Tikrit Journal for Agricultural Sciences
ISSN:1813-1646 (Print); 2664-0597 (Online)
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq
DOI: https://doi.org/10.25130/tjas.26.2.5

TJAS
Tikrit Journal for Agricultural Sciences

Potential synergistic effect of organic fertilization and spraying with stress-alleviating substances on raising the tolerance of squash to drought conditions

Kawther K. A. Dawa[1]; El-Saied E. Metwaly[1]; Mohammed E. Abo El-Nasr[2] and Nehal O. S. El-Mnily[2]
[1]Mans. Univ., Agric. Fac., Veg. Dep., EL-Mansoura, 35516, Egypt
[2]Horticulture Research Institute, Agriculture Research Center, Giza, 12619, Egypt

*Correspondence: drnehalosman@gmail.com

KEY WORDS:
Chitosan, Yeast, PEG, Squash

Received: 14/02/2026
Revision: 07/03/2026
Proofreading: 28/04/2026
Accepted: 10/04/2026
Available online: 30/06/2026

© 2026.This is an open access article under the CC by licenses http://creativecommons.org/licenses/by/4.0

ABSTRACT

Drought stress threatens many regions of the world, resulting in reduced productivity for many vegetable crops, as it negatively affects higher plants, as it causes an increase in the production of free radicals, which are responsible for the oxidation and destruction of plant cells. So, this research work was carried out using squash as tested plant, aiming to unravel the multifaceted interplay among irrigation treatments at various levels (100, 75 and 50 % of irrigation requirement IR), organic fertilizer at different rates (0.0, 12 and 24 m^3 ha^{-1}) and various stress-alleviating substances (chitosan, yeast and polyethene glycol PEG). Plant height, fresh and dry weights, leaves area, chlorophyll a and b were measured at 45 days from sowing as well as fruit yield of all pickings was measured as total yield. The squash plants receiving 100% of IR demonstrated the highest values for all aforementioned traits. Conversely, these values exhibited a gradual decrease with reduced irrigation levels, reaching their lowest values in the treatment with 50% of IR. For example, the highest values of dry weight (130.41 g $plant^{-1}$ for 1st season) were recorded with 100% of IR, while the lowest values (120.24 g $plant^{-1}$ for 1st season) were recorded with 50% of IR. Furthermore, there are a progressive increase in the values as the application rate of organic fertilizer increased from 0.0 to 12 and subsequently to 24 m^3 ha^{-1}. Spraying stimulants exerted a notable impact with the most effective treatment being PEG followed by yeast then chitosan. Notably, the performance in terms of the oxidative stress indicators and enzymatic antioxidants, subjected to water deficit (75% of IR) and fertilized with organic fertilizer (24 m^3 ha^{-1}), combined with stimulant sprays, surpassed those under conventional irrigation (100% of IR) in the absence of organic fertilizer. Finally, these findings align with the sustainable development goals, such as SDG2 (Zero Hunger) and SDG12 (Responsible Consumption and Production). Finally, these findings align with the Sustainable Development Goals, such as SDG2 (Zero Hunger) and SDG12 (Responsible Consumption and Production) via the potential of holistic strategies to mitigate the adverse effects of water scarcity on vegetable crops.

التأثير التآزري المحتمل للتسميد العضوي والرش بمواد تخفيف الإجهاد على زيادة تحمل الكوسة لظروف الجفاف

كوثر كامل أحمد ضوه [1]، السعيد السيد متولي فرج [1]، محمد السعيد أبو النصر[2]، نهال عثمان سرور المنيلي[2]
[1]جامعة المنصورة، كلية الزراعة، قسم الخضر، المنصورة، ٣٥٥١٦، مصر
[2]معهد بحوث البساتين، مركز البحوث الزراعية، الجيزة، ١٢٦١٩، مصر

الخلاصة
يُهدد الإجهاد الناتج عن الجفاف العديد من مناطق العالم، مما يؤدي إلى انخفاض إنتاجية العديد من محاصيل الخضراوات، فهو يؤثر سلبًا على النباتات الراقية من خلال تسببه في زيادة إنتاج الجذور الحرة المسؤولة عن أكسدة وتدمير الخلايا النباتية. لذلك، أُجري هذا البحث باستخدام نبات الكوسة كنبات مُختبَر، بهدف دراسة التداخل المُعقد بين معاملات الري عند مستويات مختلفة (100%، 75%، و50% من احتياجات الري)، والأسمدة العضوية بمعدلات مختلفة (0.0، 12، و24 م^3 /هكتار)، ومواد مُخففة للإجهاد (الشيتوزان، والخميرة، والبولي إيثيلين جليكول). تم قياس طول النبات، والوزن الطازج والجاف، والمساحة الورقية، ومحتوى الكلوروفيل أ وب بعد 45 يومًا من الزراعة، كما تم قياس محصول الثمار من جميع الجمعات كمحصول كلي . أظهرت نباتات القرع التي تلقت 100% من احتياجات الري أعلى القيم لجميع الصفات المذكورة. في المقابل، أظهرت هذه القيم انخفاضًا تدريجيًا مع انخفاض مستويات الري، لتصل إلى أدنى مستوياتها مع المعاملة التي استخدمت 50% من الري الموصى به. فعلى سبيل المثال، سُجلت أعلى قيم للوزن الجاف (130.41 جرام/نبات للموسم الأول) عند استخدام 100% من الري الموصى به، بينما سُجلت أدنى القيم (120.24 جرام/نبات للموسم الأول) عند استخدام 50% من الري الموصى به. علاوة على ذلك، لوحظ ازدياد تدريجي في القيم مع زيادة معدل استخدام السماد العضوي من 0 إلى 12 ثم إلى 24 م^3/هكتار. وكان لرش المحفزات تأثير ملحوظ، حيث كانت المعاملة الأكثر فعالية هي البولي إيثيلين جلايكول(PEG) ، تليها الخميرة ثم الشيتوزان. تجدر الإشارة إلى أن أداء النباتات، من حيث مؤشرات الإجهاد التأكسدي ومضادات الأكسدة الإنزيمية، التي تعرضت لنقص في المياه (75% من الكمية الموصي بها) وسُمّدت بسماد عضوي (24 م^3/هكتار) مع رشّها بمحفزات النمو، فاق أداء النباتات التي خضعت للري التقليدي (100% من الكمية الموصي بها) في غياب السماد العضوي. وتتوافق هذه النتائج مع أهداف التنمية المستدامة، مثل الهدف الثاني (القضاء على الجوع) والهدف الثاني عشر (الاستهلاك والإنتاج المسؤولان)، وذلك من خلال إمكانية تطبيق استراتيجيات شاملة للتخفيف من الآثار السلبية لنقص المياه على محاصيل الخضراوات.

