostasis and competes with essential nutrients such as potassium and calcium, resulting in nutritional imbalance and impaired metabolic activities (Parihar *et al.*, 2015) [43]. Salt stress also suppresses chlorophyll biosynthesis, decreases photosynthetic efficiency, and accelerates membrane deterioration through lipid peroxidation (Hasanuzzaman *et al.*, 2021) [28]. Furthermore, salinity promotes the excessive generation of reactive oxygen species (ROS), including superoxide radicals (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH), which cause oxidative damage to proteins, nucleic acids, membrane lipids, and cellular organelles (Gill and Tuteja, 2010) [25]. To survive under saline environments, plants activate several adaptive mechanisms, including the accumulation of compatible osmolytes such as proline, soluble sugars, and glycine betaine, together with the activation of enzymatic and non-enzymatic antioxidant defense systems that maintain cellular redox homeostasis (Hasanuzzaman *et al.*, 2021[28]*)*

The growing demand for sustainable agricultural production has encouraged the development of environmentally friendly alternatives capable of improving crop productivity while minimizing the excessive use of chemical fertilizers. In this context, plant biostimulants have emerged as promising tools for enhancing plant growth, nutrient utilization, and tolerance to environmental stresses without causing adverse ecological impacts (du Jardin, 2015) [17]. Unlike conventional fertilizers, biostimulants primarily stimulate plant physiological processes that improve nutrient use efficiency, enhance metabolic activity, strengthen stress tolerance, and ultimately increase crop productivity (Calvo *et al.*, 2014) [12]. Recent studies have demonstrated that biostimulants improve photosynthetic performance, stimulate root development, enhance nutrient uptake, and activate antioxidant defense mechanisms under adverse environmental conditions (Rouphael and Colla, 2020) [46]. Consequently, the application of plant biostimulants has become an essential component of sustainable agricultural practices, particularly in salt-affected soils where crop productivity is severely restricted.

The application of humic acid and potassium silicate has led to a significant improvement in saline soils, evidenced by a reduction in electrical conductivity, a decrease in water-soluble Na+ content, and a notable decline in the Sodium Adsorption Ratio (SAR). Furthermore, the application of humic acid has resulted in a moderate enhancement of soluble organic nitrogen content within the soil. Additionally, the levels of available phosphorus in the soil can be markedly increased by 18.7% to 101.5% through the application of humic acid. Commercial humates, particularly potassium humate, are widely utilized as soil conditioners, facilitating improved soil structure and increased water retention capacity (Karčauskienė *et al.*, 2019) [33]. Humates have also been employed to supply nutritional to plants deficiency in calcareous soils (Cieschi *et al.*, 2019). Li *et al.* (2019) [15, 22] demonstrated that the incorporation of humic acid enhances various soil nutrient contents, including total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, and organic matter, with the most substantial effects observed in the third year. As a soil conditioner, humic acid is capable of altering the ionic composition of the soil (Abe *et al.*, 2011) [1], fostering the development of soil aggregates (Chen *et al.*, 2022) [14], enhancing soil permeability (Khaled and Fawy, 2011) [34], and expediting the leaching and irrigation processes of surface salts and alkalis in the soil (Zhao *et al.*, 2019) [35].

Potassium silicate fertilizer is a slow-acting fertilizer that is hardly soluble in water, application of potassium silicate fertilizer is beneficial to the growth (Fan, *et al.*, 2019) [22] and development of plant roots and can improve the ability of plants to resist pests and diseases (Zhao *et al.*, 2019) [35]. Acidic ions in traditional potash can cause acidification in the soil. Potassium silicate fertilizer does not contain acid ions that cause acidification of the soil and can act to improve acidic soil (Goulding, 2016) [26].

Potassium silicate (PS) has attracted considerable attention as one of the most effective silicon-containing biostimulants for improving plant growth and stress tolerance. Although silicon is not considered an essential nutrient for higher plants, numerous studies have demonstrated its beneficial effects in enhancing plant resistance against both biotic and abiotic stresses, particularly salinity (Coskun *et al.*, 2016) [16]. Silicon deposition in plant tissues improves cell wall rigidity, maintains membrane integrity, reduces sodium uptake while enhancing potassium acquisition, and improves water-use efficiency (Luyckx *et al.*, 2017) [36]. Moreover, potassium silicate stimulates antioxidant enzyme activities, preserves chloroplast ultrastructure, enhances photosynthetic efficiency, and reduces oxidative damage caused by excessive reactive oxygen species (ROS) under saline conditions (Bose *et al.*, 2026) [10]. In addition to supplying soluble silicon, potassium silicate provides potassium, an essential macronutrient involved in enzyme activation, stomatal regulation, osmotic adjustment, and carbohydrate translocation, thereby further contributing to improved plant growth and productivity under salt stress (Wang *et al.*, 2021) [52]

Potassium humate (PH), a potassium salt of humic substances, has also been widely recognized as an effective natural biostimulant that enhances soil fertility and plant performance under unfavorable environmental conditions. Humic substances improve soil structure, increase cation exchange capacity, stimulate beneficial microbial activity, and enhance nutrient availability and uptake (Salehi *et al.*, 2026) [47]. Furthermore, potassium humate promotes root growth, increases chlorophyll synthesis, improves photosynthetic capacity, and activates antioxidant defense systems, thereby mitigating the adverse effects of salinity-induced oxidative stress (Rouphael and Colla, 2020) [46]. Several recent studies have reported that potassium humate enhances nutrient accumulation, water relations, osmotic adjustment, and overall crop productivity under saline conditions through its positive effects on both soil properties and plant physiological processes (Nardi *et al.*, 2016[40]*)*.

Anise (*Pimpinella anisum* L.), a member of the Apiaceae family, is one of the most economically important medicinal and aromatic plants cultivated worldwide. Its seeds contain considerable amounts of essential oil, primarily trans-anethole, which is extensively utilized in pharmaceutical, food, cosmetic, and flavoring industries due to its antimicrobial, antioxidant, anti-inflammatory, digestive, and carminative properties (Asad *et al.*, 2022) [8]. Despite its high economic value, anise is considered moderately sensitive to soil salinity, which adversely affects vegetative growth, nutrient uptake, essential oil biosynthesis, and seed yield. Therefore, developing effective agronomic strategies to alleviate salinity stress is essential for improving the productivity and quality of anise under salt-affected soils (Agrawal *et al.*, 2023[48]*)*.

