J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 16 (10):279 – 284, 2025

Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

Overcoming Water Deficit in Flax Cultivation through Foliar Spraying with Vitamins and Antitranspirants

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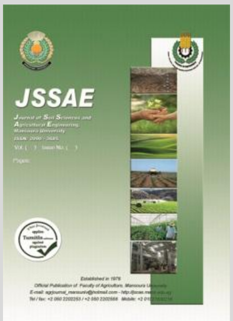

Article Information
Received 24 / 8 /2025
Accepted 18 / 9 /2025

ABSTRACT

Flax plant is an economically important crop in Egypt. However, the water scarcity conditions, which the agricultural sector suffers from, negatively impact its vegetative growth, oil yield characteristics, and fiber quality. Therefore, an approach was hypothesized that could contribute to enhancing the tolerance of flax plant to the water deficit stress. A field experiment was carried out during two successive seasons (20233/24 and 2024/25) to evaluate the effect of irrigation requirement (IR) treatments [100% of IR (equal 1316 $m^3 fed^{-1}$) and 80% of IR (equal 1052.8 $m^3 fed^{-1}$)] as main factor, antitranspirants [control (tap water), kaolin (5%,w/v) and magnesium silicate (5%,w/v)] as sub main factor, and vitamins [control (tap water), vitamin C (100 mg L^{-1}) and vitamin E (100 mg L^{-1})] as sub-sub main factor on flax performance (Giza 12 cultivar, grown for fiber and seed). Growth criteria, straw chemical constituents, fiber yield and quality, oil yield and biochemical traits of seeds were assessed. The treatment of 100% IR positively reflected on flax yield and its fiber quality compared to the 80% of IR. Magnesium silicate was superior to kaolin. V.E achieved the best performance in facing water deficit compared to V.C. The best flax performance was achieved under the combined treatment of 100 IR x magnesium silicate x V.E. On the other hand, spraying magnesium silicate combined with the vitamin E under irrigation with 80% of IR recorded the results closed to the treatment of 100 IR without foliar applications, indicating the effectiveness of this combination in mitigating the water deficit.

Keywords: Kaolin, Magnesium-silicate, Vitamin C, Vitamin E

INTRODUCTION

Flax plant (*Linum usitatissimum* L.) is a crop of high economic value due to its multiple uses in the fiber and seed industries (Emam, 2020; Bakry *et al.* 2024). On the other hand, Egypt faces problems related to water shortages, and flax, like other strategic crops, is affected due to exposure to water-deficit conditions (Sallam *et al.* 2023). Therefore, improving flax production and quality under water-deficit stress conditions is of great importance to the Egyptian agricultural and industrial sectors. Furthermore, studying how to improve flax's tolerance to water stress can contribute to the development of effective strategies to address this problem (El-Borhamy *et al.* 2022).

Antitranspirants such as kaolin and magnesium silicate are used to improve higher plant resistance to environmental stress, especially water deficit stress. Both are powerful antitranspirants that can protect plants from water deficit stress. They both form a layer that prevents water from evaporating from the stomata, and they both moderate the temperature around the leaf (Kocięcka *et al.* 2023). Magnesium, which plants can obtain from spraying with magnesium silicate, plays a significant role in photosynthesis and as a coenzyme for enzymes responsible for oil formation. All these benefits are in addition to its primary property of acting as an antitranspirant (Wissa, 2017; Elmahdy *et al.* 2022). Kaolin is a natural clay mineral that forms a protective layer on the leaves of higher plants, reducing water loss through transpiration. This layer also protects the plant from insect and fungal infections and increases the plant's ability to tolerate drought conditions (Abd Allah, 2019; Metwaly & Nada, 2020; Faghihi *et al.* 2025).

Foliar spraying with vitamins such as V.C. and V.E can play a role in promoting plant health and improving its stress response. Both are antioxidants capable of scavenging free radicals that form when plants are exposed to environmental stress (Kamal & Abd Al-Gaid, (2008; Mady, 2009; El-Baz et al. 2016). Therefore, the major aim of this research is to improve the productivity and quality of flax, which is grown for fiber and seeds, under water-deficit conditions, through foliar spraying with antitranspirants and vitamins.

MATERIALS AND METHODS

A field experiment was carried out under split split plot experimental design with three replicates during two successive seasons (20233/24 and 2024/25) in a privet farm located at Meet-Anter Village, Talkha District, Dakahlia Governorate, Egypt to evaluate the effect of irrigation requirement (IR) treatments [100% of IR (equal 1316 $m^3 fed^{-1}$) and 80% of IR (equal 1052.8 $m^3 fed^{-1}$)] as main factor, antitranspirant treatments [control (tap water), kaolin (5%,w/v) and magnesium silicate (5%,w/v)] as sub main factor , and vitamins [control (tap water), vitamin C (100 mg L^{-1}) and vitamin E (100 mg L^{-1})] as sub-sub main factor on flax performance (Giza 12 cultivar, grown for fiber and seed). The initial soil samples were analyzed as described by Tandon (2005), as their properties are shown in Table 1. Kaolin was analyzed as reported by Tandon (2005), as their properties are shown in Table 2. While Table 3 presents the characteristics of magnesium silicate.