الكلمات المفتاحية: الشيتوزان، الخميرة، البولي إيثيلين جليكول ، الكوسة .

INTRODUCTION

Squash (*Cucurbita pepo*), belongs to the Cucurbitaceae family. It is rich in essential nutrients such as vitamins, minerals and dietary fiber (Ahmed *et al.,* 2019). In Egypt, squash holds a prominent position among the preferred vegetable crops, catering to both local consumption and export markets (Okasha *et al.,* 2020). Egypt produced 469140 ton of squash from agriculture an area about 52940 fed (fed equal 4200 m^2) with an average of 21.27 ton ha^{-1} according to the Economic Affairs sector, (2023).

Climate change is closely linked to water scarcity, which emerging as a significant threat to the productivity of vegetable crops. The climate change alters rainfall patterns and increases evaporation, reducing the availability of freshwater suitable for agricultural purposes. Climate change also plays a major role in altering water quality (Dietz *et al.,* 2020).

Organic fertilizers are recognized for their pivotal role in enhancing soil quality, ultimately bolstering the plant's ability to withstand the stress imposed by water deficiency (Elsherpiny and Helmy, 2022). By providing a rich blend of nutrients, enhancing soil structure and supporting microbial activity, chicken manure becomes a valuable component in mitigating the adverse effects of water deficit conditions on squash productivity (Ibrahim *et al.,* 2023). In addition to organic fertilizers, various substances have exhibited promise in augmenting plant resistance to environmental stress, particularly drought. Notable among these are chitosan, yeast and polyethylene glycol (PEG).

Chitosan has been identified for its role in increasing plant resistance to drought stress (Waleed, 2016). Chitosan improved the performance of squash and its fruit yield and quality (Ibraheim and Mohsen, 2015). Yeast has garnered attention for its positive effects on plant growth, stress tolerance and overall crop performance. It enhanced the qualitative and quantitative traits of cowpea grown under drought stress (Gholami *et al.,* 2023). Additionally, in the agricultural context,

polyethylene glycol PEG has shown promising effects on plants, particularly in enhancing their resistance to environmental stressors (Baque *et al.,* 2016; Mustamu *et al.,* 2023). PEG 6000 improved the fruit yield and quality of cucumber grown under water deficit conditions (Wang *et al.,* 2024).

The current study hypothesized that applying various levels of organic fertilizer, combined with foliar applications of stress-alleviating substances, might benefit squash grown under water deficit, aligning with the sustainable development goals. Therefore, this research work aims to evaluate the effect of water deficit conditions, organic fertilization and spraying some stimulants on squash, thereby contributing to the sustainability of vegetable crop production in water-scarce regions such as Egypt.

MATERIALS AND METHODS

A field trial was implemented in summer during two successive seasons (2023 and 2024) *via* a strip-split plot experimental design with three replicates to assess the response of summer squash "Hour hybrid" grown under different irrigation levels as main factor (100, 75 and 50 % of irrigation requirement) to the organic fertilizer (chick droppings) at different levels (0.0, 12 and 24 m^3 ha^{-1}) as sub main factor and foliar spraying stimulants *i.e.,* chitosan, yeast and polyethylene glycol (PEG) as sub-sub main factor (Fig1). The research work was carried out at the experimental farm, Agriculture Faculty, Mansoura University, Egypt, located at coordinates 31°03′00″N 31°22′59″E.

Irrigation water treatments: The irrigation water requirements for the squash plant were estimated based on monthly climatic data collected from the Central Laboratory for Agricultural Climate, Agricultural Research Center, Ministry of Agriculture and Soil Reclamation, Egypt. The data of Table 1 represent the agro-climatic conditions of the Dakahlia Governorate (Mansoura region) during the 2023 and 2024 growing seasons. Reference evapotranspiration (ETo) values were calculated using the FAO Penman-Monteith equation and crop evapotranspiration (ETc) was determined by multiplying ETo by the crop coefficient (Kc) of squash at each growth stage, according to the following formula:

$$ETc = ETo \times Kc$$

FAO Penman-Monteith Equation for Reference Evapotranspiration (ETo) is as follows according **Allen *et al*., (1998).**

$$ETo = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T+273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)}$$

Where,

ETo = Reference evapotranspiration (mm/day)
Rn = Net radiation at the crop surface (MJ/m²/day)
G = Soil heat flux density (MJ/m²/day)
T = Mean daily air temperature at 2 m height (°C)
$\mathbf{u_2}$ = Wind speed at 2 m height (m/s)
$\mathbf{e_s}$ = Saturation vapor pressure (kPa)
$\mathbf{e_a}$ = Actual vapor pressure (kPa)
$\mathbf{(e_s - e_a)}$ = Vapor pressure deficit (kPa)
$\mathbf{\Delta}$ = Slope of saturation vapor pressure curve (kPa/°C)
$\mathbf{\gamma}$ = Psychrometric constant (kPa/°C)