Although numerous studies have investigated the individual effects of silicon- or humic acid-based biostimulants on different crops, limited information is available regarding the comparative effectiveness of potassium silicate and potassium humate applied through both soil and foliar application under saline soil conditions. Furthermore, little attention has been paid to their influence on nutrient accumulation, biochemical constituents, antioxidant activity, essential oil production, and yield performance of anise plants grown under salt stress.

Therefore, the present study was conducted to evaluate the effectiveness of potassium silicate and potassium humate applied as soil amendments and foliar sprays at different concentrations in improving vegetative growth, mineral nutrition, biochemical characteristics, essential oil percentage, and seed yield of anise (*Pimpinella anisum* L.) cultivated under saline soil conditions. The findings of this study are expected to provide sustainable agronomic approaches for enhancing the productivity and quality of medicinal and aromatic plants grown in salt-affected environments.

Materials and Methods

1. Experimental Site

Two field experiments were conducted during the period of winter of 2024 and 2025 growing seasons at the experimental farm of Wadi El-Netron, Elbahyra Governorate, Egypt. Located on GPS (30º 42 802 N, 30º 26 316 E) to investigate the effects of potassium silicate and potassium humate on the growth, productivity, mineral nutrition, biochemical characteristics, and essential oil production of anise (*Pimpinella anisum* L.) grown under saline soil conditions. The experimental soil was naturally saline. Representative soil samples (0–30 cm depth) were collected before sowing, air-dried, sieved through a 2-mm mesh, and analyzed according to standard procedures. The physical and chemical properties of the experimental soil are presented in (Table 1), was analyzed at central lab of Soil, Water and Environment Research Institute, Agricultural research center (ARC), Giza, Egypt.

Table 1: Analysis of physo-chemical properties of experiment soil during two growing seasons

Physical properties	2024	2025
Particle size distribution		
Coarse sand%	12.28	12.48
Fine sand%	42.16	42.00
Silt%	23.16	23.31
Clay%	22.40	22.21
Texture	Sandy clay loam	Sandy clay loam
Chemical analysis		
pH	7.88	7.92
EC dSm^{-1}	6.45	6.30
Organic matter (O.M %)	1.93	1.98
CaCO3 mg kg-1	126.81	126.89
Available N $g\ kg^{-1}$	28.220	29.790
Available P $mg\ kg^{-1}$	2.351	2.410
Available K $mg\ kg^{-1}$	189.450	198.674
Cations ($mmol/L^{-1}$)		
K^+	16.99	17.20
Na^+	24.25	23.90
Mg^{2+}	2.13	2.16
$Ca2^+$	21.40	21.45
Anions ($mmol/L^{-1}$)		
$SO4^{-2}$	18.42	18.45
Cl^-	18.40	18.00
HCO^{3-}	27.89	27.92

2. Plant Materials

Certified seeds of anise (*Pimpinella anisum* L.) were obtained from the Medicinal and Aromatic Plants Research Department, Agricultural Research Center (ARC), Giza, Egypt. Seeds were sown directly in the experimental field according to the recommended agricultural practices for anise cultivation under Egyptian conditions.

3. Experimental Design and Treatments

The experiment was arranged in a Completely Randomized Design (CRD) with three replicates. A total of nine treatments were evaluated, including one untreated control.

Soil application

T1: Control (without potassium silicate or potassium humate)
T2: Potassium silicate at 3 kg fed^{-1}
T3: Potassium silicate at 5 kg fed^{-1}
T4: Potassium humate at 3 kg fed^{-1}
T5: Potassium humate at 5 kg fed^{-1}

Foliar application

T6: Potassium silicate at 2 g L^{-1}
T7: Potassium silicate at 4 g L^{-1}
T8: Potassium humate at 3 g L^{-1}
T9: Potassium humate at 5 g L^{-1}

Soil and foliar applications were performed every 30 days from the early vegetative stage until harvest. Potassium silicate and potassium humate were applied separately according to the designated treatment schedule, whereas all other agricultural practices were carried out uniformly for all experimental plots following the recommendations of the Egyptian Ministry of Agriculture.

4. Potassium Silicate and Potassium Humate

Commercial potassium silicate and potassium humate products were used in the present investigation according to the manufacturer's recommendations. Potassium silicate was applied either as a soil amendment (3 and 5 kg fed^{-1}) or as a foliar spray (2 and 4 g L^{-1}). Potassium humate was also applied either through soil application (3 and 5 kg fed^{-1}) or foliar spraying (3 or 5 g L^{-1}). Fresh solutions were prepared immediately before each application using tap water, and foliar spraying was carried out until complete leaf wetting during the early morning hours to maximize absorption and minimize evaporation losses.

5. Vegetative Growth Measurements

Vegetative growth parameters were recorded at 80 days after sowing and at harvest during both experimental seasons. Five randomly selected plants were taken from each experimental plot for the determination of plant height (cm), number of branches per plant, fresh weight (g $plant^{-1}$), and dry weight (g $plant^{-1}$). Dry weight was determined after drying the plant samples in a forced-air oven at 70 ± 2°C until constant weight was achieved (AOAC, 2019) [15].

6. Yield and Yield Components

At physiological maturity, plants from each experimental plot were harvested to determine yield and its components. The following parameters were recorded: number of umbels per plant, 1000-seed weight (g), seed yield per plant (g), biological yield (g $plant^{-1}$), and seed yield per feddan (kg fed^{-1}). Seed moisture content was adjusted before weighing to ensure consistency among treatments (AOAC, 2019)

7. Determination of Mineral Contents

Fresh and oven-dried leaf samples, as well as seed samples, were ground into a fine powder and subjected to wet digestion using a sulfuric acid–hydrogen peroxide digestion procedure according to Parkinson and Allen (1975) [44].