The studied antitranspirants and vitamins were purchased from the Egyptian commercial market. The experimental unit comprised **10.5** m^2 (3.0 m long and 3.5 m width), forming 20 rows of 15 cm between rows. Flax seeds were

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DOI: 10.21608/jssae.2025.416739.1309

obtained from the Agricultural Research Center then were sown in the first week of November in both studied seasons at a rate of 80 kg fed^{-1}. Mineral fertilization was applied at a rate of 50 unit N fed^{-1}, 10 unit P fed^{-1} and 25 unit K fed^{-1} in the form of ammonium sulphate (21% N, in two equal doses with the second and third irrigations), calcium superphosphate (6.6% P, added before planting), and potassium sulphate (39% K, added in two doses with the third and fourth irrigations). Foliar application of both antitranspirats and vitamins was carried out six times, starting 45 days after sowing, with a 15-day interval, at a volume of 1000 liters fed^{-1} for each studied substance. The irrigation treatments were adjusted using a water meter on the main irrigation line. Harvest was implemented after 150 days from sowing.

Table 1. Initial soil properties and feldspar characteristics

Initial soil properties	Values
EC (suspension 1: 5)	2.25 dSm^{-1}
pH (suspension 1:2.5)	8.00
Organic matter	1.33%
Available N,P and K	32.9, 11.2 and 211 mg Kg^{-1} soil, respectively
Clay, silt and sand	49.0, 29.0 and 22.0 %, respectively with clay texture class

Table 2. Kaolin properties

Characteristics	EC, dSm^{-1} (1:10)	SiO_2	Na_2O	Al_2O_3	Fe_2O_3	K_2O	CaO
		(%)					
Values	1.40	50.0	0.10	30	0.5	0.1	0.10

Table 3. Magnesium silicate properties

Chemical Formula	**Mg_2SiO_4**
Density, g/cm^3	3.2
Melting point °C	1.9
Molecular weight, g/mol	140.7
Appearance	White to off-white powder or crystalline
pH (in water)	9.5, slightly alkaline suspension
Solubility	Insoluble in water; soluble in acids

After 90 days from sowing, digestion of flax straw samples was done using a sulphuric acid and perchloric acid mixture at ratio of 1:1 as described by Peterburgski, (1968), then straw chemical composition (NPK,%) was determined according to the guidelines of Walinga *et al.* (2013) *via* the micro-Kjeldahl method, Olsen method using spectrophotometer and flame photometer, respectively. At the same time, the chlorophyll (SPAD reading) was measured. Additionally, at 90 days from sowing, malondialdehyde (MDA, µmol g^{-1} F.W.) as oxidation indicator and peroxidase POX (unit mg^{-1} protein) as enzymatic antioxidant were estimated through the spectrophotometric method as reported by Valenzuela, (1991) and Elavarthi & Martin, (2010), respectively.

At 150 days from sowing (harvest stage), total plant height (cm), technical stem length (cm), No. of basal branches $plant^{-1}$, stem diameter (mm), straw yield (g $plant^{-1}$), straw yield (ton fed^{-1}), No. capsules $plant^{-1}$, No. seeds $capsules^{-1}$, seed yield (g $plant^{-1}$ & kg fed^{-1}) were measured.

Fiber quality traits, including total fiber (%), fiber yield (g $plant^{-1}$, kg fed^{-1}) and fiber length (cm) were measured according to the AOAC (2000) procedures as well as fiber fineness (NM) was determined according to the following equation:

Nm = (N X L) / W as mentioned by Radwan and Momtaz (1966).

Where,

Nm = Metrical number.
N = number of fibers (20 fibers and the length for each one equal 10 cm).
L = Length of fibers in mm (2000 mm).
W = Weight of fibers in mg

Additionally, biochemical characteristics, including oil seed content (%), oil yield (kg fed^{-1}), protein (%) and carbohydrates (%) were determined according to the AOAC (2000) procedures. The statistical analysis was done for the obtained data according to Gomez and Gomez (1984) using CoStat software (Version 6.303, CoHort, USA, 1998-2004).

RESULTS AND DISCUSSIONS

The studied irrigation regimes, antitranspirants and vitamins significantly affected most the evaluated measurements. The values of leaf chemical constituents (NPK,%), chlorophyll content (SPAD reading), malondialdehyde (MDA, µmol g^{-1} F.W.) as oxidation indicator and peroxidase POX (unit mg^{-1} protein) as enzymatic antioxidant of the flax plants at 90 days from sowing during seasons of 2023/24 and 2024/25 are tabled in Table 4. Table 5 illustrates the effect of the same treatments under the same conditions on growth and straw yield traits of the flax plants, including total plant height (cm), technical stem length (cm), No. of basal branches $plant^{-1}$, stem diameter (mm), straw yield (g $plant^{-1}$), straw yield (ton fed^{-1}) at harvest stage (150 days from sowing). Fiber quality traits at harvest, including total fiber (%), fiber yield (g $plant^{-1}$, kg fed^{-1}), fiber length (cm) and fiber fineness (NM) as affected by the studied irrigation regimes, antitranspirants and vitamins are shown in Table 6. Table 7 shows the values of seed yield and oil traits *i.e.*, No. capsules $plant^{-1}$, No. seeds $capsules^{-1}$, seed yield (g $plant^{-1}$ & kg fed^{-1}), oil seed content (%), oil yield (kg fed^{-1}) under the same studied conditions at harvest stage. Biochemical characteristics, including protein (%) and carbohydrates (%) under the same studied conditions at harvest stage were tabled in Table 8.

The treatment of 100% IR achieved the maximum values of all aforementioned traits, except MDA and POX, compared to the treatment of 80% IR. Concerning the traits of MDA and POX, their highest values were recorded under the treatment of water deficit (80% IR).