Daily and total monthly water requirements per feddan (1.0 feddan = 4200 m²) were then computed and converted from millimeters to cubic meters. The total seasonal irrigation water requirements were summed for each year to represent the full irrigation amount. Three irrigation regimes were applied as:

I_1: 100% of irrigation requirement (2221.65 and 2213.98 m^3 fed^{-1} in 1st and 2nd seasons, respectively)
I_2: 75% of irrigation requirement (1666.23 and1660.48 m^3 fed^{-1})
I_3: 50% of irrigation requirement (1110.82 and 1106.99 m^3 fed^{-1})

Table 1. Climatic parameters and irrigation water requirements for squash during the 2023 and 2024seasons in Mansoura, Egypt

Month	Min Temp (°C)	Max Temp (°C)	Rel. Humidity (%)	Precipitation (mm)	Wind Speed (m/s)	Sunshine (h)	ETo (mm/month)	Avg. Daily Water Req. (m^3/fed)	Total Water Req. (m^3/fed)
Season of 2023									
September	22.89	35.48	55.28	1.60	3.26	12.31	7.29	18.37	551.25
October	20.18	31.32	59.65	5.50	2.88	11.38	5.30	24.04	745.34
November	17.39	28.09	66.73	25.70	2.55	10.57	3.63	20.13	603.89
December	11.41	20.62	67.95	13.60	3.07	10.17	2.57	10.36	321.18
Average	17.97	28.88	62.40	46.40	2.94	11.11	4.70	18.23	2221.65
Season of 2024									
September	23.06	35.87	55.10	0.00	3.09	12.32	7.24	18.26	547.71
October	20.35	31.36	59.05	8.60	2.82	11.38	5.21	23.62	732.23
November	16.15	26.52	60.79	2.60	2.55	10.58	3.65	20.21	606.43
December	13.62	23.75	68.45	25.40	2.38	10.17	2.62	10.57	327.61
Average	18.29	29.37	60.85	36.60	2.71	11.11	4.68	18.16	2213.98

Reference evapotranspiration (ETo) is often calculated using the Penman-Monteith (FAO 56 PM and **Allen *et al* 1998)**

Organic fertilizer treatments: Organic fertilizer (chick-droppings) was sourced from private poultry farm. The analysis of Organic fertilizer was conducted following the procedures outlined by **Tandon (2005).** The resulting data can be found in Table 2. Organic fertilizer treatments as sub main factor were as follows;
C_1: Without soil addition of organic fertilizer (control)
C_2: Applying organic fertilizer at rate of 50 % of recommended (12 m^3 ha^{-1} equal 5 m^3 fed^{-1})
C_3: Applying organic fertilizer at rate of 100 % of recommended (24 m^3 ha^{-1} equal 10 m^3 fed^{-1})
With soil preparing (at one month before sowing), organic fertilizer was applied based on the prescribed treatments.

Table 2. Characteristics of organic fertilizer

Characteristics	Values
K, mg kg^{-1}	5.05
C:N ratio	16.0
EC,dSm^{-1}	5.50
pH	6.55
Organic matter	41.28
Total C, %	24.0
Total N, %	1.50
P , mg kg^{-1}	0.72
Zn , mg kg^{-1}	30.0
Mn, mg kg^{-1}	20.0
CEC, cmol kg^{-1}	175

Applied foliar substances: Foliar treatments represented the sub-sub main factor. Foliar applications were initiated approximately 25 days after planting, involving four spraying times with a 15-day interval between each application. Each studied substance was sprayed utilizing a volume of 200 liters fed^{-1} with the first and second foliar events, while the volume was 400 with the third and fourth foliar events liters fed^{-1}. Foliar treatments were arranged as follows:

F_1: Foliar application of chitosan at rate of 150 mgL^{-1}

F_2: Foliar application of yeast at rate of 5.0 gL^{-1}

F_3: Foliar application of polyethylene glycol PEG at rate of 5.65 g L^{-1}

Chitosan was purchased from an Egyptian commercial market, sourced from Oxford Laboratory India, consists of 93% chitosan ($C_6H_{11}NO_4X_2$). The chitosan was dissolved in a 5% acetic acid solution. Then the studied rate was prepared (150 mgL^{-1}).

Preparation of yeast solution was carried out according to Mukherjee *et al.,* (2020). To obtain a natural yeast extract at level of 5 g L^{-1}, warm water was added to activate the dry yeast (*Saccharomyces cerevisiae*), as the water was at a temperature of around 100-110°F (37-43°C). A thermometer was used to ensure the water was within this range. A modest quantity of sugar was incorporated into the warm water at a 1:1 ratio to expedite yeast activation.

Following successful yeast activation, the mixture underwent a gentle stirring process to ensure uniform dispersion of the yeast throughout the liquid. Subsequently, it was left to incubate for a duration of 24 hours in a warm environment. Then subjected to two periods of freezing and thawing for yeast cell disruption and releasing their bio-constituents directly before usage.

The analysis of yeast extract was conducted following the procedures outlined by Walinga *et al.,* (2013) and Vieira *et al.,* (2016). The resulting data can be found in Table 3. It was sprayed at rate of 5.0 gL^{-1}.

PEG-600 (from Sigma Company) was obtained from Agric. Res. Center, Giza, Egypt. Then the studied rate was prepared. The density of PEG-600 is 1.13 g cm^{-3}. It was sprayed at rate of 5.65 gL^{-1}.

Table 3. Chemical components of yeast extract

Characteristics	Values
Nitrogen,%	7.12
Phosphorus, %	0.85
Potassium,%	1.19
Magnesium,%	0.30
Copper, mg kg^{-1}	6.00
Iron, mg kg^{-1}	108
Zinc, mg kg^{-1}	89
Vitamin B_1, mg $100g^{-1}$	22
Vitamin B_6, mg $100g^{-1}$	19

Soil sampling: Sample of initial soil (0-30cm depth) was collected and analyzed according to the standard methods described by **Gee and Baudet (1986)**, **Dewis and Freitas, (1970)** for both physical and chemical analyses, as outlined in Table 4.