Nitrogen determination

Total nitrogen (N_2) was determined using the modified Kjeldahl method according to AOAC (2019). Nitrogen percentage was calculated based on the amount of ammonia recovered after distillation and titration.

Phosphorus determination

Phosphorus (P) concentration was determined spectrophotometrically (Jenway 6648 uv/vis) by the method described of Jackson, (1973) [32].

Potassium determination

Potassium (K) concentration was determined using a Flame Photometer (Jenway PFP7, Bibby Scientific Ltd., UK) following wet acid digestion according to **AOAC (2019*).***

Nitrite, Ammonium, iron, manganese and zinc determination

NO^{3-} and NH^{4+} determined according to Markus *et al*. (1985) [37]. While, Fe, Mn, and Zn were extracted by DTPA according to method described by Soltanpour and Schwab (1977) [50] and were determined by using an atomic absorption spectro-photometer model nova AA 460 analytikjena.

8. Determination of Biochemical Constituents

Total carbohydrates

Total carbohydrate content was determined according to the phenol–sulfuric acid method described by Dubois *et al*. (1956) [18]. Absorbance was measured using a UV–Visible spectrophotometer at 490 nm, and carbohydrate concentration was expressed as mg g^{-1} dry weight.

Total phenolic content

Total phenolic compounds were determined using the Folin–Ciocalteu reagent according to Singleton *et al*. (2004) [49]. Absorbance was measured at 765 nm, and the results were expressed as mg gallic acid equivalents (GAE) g^{-1} dry weight.

Proline content

Free proline concentration was determined following the acid ninhydrin method of Bates *et al*. (1973) [9]. Absorbance was measured at 520 nm, and proline concentration was expressed as mg g^{-1} fresh weight.

Antioxidant activity

Total antioxidant activity was determined using 2,2-diphenyl-1-picrylhydrazyl (DPPH) as reagent according to Brand-Williams *et al.* (1995) [11]. The antioxidant activity was expressed as percentage inhibition of DPPH radicals.

9. Essential Oil Percentage

Essential oil was extracted from mature anise seeds by hydrodistillation for three hours using a Clevenger-type apparatus according to the procedures described by Helrich (1990) [30]. The extracted oil was separated, dried over anhydrous sodium sulfate, and the oil percentage was calculated on a dry weight basis (V/W*).*

10. Statistical Analysis

The obtained data from both growing seasons were subjected to analysis of variance (ANOVA) using SPSS software version 23.0 (IBM Corp., Armonk, NY, USA). The experiment was designed using completely randomized design (CRD) with three replicates. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$) according to Artimage and Berry (1987) [7].

Results

1. **Effect of soil and foliar Application of Potassium Silicate and Potassium Humate on Vegetative Growth and Yield Components of Anise Plants during two growing seasons**

The results reported in Table (2 and 3) demonstrated that applied of potassium silicate and potassium humate as soil and foliar treatments were considerably ($P \leq 0.05$) improved all vegetative growth and yield parameters of anise plants compared with the untreated control during the first growing season. In general, the response increased with increasing application rate, and potassium silicate was consistently more effective than potassium humate.

Soil application

Soil application produced the greatest improvements in all measured traits. Potassium silicate applied at 5 kg fed^{-1} was the most effective treatment, increasing plant height by 56.0% at 80 DAS and 41.3% at harvest compared with the control. The number of branches per plant increased by 116.7%, while the number of umbels per plant increased by 51.7%. Seed yield per plant and 1000-seed weight also increased markedly by 46.2% and 72.2%, respectively. Potassium humate applied at 5 kg fed^{-1} ranked second, recording increases of 36.9% and 29.1% in plant height at 80 DAS and harvest, respectively, 77.8% in branch number, 35.2% in umbels per plant, 35.5% in seed yield per plant, and 44.4% in 1000-seed weight compared with the untreated control. The lower application rates of both potassium silicate and potassium humate also significantly improved all vegetative and yield characteristics, although their effects were lower than those obtained with the higher rates. A similar trend was observed in second season.

Foliar application

Foliar spraying also significantly enhanced vegetative growth and yield components relative to the untreated plants, but its effect was generally lower than that of soil application. Foliar application of potassium silicate at 4 g L^{-1} produced the highest values among the foliar treatments, increasing plant height by 21.4% at 80 DAS and 31.4% at harvest. Moreover, the number of branches per plant increased by 72.2%, the number of umbels per plant by 41.8%, seed yield per plant by 19.2%, and 1000-seed weight by 72.2% compared with the control. Potassium humate at 5 g L^{-1} ranked second, recording increases of 11.9% and 27.0% in plant height at 80 DAS and harvest, respectively, 44.4% in branch number, 23.8% in umbels per plant, 19.7% in seed yield per plant, and 38.9% in 1000-seed weight. Overall, soil application, particularly potassium silicate at 5 kg fed^{-1}, proved to be the most effective treatment for promoting vegetative growth and improving yield components of anise under saline soil conditions. A similar trend was observed in second season.

While, foliar application of potassium silicate was more effective than potassium humate at comparable application rates, while the higher concentrations consistently outperformed the lower concentrations in both growing seasons. Untreated plants recorded the lowest values for all measured parameters.

A comparison between the two application methods indicated that soil application generally resulted in greater improvements than foliar spraying, particularly at the higher application rates, suggesting that root application enhanced nutrient availability and utilization more efficiently under saline soil conditions.

Table 2: Effect of different rates of potassium silicate and potassium humate on some vegetative growth parameters of anise plants during 2024 [4] season.