Irrigating flax with 100% of its normal water requirements improved their studied physiological and yield parameters. At the same time, this irrigation treatment reduced the plant's self-production of peroxidase enzyme, responsible for water deficit stress defense and scavenging free radicals. This, in turn, resulted in lower levels of MDA; an indicator of the extent of oxidative stress experienced by flax plant cells, as the greater the stress, the greater MDA formation. Conversely, exposing flax plant to water deficit (irrigation with 80% of its water requirements) resulted in a decline in improvements of the flax physiological and yield parameters. In conjunction with this trend, the water deficit irrigation treatment increased the plant's self-production of peroxidase enzyme, responsible for water deficit stress defense and scavenging free radicals, which was reflected in increased MDA accumulation under water deficit conditions (El-Borhamy *et al.* 2022; Sallam *et al.* 2023).

Regarding all aforementioned traits except MDA and POX, magnesium silicate was superior to kaolin and control treatment, which came in the last order. Additionally, the vitamin E treatment achieved the highest values followed by vitamin C and lately control treatment. On the contrary, the values of MDA and POX took the opposite direction from the previous characteristics, as the highest values were achieved with the control treatments (either antitransparants of vitamins).

Magnesium silicate outperformed kaolin, possibly due to its multiple benefits compared to kaolin. Foliar application of magnesium silicate may have resulted in the formation of a thin, semi-transparent silicate layer on flax leaves, which reduced transpiration without impeding photosynthesis. Furthermore, magnesium may have improved photosynthesis in flax, as it is an essential component of chlorophyll. This may have improved plant performance and enabled it to withstand environmental stress. Also, silicate may have played an unique role in strengthening the cell walls of flax plants and increased the hardness of the leaf epidermis, resulting in reduced transpiration. This may have allowed flax plants growing under water-deficit conditions to achieve their maximum productivity without significantly reducing yield and quality (Wissa, 2017; Elmahdy *et al.* 2022). Kaolin ranked second after magnesium silicate, possibly due to its physical role in reflecting sunlight, reducing leaf temperature, and partially covering the pores. It is also less reactive to internal physiological processes (Abd Allah, 2019; Metwaly & Nada, 2020; Faghihi *et al.* 2025).

As for vitamin E superiority, it was because it's a lipid antioxidant concentrated in flax cell membranes, protecting unsaturated lipids in the membranes from lipid peroxidation. This role is particularly important under water stress, as the accumulation of free radicals directly attacks membranes. Meanwhile, vitamin C is a water-soluble antioxidant that operates primarily in the cytosol and aqueous tissues. Despite its importance in eliminating some types of free radicals (ROS), its role in protecting membranes is less significant than vitamin E. Therefore, vitamin E was more effective in protecting cells from oxidative damage resulting from water deficit, while vitamin C remained supportive but less effective(Kamal & Abd Al-Gaid, (2008; Mady, 2009; El-Baz *et al.* 2016).

The best flax performance was achieved under the combined treatment of 100 IR x magnesium silicate x vitamin E. On the other hand, spraying magnesium silicate combined with the vitamin E under irrigation with 80% of IR had a non-significant effect on the most traits of flax compared to the treatment of 100 IR without both antitranspirants and vitamins. The same trend was found for both studied seasons.

Table 4. Effect of foliar spraying with antitranspirants and vitamins on chemical leaf traits of the flax plants irrigated under different regimes at 90 days from sowing during seasons of 2023/24 and 2024/25