Table 4. Attributes of the soil under experimentation before the planting of squash (average values from both seasons under study)

Initial soil characteristics												
Particle size distribution (%)				Texture class	Field capacity	Wilting point	Saturation	Available soil nutrients			EC,	pH
C. Sand	F. Sand	Silt	Clay					N	P	K		
					(%)			(mg kg^{-1})			dSm^{-1}	
1.80	23.0	24.6	50.60	Clay	45.0	22.50	90.0	28.95	9.10	230.1	3.83	7.97

Agricultural practices and cultivation: Summer squash seeds "Hour hybrid" were obtained from the Horticulture Res. Institute, Agric. Res. Center, Giza, Egypt. With soil preparing, calcium superphosphate (15.5% P_2O_5) was incorporated at a rate of 360 kg ha^{-1}. Dry seeds of summer squash were sown on the 6 th and 15th of September in the first and second seasons, respectively at a rate of 3.0 kg ha^{-1} in both seasons. The sowing was conducted in rows, each with a width of 1.0 m and a length of 5.0 m, with a spacing of 0.5 m between each plant. Each plot included three rows.

The irrigation process was conducted using drip irrigation system at intervals of every two days, with the specific quantities of irrigation water varying based on the prescribed irrigation treatments under study. The mineral fertilization (NPK) was implemented using fertigation system, as fertilization was applied every other day with irrigation water to achieve higher nutrient absorption efficiency and reduce nutrient loss. Fertilization began after the four true leaves appeared, using 120 kg ha^{-1} of ammonium sulphate (21% N), 60 kg ha^{-1} of ammonium nitrate (33.5% N) and 120 kg ha^{-1} of potassium sulphate (48% K_2O). As for potassium, it was applied in fertigation system gradually beginning with the onset of fruit set to ensure the plants meet their potassium needs during the critical fruit development period. Phosphoric acid was also applied periodically throughout the growing season at rate of 2.4 liter ha^{-1} every week, not only as a source of phosphorus, which is essential for root growth and improved fruit set, but also to help clean the drip irrigation network and prevent clogging of the emitters, while also supplementing the phosphorus added to the soil during planting preparation. All remaining agricultural procedures for cultivating summer squash adhered to the recommendations provided by the MASR.

Harvest: The harvest commenced 50 days after sowing and extended for 45 days. Fruits were collected every two days until the conclusion of the plant's life, resulting in a total of twenty-one pickings throughout the harvesting period.

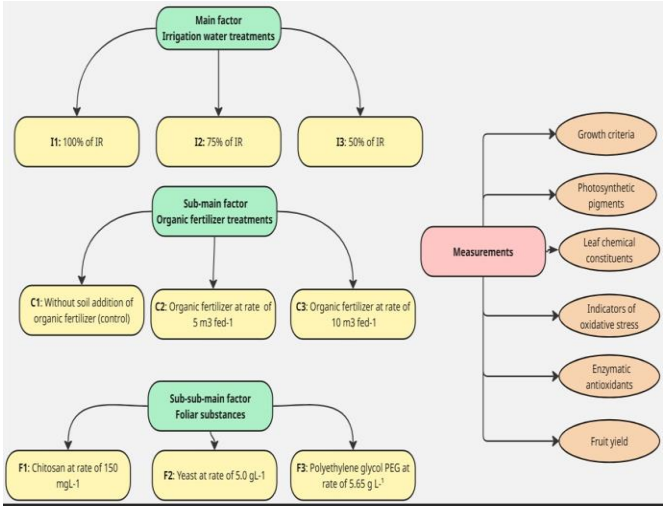

Fig 1. Flowchart of the experiment

Data recorded: Measurements and determination of the attributes of squash plants were conducted on six plants selected randomly. Plant height (cm), fresh and dry weights (g $plant^{-1}$) were manually measured at 45 days from sowing. Also, leaves area (m^2 $plant^{-1}$) were measured according to the following formula as described by Watson, (1952) at the same time.

$$\text{Leaf area} = \frac{\text{Area of the disks x fresh weight of leaves/plant}}{\text{Fresh weight of disks}}$$

Chlorophyll a & b and carotene (mg g^{-1} F.W) were spectrophotometrically determined in squash leaves as reported by Rajput and Patil, (2017) at a period of 45 days from sowing. Moreover, the squash leaves samples were digested *via* mixed of $HClO_4 + H_2SO_4$ (Peterburgski, 1968) for determining the leaf content of nitrogen, phosphorus and potassium (%) *via* Micro-

kjeldahl, spectrophotometer and flame photometer methods , respectively as mentioned by Walinga *et al.,* (2013). Also, at the same period, polyphenol oxidase (PPO) and peroxidase (POD) (unit mg^{-1} $protein^{-1}$) were spectrophotometrically determined as described by Alici and Arabaci, (2016). Malondialdehyde (MDA, biomarker of lipid peroxidation, $\mu mol.g^{-1}$) was spectrophotometrically estimated according to the standard methods reported by Davey *et al.,* (2005) at the same time. Additionally, total yield (fruit fresh weight of all pickings was measured as total yield (ton fed^{-1}).

The collected data underwent statistical analysis using the approach described by Gomez and Gomez (1984) and the software CoStat (Version 6.303, CoHort, USA, 1998–2004).

RESULT AND DISCUSSION

Table 5 illustrates the individual impacts of irrigation treatments (comprising 100%, 75% and 50% of irrigation requirements), organic fertilizer at varying levels (0, 50 and 100% of recommended) and spraying different stimulants (chitosan, yeast and polyethylene glycol PEG), as well as their interactions on foliage fresh and dry weights and leaf area during the growing seasons of 2023 and 2024.