Treatments	Plant height at 80 DAS	Plant height at harvest	No. of branches/plant	No. of umbels/plant	Seed per plant (g)	Weight of 1000 seeds (g)
Soil application						
Control	25.2e	56.4d	3.6d	26.1e	23.4d	1.9d
Potassium silicate 3kg/fed	35.0c	74.8c	6.7c	33.4c	29.1c	2.6c
Potassium silicate 5kg/fed	39.3a	79.7a	7.8a	39.6a	34.2a	3.3a
Potassium humate 3kg/fed	31.3d	69.8c	5.1c	31.5d	28.6c	2.1c
Potassium humate 5kg/fed	34.5b	72.8b	6.4b	35.3b	31.7b	2.8b
LSD (5%)	0.949	0.384	0.448	0.566	0.986	0.304
Foliar application						
Control	25.2d	56.4d	3.6d	26.1d	23.4d	1.9d
Potassium silicate 2 g/l	27.0c	69.2c	4.7c	31.4c	25.4c	2.2c
Potassium silicate 4 g/l	30.6a	74.1a	6. 2a	37a	27.9a	2.9a
Potassium humate 3 g/l	25.0d	68.3c	3.9d	30.1d	24.7c	2.1c
Potassium humate 5 g/l	28.2b	71.6b	5.2b	32.3b	28a	2.7b
LSD (5%)	1.8	0.45	0.53	1.09	1.01	0.335

Table 3: Effect of different rates of potassium silicate and potassium humate on some vegetative growth parameters of anise plants during 2025 season.

Treatments	Plant height at 80 DAS	Plant height at harvest	No. of branches/plant	No. of umbels/plant	Seed per plant (g)	Weight of 1000 seeds (g)
Soil application						
Control	26.8e	58.1e	3.8e	27.2e	24.6d	2.2d
Potassium silicate 3kg/fed	36.6b	75.4b	7.2b	34.8c	30.2b	2.9b
Potassium silicate 5kg/fed	39.2a	80.3a	8.3a	40.5a	34a	3.5a
Potassium humate 3kg/fed	30.4d	69.1d	5d	32.3d	29.7b	2.3d
Potassium humate 5kg/fed	34c	71.9c	6.3c	36.1b	32.3ab	2.9b
LSD (5%)	0.91	0.725	0.931	0.671	1.29	0.304
Foliar application						
Control	26.8d	58.1d	3.8d	27.2d	24.6d	2.2d
Potassium silicate 2 g/l	27.4c	69.9c	4.5c	32.4c	26.3c	2.5c
Potassium silicate 4 g/l	30.9a	74.8a	6. 6a	38.2a	28.1a	3.1a
Potassium humate 3 g/l	26.1d	69.2c	4.2c	30.9c	25.7cd	2.3d
Potassium humate 5 g/l	28.5b	72b	4.9b	33.4b	26.3bc	2.8b
LSD (5%)	0.87	0.84	0.68	0.61	1.22	0.29

2. Effect of Potassium Silicate and Potassium Humate on Nitrogen, Phosphorus and Potassium Contents in Fresh and Dry Leaves of Anise Plants during two growing seasons

The application of potassium silicate and potassium humate significantly ($P \leq 0.05$) improved the nitrogen (N_2), phosphorus (P), and potassium (K) contents of both fresh and dry leaves compared with the untreated control during the two experimental seasons (Tables 4 and 5). The extent of improvement depended on the application method, compound type, and applied concentration.

Soil application

During the first season, soil application of potassium silicate at 5 kg fed^{-1} was the most effective treatment, recording the highest concentrations of all determined mineral nutrients. Relative to the untreated control, nitrogen content recorded 3.5% and 4.3% in fresh and dry leaves, respectively, while phosphorus content recorded 2.6% in fresh leaves and 3.4% in dry leaves. Potassium concentration also increased 274.4 and 303.1 $mg.kg^{-1}$ in fresh leaves and dry leaves. Potassium humate applied at 5 kg fed^{-1} ranked second, whereas the untreated plants consistently exhibited the lowest nutrient concentrations. Similar improvements were obtained with the lower application rates, although their effects were less pronounced than those achieved by the higher rates.

A similar pattern was observed throughout the second season. Potassium silicate at 5 kg fed^{-1} remained the superior treatment, increasing nitrogen content at 3.8% and 4.1% in fresh and dry leaves, respectively. Phosphorus concentration increased at 2.4% and 3.3% in fresh leaves and dry leaves, while potassium content also increased 277.6 and 312.3 $mg.kg^{-1}$ fresh leaves and dry leaves , respectively, compared with the untreated control. Potassium humate at 5 kg fed^{-1} produced the second-highest values for most measured nutrients, confirming the

Foliar application

Also, foliar spraying significantly enhanced leaf mineral composition in both seasons. During the first season, foliar application of potassium silicate at 4 g L^{-1} resulted in the highest nutrient concentrations, increasing nitrogen content by 3.5% in fresh leaves and 4.5% in dry leaves compared with the control. Phosphorus content recorded 2.3% and 3.2% in fresh and dry leaves, whereas potassium concentration 268.7 and 294.7 $mg.kg^{-1}$ in fresh and dry leaves, respectively. Potassium humate at 5 g L^{-1} ranked second for most mineral constituents, while untreated plants recorded the lowest values.

The same pattern was maintained during the second season, where foliar application of potassium silicate at 4 g L^{-1} produced the highest concentrations of N, P, and K. Compared with untreated plants, nitrogen recorded 3.7% in fresh leaves and 4.2% in dry leaves, while, phosphorus 2.7% and 3.6%, as well as, potassium concentration270.7 and 301.7 $mg.kg^{-1}$ in fresh and dry leaves, respectively. Potassium humate at 5 g L^{-1} ranked second, whereas lower application rates produced moderate but statistically significant improvements over the untreated control. Overall, soil application generally resulted in slightly greater nutrient accumulation than foliar spraying, particularly for dry leaf mineral contents, indicating more efficient nutrient uptake under saline soil conditions.