Treatments			Nitrogen (%)		Phosphorus (%)		Potassium (%)		Chlorophyll (SPAD reading)		MDA (μmol.g^{-1} F.W)		POX (unit mg^{-1} protein^{-1})	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : Irrigation requirement treatments														
80% of IR			2.59^{b}	2.64^{b}	0.317^{b}	0.323^{b}	2.45^{b}	2.50^{b}	35.02^{b}	35.72^{b}	21.09^{a}	21.51^{a}	0.476^{a}	0.486^{a}
100% of IR			2.91^{a}	2.97^{a}	0.362^{a}	0.369^{a}	2.77^{a}	2.83^{a}	38.65^{a}	39.48^{a}	16.27^{b}	16.57^{b}	0.406^{b}	0.415^{b}
F. Test			**	**	**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.03	0.13	0.008	0.008	0.03	0.06	1.44	1.79	0.86	0.11	0.008	0.010
Sub main factor: Antitranspirant treatments (as foliar applications)														
Control (without)			2.63^{c}	2.68^{c}	0.324^{c}	0.330^{c}	2.50^{c}	2.55^{c}	35.57^{c}	36.30^{c}	19.65^{a}	20.02^{a}	0.466^{a}	0.475^{a}
Kaolin			2.77^{b}	2.83^{b}	0.337^{b}	0.344^{b}	2.61^{b}	2.66^{b}	36.88^{b}	37.65^{b}	18.75^{b}	19.10^{b}	0.442^{b}	0.451^{b}
Magnesium silicate			2.86^{a}	2.91^{a}	0.358^{a}	0.364^{a}	2.73^{a}	2.78^{a}	38.05^{a}	38.84^{a}	17.64^{c}	17.99^{c}	0.416^{c}	0.424^{c}
F. Test			**	**	**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.02	0.02	0.002	0.002	0.05	0.03	0.29	0.30	0.14	0.13	0.003	0.003
Sub-sub main factor: Vitamin treatments (as foliar applications)														
Control (without)			2.71^{c}	2.76^{c}	0.334^{c}	0.339^{c}	2.56^{b}	2.61^{c}	36.36^{b}	37.08^{c}	19.02^{a}	19.33^{a}	0.449^{a}	0.458^{a}
Vitamin C			2.75^{b}	2.80^{b}	0.339^{b}	0.347^{b}	2.63^{a}	2.68^{b}	36.91^{a}	37.68^{b}	18.61^{b}	19.01^{b}	0.439^{b}	0.450^{b}
Vitamin E			2.79^{a}	2.85^{a}	0.346^{a}	0.352^{a}	2.64^{a}	2.70^{a}	37.24^{a}	38.03^{a}	18.40^{c}	18.77^{c}	0.435^{c}	0.443^{c}
F. Test			**	**	**	**	*	**	*	**	**	**	**	**
LSD $_{at\ 5\%}$			0.03	0.02	0.002	0.003	0.05	0.01	0.33	0.25	0.16	0.16	0.004	0.004
Interaction														
80% of IR	Control	Control	2.41	2.45	0.294	0.297	2.31	2.35	32.85	33.43	22.40	22.70	0.513	0.522
		V. C	2.45	2.51	0.305	0.313	2.35	2.42	33.30	34.15	22.08	22.68	0.498	0.510
		V. E	2.58	2.63	0.310	0.315	2.37	2.42	34.13	34.85	21.90	22.30	0.496	0.506
	Kaolin	Control	2.61	2.64	0.311	0.315	2.39	2.42	34.54	34.89	21.42	21.91	0.488	0.495
		V. C	2.61	2.66	0.314	0.322	2.46	2.53	35.26	36.11	21.35	21.74	0.481	0.493
		V. E	2.63	2.69	0.323	0.328	2.49	2.53	35.56	36.33	21.09	21.42	0.473	0.481
	Mg silicate	Control	2.65	2.69	0.329	0.335	2.50	2.54	35.83	36.43	20.47	20.87	0.457	0.464
		V. C	2.69	2.74	0.334	0.341	2.58	2.63	36.70	37.35	19.77	20.20	0.442	0.452
		V. E	2.73	2.80	0.338	0.343	2.62	2.69	36.98	37.91	19.29	19.73	0.440	0.450
100% of IR	Control	Control	2.74	2.80	0.339	0.346	2.65	2.70	37.34	38.21	17.35	17.55	0.433	0.444
		V. C	2.78	2.82	0.346	0.352	2.67	2.71	37.90	38.43	17.15	17.44	0.427	0.436
		V. E	2.81	2.87	0.350	0.358	2.67	2.73	37.94	38.72	17.00	17.45	0.427	0.432
	Kaolin	Control	2.89	2.97	0.353	0.359	2.70	2.77	38.31	39.35	16.92	17.15	0.410	0.420
		V. C	2.92	2.99	0.355	0.364	2.80	2.86	38.68	39.59	15.89	16.28	0.402	0.412
		V. E	2.96	3.02	0.369	0.375	2.79	2.87	38.90	39.63	15.82	16.10	0.398	0.406
	Mg silicate	Control	2.99	3.05	0.378	0.384	2.83	2.89	39.30	40.18	15.56	15.79	0.394	0.402
		V. C	3.03	3.09	0.383	0.390	2.91	2.96	39.59	40.46	15.41	15.70	0.386	0.397
		V. E	3.05	3.12	0.385	0.393	2.92	2.99	39.92	40.72	15.31	15.62	0.377	0.382
F. Test			*	*	*	*	*	*	*	*	**	**	**	**
LSD $_{at\ 5\%}$			0.06	0.05	0.007	0.007	0.11	0.03	0.82	0.72	0.39	0.39	0.009	0.009
A x B			*	*	**	**	*	*	**	**	**	**	**	**
A x C			*	*	*	*	*	**	*	**	*	*	*	*
B x C			*	*	*	*	*	**	*	*	*	*	*	*

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 5. Effect of foliar spraying with antitranspirants and vitamins on growth and straw yield traits of the flax plants irrigated under different regimes at 150 days from sowing during seasons of 2023/24 and 2024/25