Table 5: The individual impacts of irrigation treatments, organic fertilizer, spraying different stimulants and their interactions on squash growth criteria at 45 days from sowing during the growing seasons of 2023 and 2024

Treatments		Fresh weight, g $plant^{-1}$		Dry weight, g $plant^{-1}$		Leaves area, m^2 $plant^{-1}$	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
A : Irrigation treatments							
100% of irrigation requirement		934.59a	947.00a	130.41a	132.92a	9731.5a	9859.6a
75% of irrigation requirement		869.19b	879.93b	126.58b	129.25b	9168.9b	9287.0b
50% of irrigation requirement		750.41c	760.89c	120.24c	122.60c	8002.5c	8121.7c
F test		**	**	**	**	**	**
B: Organic fertilization							
Without organic fertilizer (control)		805.93c	817.11c	123.24c	125.71c	8548.5c	8668.8c
Organic fertilizer (12 m^3 ha^{-1})		855.44b	866.19b	125.90b	128.37b	8999.4b	9115.5b
Organic fertilizer (24 m^3 ha^{-1})		892.81a	904.52a	128.08a	130.68a	9355.0a	9484.1a
F test		**	**	**	**	**	**
C: Foliar applications							
Chitosan (150 mgL^{-1})		842.19c	853.11c	125.23b	127.72b	8884.6c	9007.0c
Yeast (5.0 gL^{-1})		849.56b	860.63b	125.7ab	128.2ab	8958.6b	9077.2b
PEG (5.65 gL^{-1})		862.44a	874.07a	126.32a	128.87a	9059.7a	9184.1a
F test		**	**	**	**	**	**
LSD at 5%	**Irrigation treatments (Factor A)**	**17.88**	**22.47**	**2.44**	**3.34**	**12.1225**	**25.28**
	Organic fertilization (Factor B)	**6.52**	**4.80**	**0.53**	**0.65**	**11.765**	**5.29**
	Foliar applications (Factor C)	**5.32**	**5.37**	**0.78**	**0.79**	**22.5875**	**0.8775**

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

The data indicate that squash plants receiving 100% of irrigation requirements demonstrated the highest values for foliage fresh and dry weights and leaf area. Conversely, these values exhibited a gradual decrease with reduced irrigation water quantities, reaching their lowest values in the treatment with 50% of irrigation requirements. Furthermore, the data of Table 5 illustrate a progressive increase in the values of foliage fresh and dry weights and leaf area as the application rate of organic fertilizer increased from 0.0 to 50 and subsequently to 100% of the recommended dosage.

Table 5: Cont. (Interaction).

Treatments			Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaves area, cm^2 plant^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
		F_1	868.33	881.33	126.71	129.42	9222.428	9367.573
	C_1	F_2	874.67	886.33	127.06	129.27	9280.928	9387.073
		F_3	892.33	904.00	127.52	130.12	9327.50	9454.25
		F_1	941.67	952.33	130.65	133.39	9778.178	9890.823
I_1	C_2	F_2	948.33	959.00	131.15	133.34	9832.323	9939.573
		F_3	957.33	968.00	131.58	134.22	9887.573	10000.25
		F_1	968.00	981.33	132.55	135.08	10021.93	10163.82
	C_2	F_2	976.67	994.33	132.95	135.61	10083.68	10263.5
		F_3	984.00	996.33	133.51	135.82	10149.75	10270.0
		F_1	815.33	827.33	123.73	126.11	8690.50	8824.823
	C_1	F_2	823.00	833.00	124.03	126.46	8768.50	8876.823
		F_3	827.67	840.00	124.51	127.48	8830.25	8970.00
		F_1	846.33	858.00	125.19	128.17	9007.928	9130.323
I_2	C_2	F_2	852.67	862.33	125.70	128.38	9084.823	9194.25
		F_3	899.33	914.00	128.11	130.54	9403.323	9546.323
		F_1	913.00	921.33	128.88	130.99	9510.573	9614.573
	C_2	F_2	919.00	926.00	129.37	132.57	9586.428	9676.323
		F_3	926.33	937.33	129.68	132.51	9638.428	9750.00
		F_1	708.33	716.00	118.02	120.39	7524.823	7602.823
	C_1	F_2	717.67	727.33	118.61	120.86	7593.073	7696.00
		F_3	726.00	738.67	119.00	121.27	7699.25	7840.073
		F_1	744.00	754.33	119.86	122.11	7902.928	8031.823
I_3	C_2	F_2	751.00	760.00	120.24	122.38	8000.428	8100.073
		F_3	758.33	767.67	120.66	122.84	8097.928	8206.25
		F_1	774.67	786.00	121.48	123.86	8302.678	8437.00
	C_2	F_2	783.00	797.33	121.98	124.69	8398.00	8561.573
		F_3	790.67	800.67	122.29	124.99	8504.178	8620.073
F test			**	**	**	**	**	**
LSD at 5%			**15.97**	**16.12**	**2.34**	**2.36**	**67.73**	**2.6325**

I_1: 100% of irrigation requirement, **I_2:** 75% of irrigation requirement, **I_3:** 50% of irrigation requirement, **C_1:** Without organic fertilizer (control); **C_2:** Organic fertilizer (12 m^3 ha^{-1}), **C_3:** Organic fertilizer (24 m^3 ha^{-1}), **F_1:** Chitosan (150 mgL^{-1}), **F_2:** Yeast (5.0 gL^{-1}) and **F_3:** PEG (5.65 gL^{-1})

On the other hand, the foliar application of stimulants exerted a notable impact on plant foliage fresh and dry weights and leaf area, with the most effective treatment being polyethylene glycol (PEG), followed by yeast and then chitosan. Regarding the interaction effects outlined in Table 5, the highest values for foliage fresh and dry weights and leaf area were achieved through the combined treatment of 100% irrigation water, the complete recommended organic fertilizer dosage(100%) and the application of polyethylene glycol (PEG) as a foliar spray. Notably, it is important to highlight that the growth parameters of plants subjected to water deficit treatments (75% of irrigation requirements) and fertilized with 100% of the recommended organic dosage, combined with stimulant sprays, surpassed those under conventional irrigation (100%) in the absence of organic fertilizer. This suggests that the simultaneous use of recommended organic fertilizer and stimulants under water deficit conditions yielded more favorable outcomes in terms of plant growth parameters compared to traditional irrigation without organic supplementation. The same trend was found for both studied seasons.