Table 4: Effect of different rates of potassium silicate and potassium humate on macronutrients content of anise plants during 2024 [4] season

Treatments	N %	P%	K $mg.kg^{-1}$	N %	P%	K $mg.kg^{-1}$
	Fresh leaves			Dry leaves		
Soil application						
Control	2.47d	1.19e	225.6c	3.1d	1.9d	251.4d
Potassium silicate 3kg/fed	3b	2.4b	268.3a	3.8b	3b	295.3ab
Potassium silicate 5kg/fed	3.5a	2.6a	274.4a	4.3a	3.4a	303.1a
Potassium humate 3kg/fed	2.8c	1.9d	259.6b	3.5c	2.6c	286.4c
Potassium humate 5kg/fed	3.1b	2.1c	267.9b	3.9b	2.8d	290.7bc
LSD (5%)	0.22	0.09	9.6	0.28	0.18	10.5
Foliar application						
Control	2.47e	1.19d	225.6c	3.1d	1.9d	251.4d
Potassium silicate 2 g/l	3.2c	2b	261.4a	4.1b	2.8b	287.6b
Potassium silicate 4 g/l	3.5a	2.3a	268.7a	4.5a	3.2a	294.7a
Potassium humate 3 g/l	3d	1.8c	249.4b	3.6c	2.5c	275.6c
Potassium humate 5 g/l	3.3b	2.1b	254.2b	4.1b	2.8b	282.3bc
LSD (5%)	0.14	0.15	8.9	0.27	0.29	10.1

Table 5: Effect of different rates of potassium silicate and potassium humate on macronutrients content of anise plants during 2025 season

Treatments	N %	P%	K $mg.kg^{-1}$	N %	P%	K $mg.kg^{-1}$
	Fresh leaves			Dry leaves		
Soil Application						
Control	2.6d	1.5e	234.4c	2.8d	1.7c	261.7d
Potassium silicate 3kg/fed	3.3b	2.6b	271.2a	3.5b	3.1a	297.1ab
Potassium silicate 5kg/fed	3.8a	2.4a	277.6a	4.1a	3.3a	312.3a
Potassium humate 3kg/fed	2.9c	2.1d	268.1a	3.2c	2.8b	291.4b
Potassium humate 5kg/fed	3.4b	2.3c	256b	3.8b	3.2a	278.6c
LSD (5%)	0.26	0.09	9.6	0.28	0.18	10.1
Foliar Application						
Control	2.6e	1.5d	234.4c	2.8d	1.7d	261.7d
Potassium silicate 2 g/l	3.1d	2.4b	273.6a	4b	3.3b	297.6ab
Potassium silicate 4 g/l	3.7a	2.7a	270.7a	4.2a	3.6a	301.7a
Potassium humate 3 g/l	3.3c	2d	265.3b	3.7c	2.6d	285.4c
Potassium humate 5 g/l	3.5b	2.2c	269.2b	3.8b	2.9c	289.3bc
LSD (5%)	0.18	0.19	9.4	0.29	0.32	10.4

3. Effect of Potassium Silicate and Potassium Humate on Biochemical Constituents and Essential Oil Percentage of Anise Plants during two growing seasons

The application of potassium silicate and potassium humate significantly ($P \leq 0.05$) affected the biochemical constituents and essential oil percentage of anise plants during both growing seasons (Tables 6 and 7). Both soil and foliar applications enhanced antioxidant activity, total carbohydrates, and essential oil percentage, while reducing total phenols and proline contents compared with the untreated control. The magnitude of the response varied according to the applied compound, concentration, and application method.

Soil application

During the first season, soil application of potassium silicate at 5 kg fed^{-1} produced the greatest improvement in all biochemical parameters. Compared with the untreated control, antioxidant activity increased by 46.5%, total carbohydrates increased by 112.5%, while, essential oil percentage increased by 50.0%. In contrast, total phenols and proline contents decreased by 40.8% and 37.2%, respectively. Potassium humate applied at 5 kg fed^{-1} ranked second, recording increases of 37.2% in antioxidant activity, 95.8% in total carbohydrates, and 27.8% in essential oil percentage, accompanied by reductions of 39.1% in total phenols and 33.0% in proline content. Similar trends were recorded with the lower application rates; however, their effects were less pronounced than those observed at the higher rates.

A comparable response was obtained during the second season, where potassium silicate at 5 kg fed^{-1} remained the most effective treatment. Relative to the untreated control, antioxidant activity increased by 46.8%, total carbohydrates by 96.3%, and essential oil percentage by 47.4%, whereas total phenols and proline contents decreased by 44.4% and 38.2%, respectively. Potassium humate at 5 kg fed^{-1} again ranked second, confirming the consistency of treatment performance across both experimental seasons.

Foliar application

Foliar spraying with potassium silicate and potassium humate also significantly improved the biochemical composition of anise plants in both seasons. During the first season, potassium silicate applied at 4 g L^{-1} was the most effective foliar treatment, increasing antioxidant activity by 40.0%, total carbohydrates by 100.0%, and essential oil percentage by 38.9% compared with the untreated control. Meanwhile, total phenols and proline contents declined by 41.8% and 32.1%, respectively. Potassium humate at 5 g L^{-1} ranked second, whereas the lower concentrations produced moderate but significant improvements over the untreated plants.

Table 6: Effect of different rates of potassium silicate and potassium humate on some chemical composition of seeds anise plants during 2024 [4] season

Treatments	Antioxidants (%)	Total Phenols (mg/100 g.d.w)	Carbohydrates (mg/100 g.d.w)	Proline (mg/g.d.w)	Oil %
Soil Application					
Control	50.8d	29.4a	2.4c	145.3a	1.8d
Potassium silicate 3kg/fed	69.2b	18.1c	4.4b	102.1c	2.1c
Potassium silicate 5kg/fed	74.4a	17.4d	5.1a	91.3e	2.7a
Potassium humate 3kg/fed	67.4c	20.2b	3.9b	104.8b	1.9d
Potassium humate 5kg/fed	69.7b	17.9d	4.7b	97.4d	2.3b
LSD (5%)	1.4	1.6	0.97	2.4	0.3
Foilar Application					
Control	50.8d	29.4a	2.4c	145.3a	1.8d
Potassium silicate 2 g/l	67.7b	19.5b	4.1ab	110.3c	2c
Potassium silicate 4 g/l	71.1a	17.1c	4.8a	98.6e	2.5a
Potassium humate 3 g/l	64c	19.9b	3.7b	113.8b	1.9d
Potassium humate 5 g/l	68.6b	17.6c	4.4ab	102.4d	2.2b
LSD (5%)	1.1	1.5	0.89	2.7	0.37

The same trend was maintained during the second season, with foliar application of potassium silicate at 4 g L^{-1} producing the highest antioxidant activity, carbohydrate accumulation, and essential oil percentage, while simultaneously recording the lowest total phenol and proline contents. Compared with the untreated control, antioxidant activity increased by 38.7%, total carbohydrates by 70.4%, as well as, essential oil percentage increased by 31.6%, whereas total phenols and proline contents decreased by 42.4% and 35.2%, respectively. Potassium humate at 5 g L^{-1} remained the second most effective treatment for most measured biochemical parameters. Overall, soil application generally resulted in greater biochemical improvements than foliar spraying, particularly at the higher application rates of potassium silicate, indicating superior physiological performance and enhanced tolerance to saline soil conditions.