Treatments			Total plant height (cm)		Technical stem length (cm)		No. of basal branches/plant		Stem diameter (mm)		Straw yield/plant (g)		Straw yield/fed (ton)	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : Irrigation requirement treatments														
80% of IR			91.78^{b}	93.62^{b}	70.17^{b}	71.51^{b}	1.67^{b}	1.67^{b}	1.37^{b}	1.39^{b}	1.69^{b}	1.72^{b}	3.15^{b}	3.22^{b}
100% of IR			100.38^{a}	102.53^{a}	76.51^{a}	77.89^{a}	3.11^{a}	3.07^{a}	2.13^{a}	2.18^{a}	2.17^{a}	2.21^{a}	4.33^{a}	4.41^{a}
F. Test			**	**	**	**	**	**	**	**	**	**	**	**
LSD $_{at 5\%}$			0.68	0.68	0.25	0.25	0.96	0.42	0.01	0.01	0.02	0.05	0.08	0.09
Sub main factor: Antitranspirant treatments (as foliar applications)														
Control (without)			93.66^{c}	95.42^{c}	71.33^{c}	72.50^{c}	1.89^{c}	1.89^{c}	1.62^{c}	1.65^{c}	1.81^{c}	1.85^{c}	3.40^{c}	3.46^{c}
Kaolin			95.94^{b}	98.09^{b}	73.16^{b}	74.62^{b}	2.39^{b}	2.33^{b}	1.74^{b}	1.77^{b}	1.92^{b}	1.96^{b}	3.73^{b}	3.80^{b}
Magnesium silicate			98.65^{a}	100.71^{a}	75.53^{a}	76.97^{a}	2.89^{a}	2.89^{a}	1.90^{a}	1.94^{a}	2.06^{a}	2.10^{a}	4.10^{a}	4.18^{a}
F. Test			**	**	**	**	**	**	**	**	**	**	**	**
LSD $_{at 5\%}$			1.24	1.27	0.53	0.54	0.41	0.28	0.01	0.02	0.02	0.02	0.04	0.04
Sub-sub main factor: Vitamin treatments (as foliar applications)														
Control (without)			95.01^{b}	96.99^{b}	72.38^{c}	73.54^{c}	2.17^{a}	2.22^{a}	1.69^{b}	1.72^{c}	1.88^{b}	1.91^{c}	3.64^{c}	3.70^{c}
Vitamin C			96.33^{a}	98.25^{a}	73.05^{b}	74.64^{b}	2.50^{a}	2.39^{a}	1.73^{b}	1.76^{b}	1.92^{b}	1.96^{b}	3.73b	3.81^{b}
Vitamin E			96.91^{a}	98.98^{a}	74.58^{a}	75.91^{a}	2.50^{a}	2.50^{a}	1.84^{a}	1.88^{a}	1.98^{a}	2.03^{a}	3.86^{a}	3.94^{a}
F. Test			*	*	**	**	*NS	*NS	*	**	*	**	**	**
LSD $_{at 5\%}$			0.98	1.00	0.61	0.62	*NS	*NS	0.04	0.04	0.04	0.01	0.01	0.01
Interaction														
80% of IR	Control	Control	88.32	89.94	66.11	66.83	1.00	1.00	1.13	1.16	1.54	1.58	2.77	2.84
		V. C	89.72	91.62	68.71	70.54	1.33	1.33	1.17	1.19	1.56	1.59	2.81	2.84
		V. E	90.57	92.09	69.81	70.77	1.33	1.33	1.21	1.23	1.59	1.63	2.92	2.99
	Kaolin	Control	90.74	92.45	69.90	71.10	1.33	1.33	1.28	1.31	1.64	1.68	3.01	3.09
		V. C	91.83	93.48	70.02	71.77	1.67	1.67	1.33	1.35	1.67	1.70	3.14	3.18
		V. E	92.05	94.60	70.89	71.98	1.67	2.00	1.36	1.38	1.69	1.72	3.23	3.29
	Mg silicate	Control	93.77	95.27	71.24	72.62	2.00	2.00	1.43	1.45	1.73	1.77	3.37	3.44
		V. C	94.32	95.98	71.55	73.03	2.33	2.00	1.44	1.47	1.78	1.82	3.48	3.56
		V. E	94.71	97.14	73.29	74.92	2.33	2.33	1.95	2.01	2.00	2.04	3.86	3.90
100% of IR	Control	Control	96.96	98.96	74.14	74.96	2.33	2.33	1.99	2.02	2.02	2.05	3.88	3.92
		V. C	97.75	99.27	74.23	75.54	2.67	2.67	2.08	2.11	2.05	2.10	3.91	4.00
		V. E	98.62	100.65	74.98	76.36	2.67	2.67	2.13	2.17	2.09	2.13	4.10	4.19
	Kaolin	Control	99.26	101.96	75.29	76.93	3.00	3.00	2.13	2.18	2.15	2.17	4.21	4.25
		V. C	100.91	102.97	75.94	77.77	3.33	3.00	2.16	2.22	2.17	2.24	4.35	4.49
		V. E	100.86	103.08	76.90	78.17	3.33	3.00	2.17	2.22	2.20	2.24	4.45	4.52
	Mg silicate	Control	101.01	103.38	77.63	78.79	3.33	3.67	2.18	2.22	2.21	2.25	4.57	4.64
		V. C	103.43	106.20	77.86	79.18	3.67	3.67	2.18	2.23	2.28	2.32	4.70	4.79
		V. E	104.66	106.32	81.64	83.28	3.67	3.67	2.20	2.26	2.34	2.41	4.78	4.90
F. Test			*	*	**	*	*	*	**	**	*	**	**	**
LSD $_{at 5\%}$			2.41	2.46	1.49	1.52	0.84	0.84	0.09	0.09	0.09	0.02	0.03	0.03
A x B			**	*	*	*	*NS	*NS	**	**	**	**	*	*
A x C			*	*	*	*	*NS	*NS	**	**	**	**	*	**
B x C			*	*	**	**	*NS	*NS	**	**	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

***NS= non-significant**

Table 6. Effect of foliar spraying with antitranspirants and vitamins on fiber yield and quality traits of the flax plants irrigated under different regimes at 150 days from sowing during seasons of 2023/24 and 2024/25