Data presented in Tables 6 and 7 clearly indicate the impact of studied irrigation treatments, organic fertilizer and the application of various stimulants (chitosan, yeast and PEG) on photosynthetic pigments in leaves, including chlorophyll a and b as well as carotene (Table 6) as well as leaves chemical constituents (NPK) (Table 7) of squash plants at the 45-day mark from sowing. These observations were made during the growing seasons of 2023 and 2024. Data show that squash plants irrigated with 100% of irrigation requirements had the highest values of photosynthetic pigments [chlorophyll a, b and carotene] and chemical constituents (N, P, K). The treatment of 75% of irrigation requirements came in the second order, while the treatment of 50% of irrigation requirements came in the last order.

Table 6. The individual impacts of irrigation treatments, organic fertilizer, spraying different stimulants and their interactions on photosynthetic pigments in leaves of squash growth at 45 days from sowing during the growing seasons of 2023 and 2024

Treatments	*Chl. a*, mg g^{-1}		*Chl. b*, mg g^{-1}		Carotene, mg g^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
A : Irrigation treatments						
100% of irrigation requirement	0.955a	0.978a	0.622a	0.636a	0.282a	0.296c
75% of irrigation requirement	0.909b	0.929b	0.560b	0.571b	0.252b	0.265b
50% of irrigation requirement	0.816c	0.833c	0.458c	0.469c	0.202c	0.212a
F test	**	**	**	**	**	**
B: Organic fertilization						
Without organic fertilizer (control)	0.862c	0.879c	0.503c	0.515c	0.225c	0.236c
Organic fertilizer (12 m^3 ha^{-1})	0.896b	0.916b	0.551b	0.562b	0.247b	0.259b
Organic fertilizer (24 m^3 ha^{-1})	0.922a	0.945a	0.586a	0.599a	0.264a	0.277a
F test	**	**	**	**	**	**
C: Foliar applications						
Chitosan (150 mgL^{-1})	0.886c	0.906c	0.538c	0.551c	0.241c	0.253c
Yeast (5.0 gL^{-1})	0.892b	0.912b	0.545b	0.557b	0.245b	0.257b
PEG (5.65 gL^{-1})	0.901a	0.922a	0.556a	0.569a	0.250a	0.263a
F test	**	**	**	**	**	**
LSD at 5% **Irrigation treatments (Factor A)**	**0.008**	**0.010**	**0.006**	**0.004**	**0.002**	**0.002**
Organic fertilization (Factor B)	**0.009**	**0.009**	**0.003**	**0.006**	**0.002**	**0.002**
Foliar applications (Factor C)	**0.005**	**0.005**	**0.04**	**0.003**	**0.002**	**0.007**

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

Table 6: Cont. (Interaction).

Treatments			*Chl. a*, mg g^{-1}		*Chl. b*, mg g^{-1}		Carotene, mg g^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
		F_1	0.913	0.934	0.562	0.573	0.250	0.262
	C_1	F_2	0.918	0.936	0.571	0.587	0.255	0.268
		F_3	0.925	0.947	0.578	0.593	0.258	0.271
		F_1	0.959	0.978	0.630	0.646	0.286	0.299
I_1	C_2	F_2	0.965	0.989	0.634	0.649	0.289	0.305
		F_3	0.968	0.988	0.639	0.652	0.291	0.306
		F_1	0.977	1.004	0.656	0.672	0.299	0.314
	C_2	F_2	0.983	1.010	0.659	0.676	0.303	0.317
		F_3	0.987	1.014	0.665	0.680	0.305	0.321
		F_1	0.868	0.887	0.511	0.522	0.227	0.238
I_2	C_1	F_2	0.873	0.890	0.518	0.528	0.232	0.243
		F_3	0.880	0.902	0.526	0.537	0.236	0.247

		F_1	0.894	0.914	0.541	0.552	0.241	0.253
	C_2	F_2	0.900	0.920	0.548	0.555	0.245	0.258
		F_3	0.929	0.950	0.582	0.590	0.264	0.277
		F_1	0.940	0.961	0.598	0.612	0.271	0.284
	C_2	F_2	0.945	0.964	0.605	0.617	0.276	0.289
		F_3	0.950	0.970	0.616	0.631	0.280	0.294
		F_1	0.784	0.795	0.412	0.421	0.186	0.196
	C_1	F_2	0.795	0.805	0.424	0.434	0.188	0.197
		F_3	0.800	0.818	0.430	0.439	0.192	0.202
		F_1	0.810	0.827	0.452	0.465	0.199	0.209
I_3	C_2	F_2	0.815	0.835	0.459	0.470	0.202	0.212
		F_3	0.823	0.839	0.470	0.483	0.206	0.216
		F_1	0.834	0.854	0.483	0.495	0.211	0.221
	C_2	F_2	0.838	0.856	0.491	0.501	0.215	0.226
		F_3	0.845	0.869	0.500	0.513	0.220	0.231
F test			**	**	**	**	**	**
LSD at 5%			**0.016**	**0.014**	**0.011**	**0.010**	**0.005**	**0.005**

I_1: 100% of irrigation requirement**, I_2:** 75% of irrigation requirement, **I_3:** 50% of irrigation requirement**, C_1:** Without organic fertilizer (control)**; C_2:** Organic fertilizer (12 m^3 ha^{-1})**, C_3:** Organic fertilizer (24 m^3 ha^{-1})**, F_1:** Chitosan (150 mgL^{-1})**, F_2:** Yeast (5.0 gL^{-1}) and **F_3:** PEG (5.65 gL^{-1})**