Table 7: Effect of different rates of potassium silicate and potassium humate on some chemical composition of seeds anise plants during 2025 season

Treatments	Antioxidants (%)	Total Phenols (mg/100 g.d.w)	Carbohydrates (mg/100 g.d.w)	Proline (mg/g.d.w)	Oil %
Soil Application					
Control	51.9d	30.2a	2.7c	149.3a	1.9d
Potassium silicate 3kg/fed	68.4c	18.6b	4.2b	105.3b	2.2c
Potassium silicate 5kg/fed	76.2a	16.8dc	5.3a	92.3d	2.8a
Potassium humate 3kg/fed	69.4c	19.8b	4b	106.4b	1.8d
Potassium humate 5kg/fed	71.7b	18.4b	4.5b	97.7c	2.4b
LSD (5%)	1.5	1.7	0.87	2.8	0.38
Foilar Application					
Control	51.9e	30.2a	2.7b	149.3a	1.9c
Potassium silicate 2g/l	67.7c	19.1b	4.3a	106.4c	2.1b
Potassium silicate 4g/l	72a	17.4c	4.6a	96.7e	2.5a
Potassium humate 3g/l	64.5d	19.6b	3.5a	112.8b	1.8c
Potassium humate 5g/l	69.4b	17.9c	4.6a	103.1d	2.1b
LSD (5%)	1.4	1.5	0.85	2.8	0.39

4. Effect of Potassium Silicate and Potassium Humate on Nitrogen, Phosphorus and Potassium Contents of Anise Seeds during two growing seasons

The results presented in Table 8 revealed that both potassium silicate and potassium humate significantly ($P \leq 0.05$) enhanced the nitrogen (N_2), phosphorus (P), and potassium (K) contents of anise seeds during both growing seasons compared with the untreated control. The response was concentration-dependent, with the higher application rates consistently producing greater improvements than the lower rates.

Soil application

During the first season, soil application of potassium silicate at 5 kg fed^{-1} produced the highest seed mineral contents. Compared with the untreated control, seed nitrogen increased by 90.5%, phosphorus by 94.4%, and potassium by 54.8%. Potassium humate applied at 5 kg fed^{-1} ranked second, recording increases of 61.9%, 72.2%, and 35.5% in N, P, and K contents, respectively. Although the lower application rates of both compounds significantly improved seed mineral composition compared with the control, their effects remained lower than those achieved by the higher application rates. A similar trend was observed during the second season, where potassium silicate at 5 kg fed^{-1} remained the superior treatment, increasing seed nitrogen, phosphorus, and potassium contents by 86.4%, 85.0%, and 51.5%, respectively, relative to the untreated control. Potassium humate at 5 kg fed^{-1} again ranked second, confirming the consistency of treatment performance across both growing seasons.

Foliar application

Foliar spraying also significantly enhanced seed mineral composition compared with the untreated plants. During the first season, potassium silicate applied at 4 g L^{-1} produced the greatest increases in seed N, P, and K contents, exceeding the control by 85.7%, 77.8%, and 38.7%, respectively. Potassium humate at 5 g L^{-1} ranked second, with corresponding increases of 61.9%, 61.1%, and 29.0%, respectively. Lower application rates produced moderate but significant improvements over the control treatment. The same trend persisted during the second season, where foliar application of potassium silicate at 4 g L^{-1} resulted in the highest seed nutrient concentrations, increasing nitrogen by 68.2%, phosphorus by 65.0%, and potassium by 24.2% compared with the untreated control. Potassium humate at 5 g L^{-1} remained the second most effective treatment, while untreated plants consistently recorded the lowest values for all measured nutrients. Overall, soil application was generally more effective than foliar spraying in enhancing seed mineral accumulation, particularly at the higher application rates of potassium silicate.

Table 8: Effect of different rates of potassium silicate and potassium humate on NPK Contents of Anise Seeds at two growing seasons 2024 [4] and 2025

Treatments	N %	P %	K ($mg.kg^{-1}$)	N %	P %	K ($mg.kg^{-1}$)
	2024			2025		
Soil Application						
Control	0.21c	0.18d	0.31d	0.22d	0.2d	0.33d
Potassium silicate 3kg/fed	0.36b	0.26c	0.41b	0.35b	0.25c	0.43b
Potassium silicate 5kg/fed	0.4a	0.35a	0.48a	0.41a	0.37a	0.5a
Potassium humate 3kg/fed	0.32b	0.25c	0.39c	0.31c	0.27bc	0.4c
Potassium humate 5kg/fed	0.34b	0.31b	0.42b	0.33b	0.29b	0.44b
LSD (5%)	0.021	0.02	0.05	0.03	0.02	0.02
Foilar Apllication						
Control	0.21d	0.18d	0.31b	0.22c	0.2c	0.33d
Potassium silicate 2g/l	0.34b	0.24c	0.39a	0.32b	0.26b	0.37bc
Potassium silicate 4g/l	0.39a	0.32a	0.43a	0.37a	0.33a	0.41a
Potassium humate 3g/l	0.31c	0.24c	0.37a	0.32b	0.25b	0.36c
Potassium humate 5g/l	0.34b	0.29b	0.4a	0.34b	0.31a	0.39ab
LSD (5%)	0.02	0.04	0.06	0.03	0.02	0.02

5. Soil properties after harvest

Results present in Table (9) show that the decrease of soil pH and soil salinity in soil treated with Potassium silicate application at 5 kg/fed and increase of available N, P , K and Fe, Mn and Zn contents in soil applied of potassium silicate than other treatments. These results are in agreement by Niel *et al*. (2026) [41] reported that the soil pH tends to slightly decrease with increasing the rates of potassium silicate. Ahmed et al. (2024) [4] indicated that the potassium silicate was improving the soil structure by replacing Na on exchange sites and turn soil structure to flocculate. In this way drainage of soils improved and leaching of salts becomes possible. Al-Toobi *et al*. (2023) [5] indicated that EC (dSm-1) soil decreased as affected by the application of silicate on saline soil. As well as, Nile *et al*. (2026) [41] suggested that the application of silicate sources has a significant positive effect on the availability of macro- and micronutrients in the soil.