Treatments			Total fiber (%)		Fiber yield/plant (g)		Fiber yield/fed (kg)		Fiber length (cm)		Fiber fineness (NM)	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : Irrigation requirement treatments												
80% of IR			14.62^{b}	15.04^{b}	0.247^{b}	0.260^{b}	462.22^{b}	485.63^{b}	65.60^{b}	67.56^{b}	138.30^{b}	142.65^{b}
100% of IR			16.58^{a}	17.06^{a}	0.360^{a}	0.378^{a}	720.28^{a}	755.17^{a}	71.46^{a}	73.79^{a}	156.20^{a}	161.03^{a}
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at 5\%}$			0.05	0.01	0.001	0.010	21.21	19.39	3.27	0.70	0.21	0.21
Sub main factor: Antitranspirant treatments (as foliar applications)												
Control (without)			14.83^{c}	15.24^{c}	0.270^{c}	0.283^{c}	507.84^{c}	531.91^{c}	66.36^{c}	68.48^{c}	141.46^{c}	146.02^{c}
Kaolin			15.65^{b}	16.13^{b}	0.303^{b}	0.319^{b}	590.99^{b}	620.80^{b}	68.57^{b}	70.57^{b}	146.78^{b}	151.22^{b}
Magnesium silicate			16.31^{a}	16.77^{a}	0.338^{a}	0.355^{a}	674.92^{a}	708.49^{a}	70.65^{a}	72.98^{a}	153.51^{a}	158.28^{a}
F. Test			**	**	**	**	**	**	**	**	**	**
LSD $_{at 5\%}$			0.26	0.18	0.007	0.010	14.01	12.02	0.54	0.70	0.28	0.29
Sub-sub main factor: Vitamin treatments (as foliar applications)												
Control (without)			15.39^{b}	15.88^{c}	0.292^{c}	0.307^{c}	566.28^{c}	594.17^{c}	67.58^{c}	69.62^{c}	145.10^{c}	149.34^{c}
Vitamin C			15.60^{ab}	16.03^{b}	0.302^{b}	0.318^{b}	590.11^{b}	619.53^{b}	68.46^{b}	70.76^{b}	147.46^{b}	151.90^{b}
Vitamin E			15.81^{a}	16.23^{a}	0.317^{a}	0.332^{a}	617.37^{a}	647.52^{a}	69.55^{a}	71.65^{a}	149.19^{a}	154.27^{a}
F. Test			*	**	**	**	**	**	**	**	**	**
LSD $_{at 5\%}$			0.27	0.13	0.009	0.006	9.63	6.13	0.54	0.60	0.46	0.48
Interaction												
80% of IR	Control	Control	14.08	14.46	0.217	0.228	389.45	410.14	62.42	64.10	133.64	138.09
		V. C	14.13	14.53	0.220	0.231	396.87	412.80	63.94	66.28	133.99	139.16
		V. E	14.25	14.63	0.226	0.238	415.62	436.92	65.07	66.59	134.64	139.37
	Kaolin	Control	14.38	14.96	0.236	0.251	432.64	462.32	65.83	67.54	135.62	139.71
		V. C	14.47	14.95	0.241	0.254	453.98	476.09	65.81	67.94	137.66	141.03
		V. E	14.75	15.09	0.249	0.259	476.04	496.13	66.03	68.15	139.49	144.72
	Mg silicate	Control	15.08	15.47	0.261	0.273	508.71	532.88	66.05	68.63	141.40	145.51
		V. C	15.18	15.52	0.270	0.282	528.89	552.98	66.89	69.10	143.24	146.82
		V. E	15.24	15.74	0.304	0.321	577.77	597.44	68.31	69.73	144.99	149.42
100% of IR	Control	Control	15.28	15.74	0.309	0.323	592.62	616.44	68.58	70.74	146.79	151.74
		V. C	15.43	15.84	0.316	0.333	603.32	633.67	68.89	71.27	148.89	152.61
		V. E	15.83	16.27	0.331	0.347	649.15	681.49	69.26	71.88	150.78	155.14
	Kaolin	Control	16.36	16.97	0.351	0.368	689.28	721.55	70.19	72.27	152.71	156.42
		V. C	16.86	17.30	0.366	0.387	734.14	776.29	71.63	73.47	156.55	160.97
		V. E	17.08	17.53	0.375	0.393	759.89	792.45	71.95	74.07	158.63	164.44
	Mg silicate	Control	17.16	17.69	0.379	0.397	784.97	821.68	72.40	74.41	160.44	164.56
		V. C	17.52	18.06	0.400	0.419	823.45	865.32	73.57	76.50	164.43	170.83
		V. E	17.68	18.11	0.414	0.436	845.72	887.67	76.67	79.50	166.60	172.55
F. Test			*	*	*	**	**	**	**	*	**	**
LSD $_{at 5\%}$			0.67	0.31	0.023	0.007	23.59	15.01	1.31	1.47	1.13	1.17
A x B			**	**	**	**	**	**	**	**	**	**
A x C			*	**	*	**	**	**	**	*	**	**
B x C			*	*	*	**	**	**	**	*	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 7. Effect of foliar spraying with antitranspirants and vitamins on seed yield and oil traits of the flax plants irrigated under different regimes at 150 days from sowing during seasons of 2023/24 and 2024/25