Table 7. The individual impacts of irrigation treatments, organic fertilizer, spraying different stimulants and their interactions on chemical constituents in leaves of squash growth at 45 days from sowing during the growing seasons of 2023 and 2024

Treatments		N, %		P, %		K, %	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
A : Irrigation treatments							
100% of irrigation requirement		3.24a	3.31a	0.462a	0.481a	2.92a	2.95a
75% of irrigation requirement		2.95b	3.02b	0.425b	0.443b	2.64b	2.68b
50% of irrigation requirement		2.42c	2.46c	0.364c	0.379c	2.13c	2.16c
F test		**	**	**	**	**	**
B: Organic fertilization							
Without organic fertilizer (control)		2.67c	2.72c	0.391c	0.408c	2.37c	2.40c
Organic fertilizer (12 m^3 ha^{-1})		2.89b	2.95b	0.420b	0.437b	2.57b	2.61b
Organic fertilizer (24 m^3 ha^{-1})		3.05a	3.12a	0.441a	0.458a	2.74a	2.78a
F test		**	**	**	**	**	**
C: Foliar applications							
Chitosan (150 mgL^{-1})		2.83b	2.89c	0.412c	0.429c	2.52c	2.55c
Yeast (5.0 gL^{-1})		2.86b	2.92b	0.416b	0.432b	2.56b	2.60b
PEG (5.65 gL^{-1})		2.92a	2.98a	0.423a	0.441a	2.61a	2.65a
F test		**	**	**	**	**	**
LSD at 5%	**Irrigation treatments (Factor A)**	**0.04**	**0.07**	**0.001**	**0.004**	**0.03**	**0.07**
	Organic fertilization (Factor B)	**0.04**	**0.02**	**0.003**	**0.004**	**0.02**	**0.02**
	Foliar applications (Factor C)	**0.04**	**0.02**	**0.003**	**0.003**	**0.02**	**0.02**

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

Also, the data of Tables 6 and 7 indicate that the values of photosynthetic pigments [chlorophyll a, b and carotene] and chemical constituents (N, P, K) increased as the level of organic fertilizer increased, as the highest values were realized when 100% of recommended was added. Regarding the foliar application of stimulants, the data indicate that the superior treatment for obtaining the maximum values of photosynthetic pigments [chlorophyll a, b and carotene] and chemical constituents (N, P, K) was polyethylene glycol

(PEG), followed by yeast and then chitosan. The interaction effects presented in Tables 6 and 7 reveal that the most elevated values for photosynthetic pigments [chlorophyll a, b and carotene] and essential chemical constituents (NPK) were achieved when employing a comprehensive approach. This approach involved 100% irrigation water, the complete recommended dosage of organic fertilizer (100%) and the foliar application of polyethylene glycol (PEG). Notably, it is crucial to emphasize that, under water deficit conditions (75% irrigation requirements), plants fertilized with 100% recommended organic dosage, in conjunction with stimulant sprays, exhibited higher concentrations of photosynthetic pigments and chemical constituents compared to those under conventional irrigation (100%) without organic fertilizer. This consistent trend across both studied seasons underscores the synergistic benefits of combining nutrient supplementation and foliar stimulation under water deficit conditions.

Table 7: Cont. (Interaction).

Treatments			N, %		P, %		K, %	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
		F_1	2.95	3.02	0.425	0.441	2.62	2.65
	C_1	F_2	2.99	3.05	0.430	0.449	2.67	2.71
		F_3	3.03	3.11	0.436	0.455	2.70	2.74
		F_1	3.27	3.34	0.465	0.484	2.94	2.97
I_1	C_2	F_2	3.29	3.37	0.470	0.489	2.97	3.01
		F_3	3.33	3.39	0.474	0.496	3.02	3.05
		F_1	3.40	3.49	0.482	0.501	3.08	3.11
	C_2	F_2	3.42	3.52	0.486	0.504	3.12	3.16
		F_3	3.45	3.54	0.489	0.508	3.15	3.19
		F_1	2.72	2.78	0.396	0.411	2.41	2.45
	C_1	F_2	2.75	2.82	0.401	0.416	2.45	2.50
		F_3	2.79	2.86	0.404	0.420	2.48	2.52
		F_1	2.86	2.93	0.413	0.430	2.54	2.57
I_2	C_2	F_2	2.90	2.96	0.418	0.435	2.57	2.61
		F_3	3.06	3.14	0.440	0.459	2.74	2.78
		F_1	3.12	3.19	0.449	0.466	2.83	2.86
	C_2	F_2	3.17	3.23	0.451	0.470	2.86	2.90
		F_3	3.20	3.26	0.458	0.475	2.90	2.94
		F_1	2.23	2.26	0.340	0.355	1.95	1.98
	C_1	F_2	2.26	2.29	0.345	0.356	1.99	2.02
		F_3	2.30	2.35	0.348	0.364	2.03	2.08
		F_1	2.38	2.43	0.361	0.375	2.10	2.10
I_3	C_2	F_2	2.42	2.48	0.365	0.376	2.14	2.20
		F_3	2.47	2.52	0.371	0.385	2.17	2.22
		F_1	2.52	2.58	0.380	0.395	2.23	2.29
	C_2	F_2	2.56	2.61	0.383	0.396	2.25	2.30
		F_3	2.61	2.67	0.388	0.405	2.28	2.31
F test			**	**	**	**	**	**
LSD at 5%			**0.12**	**0.06**	**0.009**	**0.009**	**0.05**	**0.05**