All treatments recorded no significant impacts on either soil EC or pH immediately after plant harvest. These results suggest that the modes of actions of the used additives were to enhance plants' ability to cope with stress conditions rather than directly improving the characteristics of the salt affected soil. These additives raised considerably nutrient availability in soil, including NH^{4+}, NO^{3-}, P, K, Fe, Mn, and Zn as well as soil organic matter. These increases were more obvious when the materials were applied in either or both application type of the soil organism and organic materials K-silicate demonstrating greater effectiveness compared to K-humate. These K-salts enhance the accumulation of active ingredients in plants, especially antioxidants, which help plants to cope with abiotic conditions (El-Attar *et al.*, 2023) [20]. This may enhance physiological activities via increasing the release of root exudates (Xu *et al.*, 2021) [52], thereby increase nutrient availability (Fauzan *et al.*, 2025) [23]. Additionally, the activities of soil biota, that increase nutrient availability (tantriani *et al.*, 2020) [51], while K-humate in the rhizosphere, increase nutrient availability in soil (El-Atrony *et al.*, 2025) [19].

Table 9: Properties of the salt affected soil by the end of the trial experimental period

Treatment	E.C (Dsm^{-1})	pH	Organic matter (%)	Soil available nutrients ($mg.Kg^{-1}$)						
				No^{3-}	NH^{4+}	P	K	Fe	Mn	Zn
T1	5.39f	7.77d	1.41a	39.78a	32.67a	3.15a	289.4a	1.82a	6.2e	0.34a
T2	4.80e	7.70c	1.71bcd	52d	54.33e	4.94c	372.1e	3.36d	1.15a	0.38a
T3	2.74a	7.40a	1.87d	85.55i	66.04i	5.41e	418.91i	3.68f	1.37b	0.43ab
T4	2.88a	7.69c	1.76cd	80.50h	59.42g	5.13d	381.2g	3.42de	1.28b	0.43ab
T5	5.79g	7.68bcd	1.81cd	77.67g	59.67h	5.25de	397.4h	3.59ef	1.22b	0.44ab
T6	5.31f	7.59bc	1.58b	46.33b	39.14b	4.42b	317.4b	2.52b	1.9d	0.47ab
T7	4.60d	7.54abc	1.68bc	57e	45.00c	4.87c	368.54d	2.65bc	1.9d	0.56bc
T8	4.30c	7.57abc	1.59b	48.33c	52d	4.47b	326c	2.61bc	1.6c	0.60b
T9	3.94b	7.51ab	1.7bc	77.47f	56.67f	4.91c	376.97f	2.73c	1.2b	0.65c
LSD ($P \leq 0.05$)	0.28	0.057	0.16	1.6	2.1	0.24	3.1	0.14	0.11	0.21

Control (T1), Application of K-silicate $3Kg.fed^{-1}$ (T2), K-silicate $5Kg.fed^{-1}$ (T3), K-humate $3Kg.fed^{-1}$ (T4), K-humate $5Kg.fed^{-1}$ (T5), Foliar: K-silicate $2gm.L^{-1}$ (T6), K-silicate $4gm.L^{-1}$(T7), K-humate 3gm. L^{-1} (T8), K-humate 5 gm. L^{-1} (T9).

The highest increases in nutrient availability soil organic matter were observed in the treatment combining K-silicate; findings emphasize the possibility of both the K-silicate and K-humate, mainly whilst linked with soil application, developing nutrient readiness in soils suffering from salinity stress. Though the treatments under study could not entirely modify soil EC or pH, yet their aptitude to upgrade nutrient availability and soil content of the organic matter recommends a beneficial task in holding plant growth under saline stress. The superior performance of K-silicate, specifically upon its co-application with soil application at a rate of $5Kg.fed^{-1}$, draw attention to the importance of synergistic collaborations between materials on one hand and either of the used of rates on the other hand. This tactic can be considered a promising approach for improving plant pliability and output in soils under saline stress. However, more research works are needed to discover longstanding effects and boost application practices for distinct agricultural usage.

The increases in soil content of the organic matter owing to the abovementioned additives are expected to improve some soil chemical properties. The soil content of the available nutritive elements, which are crucial for maintainable agriculture. This, contributes to the longstanding upgrading of soil health under saline stress (Oldfield *et al.*, 2018) [42].

Generally, data in Table (9) showed that the soil application of potassium silicate and potassium humate methods recoded a benefit effect on soil than that foliar application with potassium silicate and potassium humate improve saline soil conditions. The either of potassium silicate and potassium humate improved some chemical properties e.g. soil structure, water retention, as well as the soil content of organic matter decreased in pH and EC, also, increased the available nutritive elements.