Treatments			No. capsules / plant		No. seeds / capsules		Seed yield/ plant (g)		Seed yield/ fed (kg)		Oil seed content %		Oil yield/ fed (kg)	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : Irrigation requirement treatments														
80% of IR			12.63^{b}	13.00^{b}	7.41^{b}	7.74^{b}	0.472^{b}	0.486^{b}	523.32^{b}	538.65^{b}	32.54^{b}	33.49^{b}	170.59^{b}	180.69^{b}
100% of IR			15.44^{a}	15.85^{a}	8.56^{a}	8.74^{a}	0.601^{a}	0.618^{a}	637.45^{a}	657.81^{a}	35.90^{a}	36.92^{a}	228.96^{a}	243.03^{a}
F. Test			**	**	**	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			1.11	1.30	0.84	0.55	0.013	0.013	6.62	3.10	0.22	0.03	4.26	1.62
Sub main factor: Antitranspirant treatments (as foliar applications)														
Control (without)			13.00^{c}	13.39^{c}	7.67^{b}	7.83^{c}	0.494^{c}	0.507^{c}	538.45^{c}	555.43^{c}	33.54^{c}	34.44^{c}	181.77^{c}	192.57^{c}
Kaolin			14.00^{b}	14.33^{b}	7.94^{ab}	8.22^{b}	0.536^{b}	0.554^{b}	580.84^{b}	598.11^{b}	34.24^{b}	35.30^{b}	199.83^{b}	212.08^{b}
Magnesium silicate			15.11^{a}	15.56^{a}	8.33^{a}	8.67^{a}	0.579^{a}	0.594^{a}	621.85^{a}	641.15^{a}	34.87^{a}	35.87^{a}	217.72^{a}	230.93^{a}
F. Test			**	**	*	**	**	**	**	**	**	**	**	**
LSD $_{at\ 5\%}$			0.54	0.57	0.52	0.30	0.004	0.014	5.84	1.76	0.47	0.38	4.35	2.10
Sub-sub main factor: Vitamin treatments (as foliar applications)														
Control (without)			13.72^{b}	14.06^{b}	7.83^{a}	8.00^{b}	0.522^{c}	0.539^{c}	566.43^{c}	581.88^{c}	33.93^{b}	35.01^{b}	193.44^{c}	204.97^{c}
Vitamin C			14.06^{ab}	14.50^{ab}	7.94^{a}	8.28^{ab}	0.536^{b}	0.550^{b}	580.04^{b}	600.47^{b}	34.25^{a}	35.13^{b}	199.77^{b}	212.17^{b}
Vitamin E			14.33^{a}	14.72^{a}	8.17^{a}	8.44^{a}	0.550^{a}	0.566^{a}	594.67^{a}	612.34^{a}	34.47^{a}	35.48^{a}	206.12^{a}	218.43^{a}
F. Test			*	*	*NS	*	**	**	**	**	*	*	**	**
LSD $_{at\ 5\%}$			0.45	0.47	*NS	0.42	0.004	0.005	4.82	1.73	0.27	0.28	1.98	1.54
Interaction														
80% of IR	Control	Control	11.33	11.67	7.00	6.67	0.418	0.432	463.13	474.85	31.00	32.10	143.58	152.41
		V. C	11.67	12.33	7.00	7.33	0.432	0.440	478.70	496.32	31.76	32.41	152.04	160.87
		V. E	12.00	12.33	7.33	7.67	0.446	0.458	495.41	506.63	32.03	32.80	158.65	166.19
	Kaolin	Control	12.33	12.67	7.33	7.67	0.460	0.478	507.82	519.93	32.29	33.59	164.01	174.62
		V. C	12.67	13.00	7.33	7.67	0.472	0.489	524.71	541.42	32.77	33.57	171.99	181.76
		V. E	13.00	13.33	7.67	8.00	0.483	0.495	538.80	559.73	32.85	33.96	176.96	190.11
	Mg silicate	Control	13.33	13.67	7.67	8.00	0.498	0.511	553.24	570.27	33.08	34.06	183.06	194.23
		V. C	13.67	14.00	7.67	8.33	0.513	0.523	565.85	584.72	33.45	34.15	189.30	199.67
		V. E	13.67	14.00	7.67	8.33	0.527	0.544	582.19	597.02	34.62	34.74	195.75	206.34
100% of IR	Control	Control	14.00	14.33	8.00	8.33	0.544	0.560	584.01	601.25	35.29	35.32	206.07	218.36
		V. C	14.33	14.67	8.33	8.33	0.556	0.569	597.08	617.88	35.53	36.38	212.15	224.80
		V. E	14.67	15.00	8.33	8.67	0.569	0.585	612.38	635.63	35.62	36.63	218.16	232.82
	Kaolin	Control	15.00	15.33	8.33	8.67	0.585	0.608	625.90	643.48	35.76	36.70	223.82	236.17
		V. C	15.33	15.67	8.33	8.67	0.601	0.616	638.35	660.02	35.80	36.93	228.52	243.71
		V. E	15.67	16.00	8.67	8.67	0.616	0.637	649.48	664.11	35.98	37.05	233.67	246.08
	Mg silicate	Control	16.33	16.67	8.67	8.67	0.630	0.644	664.49	681.50	36.13	37.28	240.09	254.04
		V. C	16.67	17.33	9.00	9.33	0.644	0.664	675.56	702.46	36.20	37.33	244.61	262.21
		V. E	17.00	17.67	9.33	9.33	0.659	0.675	689.77	713.92	36.75	37.69	253.52	269.06
F. Test			*	*	*	*	**	**	**	**	*	*	**	**
LSD $_{at\ 5\%}$			1.11	1.16	0.99	1.03	0.011	0.011	11.80	4.24	0.65	0.69	4.82	3.76
A x B			*	*	*	*	*	*	*	**	*	**	*	**
A x C			*	*	*	*	*	*	*	*	*	*	*	*
B x C			*	*	*	*	*	*	*	*	*	*	*	*

Means within a row followed by a different letter (s) are statistically different at a 0.05 level ***NS= non-significant**

Table 8. Effect of foliar spraying with antitranspirants and vitamins on seed biochemical composition of the flax plants irrigated under different regimes at 150 days from sowing during seasons of 2023/24 and 2024/25