Discussion

The significant improvement in vegetative growth and yield components of anise plants following the application of potassium silicate and potassium humate under saline soil conditions can be attributed to their complementary physiological roles in alleviating salt-induced stress. Salinity disrupts water uptake, nutrient acquisition, photosynthesis, and cellular metabolism, ultimately reducing plant growth and productivity. In the present study, both compounds effectively mitigated these adverse effects, resulting in significant increases in plant height, branch number, umbels per plant, seed yield, and 1000-seed weight, particularly at the higher application rates**.**

The superior performance of potassium silicate may be explained by the multifunctional role of silicon in improving plant tolerance to salinity. Silicon enhances the structural stability of cell walls, maintains plasma membrane integrity, and limits the uptake and translocation of toxic Na^+ ions while promoting K^+ absorption, thereby maintaining a favorable K^+/Na^+ ratio. Furthermore, silicon enhances chlorophyll biosynthesis, improves photosynthetic efficiency, increases water-use efficiency, and stimulates antioxidant defense systems, which collectively reduce oxidative damage caused by reactive oxygen species (ROS) generated under salt stress (Hasanuzzaman *et al.*, 202***0*** and Rady *et al.*, 2024[45]***)***

Potassium supplied through potassium silicate also plays an essential physiological role by regulating stomatal movement, activating more than sixty enzymes involved in carbohydrate metabolism, enhancing protein synthesis, facilitating assimilate translocation, and maintaining cellular osmotic balance. These physiological processes contribute directly to increased biomass accumulation, improved reproductive growth, and greater seed production under saline conditions (Rady *et al.*, 2024[45]***)***

The positive response observed following potassium humate application is mainly associated with the biological activity of humic substances. Potassium humate improves soil aggregation, increases cation exchange capacity, stimulates beneficial rhizosphere microorganisms, and enhances nutrient availability and root absorption. In addition, humic substances exhibit auxin-like activity that stimulates root proliferation, increases chlorophyll formation, enhances nutrient uptake efficiency, and improves plant water status under abiotic stress conditions. These mechanisms collectively explain the significant improvements observed in vegetative growth and yield compared with untreated plants (El-Beltagi *et al.*, 2023 and Canellas *et al.*, 2023) [21]***.***

Both treatments have been shown to promote growth, with observed increases in the content of nitrogen found in both leaves and seeds as well as in phosphorus and potassium. Better accumulation of nutrients leads to increased nutrient acquisition and root activity, which is essential for the production of chlorophyll, enzymes, protein, and energy metabolism. The retention of membrane selectivity and ionic competition in saline solutions can enhance the transportation of nutrients, as demonstrated by silicon. Humic substances also have an improved ability to stimulate root growth and serve as chelators, increasing access to nutrients (Shabana *et al.*, 2023 and Canellas *et al.*, 2024[13, 48])**.**

This study's biochemical responses are also consistent with the increased salt tolerance induced by both biostimulants. The treatment of plants with treated compounds exhibited lower oxidative and osmotic stress than untreated plants, as indicated by an increase in antioxidant activity and total carbohydrate content, along with reduced levels of proline and overall phenolic contents. A higher level of antioxidant activity enhances ROS scavenging, which protect[clarification needed] cellular membranes and photosynthetic machinery, while increased accumulation of carbohydrates reflects improved photosisynthesis performance and assimilation. Proline accumulation may be reduced in response to severe salinity, indicating that treated plants experienced less physiological stress (Hasanuzzaman *et al*, 2020; Canellas *et al.*, 2024) [13, 27]

An increase in the essential oil percentage in treated plants may be a consequence of improved photosynthetic efficiency and increased carbon allocation for secondary metabolite biosynthesis. The provision of enhanced mineral nutrition, particularly potassium nutrition in particular, increases the importance of enzyme activities related to terpene biosynthesis, and silicon is an important mediator for maintaining cellular metabolism under stress conditions, thus encouraging the accumulation of essential oil constituents. The application of potassium silicate and potassium humate under saline conditions has been shown to have similar effects on growth, nutrient uptake, physiological performance, and stress tolerance in many crops (Hassanein *et al*, 2022 and Shabana *et al*., 2023[3, 29]*)*

In the current study, it was observed that soil application is more effective than foliar spraying due to the constant availability of potassium silicate and other potassium humate within the rhizosphere during all seasons of growth. While soil application enhances the physicochemical attributes of soil, promotes microbial activity, encourages root growth, and sustains food supply, it differs from foliar application in that it induces swift physiological reactions with a shorter response time. Therefore, soil application resulted in better vegetative, nutritional and biochemical properties as well as higher yields compared to foliar spraying under a saline soil (Shabana *et al.,* 2023[48] and Abed *et al*, 2004)

As a whole, the results indicate that potassium silicate, applied at 0.50% more than the standard application rate, significantly alleviated salinity stress when mixed with other compounds to improve growth and nutrient status, biochemical properties, essential oil accumulation, and seed productivity of anise plants. The findings indicate that potassium silicate and potassium humate can serve as ecological biostimulants for the sustainable cultivation of aromatic and medicinal plants in salt-stressed environments

Conclusion

Both potassium silicate and potassium humate were found to be eco-friendly biostimulants that enhanced the growth, productivity, and physiological performance of anise (*Pimpinella anisum* L.) grown under saline soil conditions according to our findings. The application of both soil and foliar solutions resulted in a marked improvement in vegetative growth, yield components, mineral nutrient accumulation, biochemical constituents, and essential oil percentage when compared to the untreated control. The response was dependent on the type of compound, method of application, and concentration**.**

The use of potassium silicate at 5 kg/fed^{-1} in soil consistently demonstrated the greatest improvements in vegetative growth, seed yield, leaf and seed mineral contents (N, P, and K), antioxidant activity, total carbohydrates, as well as essential oil percentage, despite salinity-induced stress, which was also effectively alleviated by reducing proline and total phenolic contents. A foliar treatment with potassium silicate at 4 g/L^{-1} demonstrated remarkable benefits. Despite being measured at a higher application rate, potassium humate was significantly more effective than the untreated control on all parameters**.**

Generally speaking, the success of soil application overfoliar spraying suggested that continuous availability in relation to nutrient content in the rhizosphere and better soil physicochemical properties may have contributed to greater apportionment by nutrients and enhanced plant performance. The consistency of the results obtained over the course of two growing seasons proves that these treatments are reliable and stable under saline conditions**.**

Hence, the use of potassium silicate as a soil amendment at 5 kg/fed^{-1} can be suggested as an environmentally friendly and sustainable approach to improve anise productivity and quality in soils that are affected by salt. As a complementary biostimulant, potassium humate can be integrated into sustainable crop management initiatives.

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