Treatments			Protein (%)		Carbohydrates (%)	
			1st season	2nd season	1st season	2nd season
Main factor : Irrigation requirement treatments						
80% of IR			19.31^{b}	19.87^{b}	24.70^{b}	25.42^{b}
100% of IR			21.64^{a}	22.26^{a}	27.01^{a}	27.83^{a}
F. Test			**	**	**	**
LSD $_{at\ 5\%}$			0.13	0.01	0.03	0.20
Sub main factor: Antitranspirant treatments (as foliar applications)						
Control (without)			19.56^{c}	20.09^{c}	25.21^{c}	25.93^{c}
Kaolin			20.61^{b}	21.27^{b}	25.61^{b}	26.40^{b}
Magnesium silicate			21.26^{a}	21.84^{a}	26.74^{a}	27.54^{a}
F. Test			**	**	**	**
LSD $_{at\ 5\%}$			0.27	0.23	0.28	0.32
Sub-sub main factor: Vitamin treatments (as foliar applications)						
Control (without)			20.20^{c}	20.82^{b}	25.70^{b}	26.45^{b}
Vitamin C			20.44^{b}	20.98^{b}	25.88^{ab}	26.64^{a}
Vitamin E			20.79^{a}	21.39^{a}	25.99^{a}	26.80^{a}
F. Test			**	*	*	*
LSD $_{at\ 5\%}$			0.16	0.17	0.21	0.17
Interaction						
80% of IR	Control	Control	17.94	18.56	23.46	24.02
		V. C	18.25	18.60	23.61	24.29
		V. E	19.19	19.69	23.76	24.50
	Kaolin	Control	19.41	20.05	23.98	24.53
		V. C	19.44	20.10	24.19	24.96
		V. E	19.55	20.18	24.42	25.39
	Mg silicate	Control	19.71	20.28	26.07	26.88
		V. C	20.01	20.42	26.31	27.06
		V. E	20.31	20.98	26.51	27.19
100% of IR	Control	Control	20.41	20.97	26.68	27.52
		V. C	20.68	21.20	26.89	27.61
		V. E	20.92	21.49	26.89	27.65
	Kaolin	Control	21.50	22.27	26.93	27.81
		V. C	21.71	22.30	27.06	27.83
		V. E	22.03	22.74	27.07	27.91
	Mg silicate	Control	22.25	22.80	27.11	27.93
		V. C	22.54	23.25	27.20	28.07
		V. E	22.72	23.27	27.26	28.14
F. Test			*	**	*	*
LSD $_{at\ 5\%}$			0.39	0.41	0.50	0.41
A x B			*	*	**	**
A x C			*	*	*	*
B x C			*	*	*	*

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

CONCLUSION

According to the obtained findings, the treatment of 100% IR positively reflected on flax yield and its fiber quality compared to the 80% of IR. Magnesium silicate was superior to kaolin. Vitamin E achieved the best performance in facing water deficit compared to Vitamin C. The best flax performance was achieved under the combined treatment of 100 IR x magnesium silicate x Vitamin E. On the other hand, spraying magnesium silicate combined with the vitamin E under irrigation with 80% of IR recorded the results closed to the treatment of 100 IR without foliar applications, indicating the effectiveness of this combination in mitigating the water deficit. Finally, it can be recommended to the combining foliar spraying with magnesium silicate and vitamin E on flax grown under water deficit stress, as this treatment contributes to increasing water use efficiency and maintaining growth, productivity, and quality in the flax crop.

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التغلب علي العجز المائي في زراعة الكتان من خلال الرش الورقي بالفيتامينات ومضادات النتح

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الملخص

الكتان هو محصول اقتصادي هام في مصر .إلا أن ندرة المياه التي يعاني منها القطاع الزراعي المصري تؤثر بشكل سلبي على نموّه الخضري، وإنتاجيته من الزيت، وجودة أليافه. لذا تم افتراض نهجٌ يُسهم في تحسين قدرة نبات الكتان على تحمّل إجهاد العجز المائي . أجريت تجربة حقلية خلال موسمين متتاليين (24/2023 و25/2024) لتقييم تأثير معاملات مختلفه من متطلبات الري [100% من متطلبات الري (تعادل1316 م ^{3} فدان $^{-1}$) و80 % من متطلبات الري (تعادل1052.8 م ^{3} فدان $^{-1}$)] كعامل دراسة رئيسي، ومضادات النتح [الكنترول (ماء الصنبور)، الكاؤلين (5٪، وزن / حجم) وسيليكات المغنيسيوم (5٪، وزن / حجم)] كعامل منشق أول، والفيتامينات [الكنترول (ماء الصنبور)، فيتامين C (100 ملجم لتر $^{-1}$) وفيتامين E (100 ملجم لتر$^{-1}$)] كعامل منشق ثاني على أداء الكتان (صنف جيزة 12، المزروع بغرض الألياف والبذور) .تم تقييم معايير النمو والمكونات الكيميائية للقش ومحصول الألياف وجودتها ومحصول الزيت والصفات البيوكميائية للبذور. أظهرت النتائج أن توافر الاحتياجات المائية الكاملة (100% من متطلبات الري) انعكس إيجابًا على نمو نبات الكتان وإنتاجيته من الألياف والزيت وجودتها مقارنةً بالري الناقص (80%). كما تفوقت سيليكات المغنيسيوم على الكاؤلين كمضاد نتح، بينما أثبت فيتامين E كفاءة أعلى من فيتامين C في تعزيز قدرة النبات على مواجهة الإجهاد المائي. وحقق دمج الري الكامل مع الرش بسيليكات المغنيسيوم وفيتامين E أفضل أداء لنبات الكتان. ومن ناحية أخرى، فإن استخدام سيليكات المغنيسيوم مع فيتامين E عند 80% من متطلبات الري أدى إلى نتائج مقاربة للري الكامل دون معاملات رش، مما يشير إلى كفاءة هذه التوليفة في التخفيف من حدة الإجهاد المائي.