I_1: 100% of irrigation requirement, **I_2:** 75% of irrigation requirement, **I_3:** 50% of irrigation requirement, **C_1:** Without organic fertilizer (control); **C_2:** Organic fertilizer (12 m^3 ha^{-1}), **C_3:** Organic fertilizer (24 m^3 ha^{-1}), **F_1:** Chitosan (150 mgL^{-1}), **F_2:** Yeast (5.0 gL^{-1}) and **F_3:** PEG (5.65 gL^{-1})

Data presented in Table 8 indicate the individual effects of studied irrigation treatments, organic fertilizer levels, spraying various stimulants (chitosan, yeast and PEG) as well as their combined impact on the indicators of oxidative stress, including proline (non-enzymatic antioxidant) and malondialdehyde (MDA) as well as enzymatic antioxidants such as polyphenol oxidase and peroxidase in leaves at a period of 45 days from sowing during the growing seasons of 2023 and 2024. MDA is a biomarker that reflects the extent of oxidative stress in plants. Its concentration increases with plant cell damage caused by stress, as it is the product of lipid peroxidation. Generally, it can be said that a high value indicates significant environmental damage to the plant. The peak levels of proline, malondialdehyde, polyphenol oxidase and peroxidase were observed in response to the water deficit stress treatment equivalent to 50% of the traditional irrigation amount. Conversely, the content of these indicators exhibited a decreasing trend as the irrigation water amount increased. The lowest values were recorded when plants were subjected to irrigation with 100% of the traditional amount. Conversely, as the irrigation water amount increases to 100% of the traditional level, the plants experience less stress, leading to lower accumulation of proline and decreased activity of MDA, PPO and POD. Concerning the organic fertilizer levels, the maximum values of proline, malondialdehyde, polyphenol oxidase and peroxidase were observed in the control treatment, where no organic fertilizer was applied.

Conversely, the content of these indicators exhibited a declining pattern in response to introducing organic fertilizer into the soil, with values gradually decreasing as the amount of added organic fertilizer increased. Regarding foliar applications, chitosan treatment exhibited the highest values for proline, malondialdehyde, polyphenol oxidase and peroxidase. followed by yeast treatment. In contrast, the treatment involving polyethylene glycol resulted in the lowest values for proline, MDA, PPO and POD. In analyzing and discussing the individual impact of the investigated treatments, it can be asserted that the most favorable combined treatment is indicated by the lowest values. The optimal outcome was observed when plants were subjected to 100% of the irrigation requirements, received organic fertilizer at 100% of the recommended rate and were sprayed with polyethylene glycol.

Table 8. The individual impacts of irrigation treatments, organic fertilizer, spraying different stimulants and their interactions on indicators of oxidative stress at 45 days from sowing during the growing seasons of 2023 and 2024

Treatments	Proline, µg.g^{-1} F.W		MDA, µmol.g^{-1} F.W		PPO, unit mg^{-1} protein^{-1}		POD, unit mg^{-1} protein^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
A : Irrigation treatments								
100% of irrigation requirement	6.77c	6.88c	9.44c	9.54c	7.12c	6.06c	6.32c	5.36c
75% of irrigation requirement	7.92b	8.04b	10.36b	10.51b	7.73b	6.63b	7.16b	6.18b
50% of irrigation requirement	9.50a	9.66a	11.67a	11.87a	8.69a	7.50a	8.24a	7.09a
F test	**	**	**	**	**	**	**	**
B: Organic fertilization								
Without organic fertilizer (control)	8.68a	8.81a	11.00a	11.18a	8.27a	7.13a	7.78a	6.51a
Organic fertilizer (12 m^3 ha^{-1})	8.03b	8.16b	10.60b	10.74b	7.81b	6.61b	7.23b	6.24b
Organic fertilizer (24 m^3 ha^{-1})	7.47c	7.60c	9.86c	10.01c	7.47c	6.44c	6.75c	5.88c
F test	**	**	**	**	**	**	**	**
C: Foliar applications								

Chitosan (150 mgL^{-1})		8.19a	8.33a	10.64a	10.77a	7.93a	6.78a	7.35a	6.33a
Yeast (5.0 gL^{-1})		8.11b	8.24b	10.53b	10.70b	7.86b	6.72b	7.25b	6.18b
PEG (5.65 gL^{-1})		7.88c	8.01c	10.29c	10.45c	7.76c	6.68b	7.14c	6.12c
F test		**	**	**	**	**	**	**	**
LSD at 5%	**Irrigation treatments (Factor A)**	**0.16**	**0.22**	**0.13**	**0.29**	**0.06**	**0.08**	**0.10**	**0.13**
	Organic fertilization (Factor B)	**0.04**	**0.03**	**0.06**	**0.05**	**0.07**	**0.07**	**0.08**	**0.03**
	Foliar applications (Factor C)	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.04**	**0.07**	**0.04**

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

Table 8: Cont. (Interaction).

Treatments			Proline, µg.g^{-1} F.W		MDA, µmol.g^{-1} F.W		PPO, unit mg^{-1} $protein^{-1}$		POD, unit mg^{-1} $protein^{-1}$	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
I_1	C_1	F_1	7.91	8.04	10.30	10.41	7.74	6.73	7.20	5.90
		F_2	7.75	7.87	10.26	10.41	7.65	6.66	7.10	5.74
		F_3	7.57	7.68	10.14	10.24	7.59	6.22	7.00	6.02
	C_2	F_1	6.67	6.77	9.47	9.56	7.06	5.71	6.32	5.31
		F_2	6.63	6.76	9.40	9.50	6.97	5.99	6.21	5.29
		F_3	6.23	6.36	9.35	9.44	6.92	5.81	6.07	5.29
	C_2	F_1	6.11	6.18	8.78	8.89	6.76	5.74	5.78	5.03
		F_2	6.04	6.13	8.66	8.77	6.72	5.84	5.65	4.64
		F_3	6.01	6.10	8.57	8.67	6.67	5.81	5.53	5.04
I_2	C_1	F_1	8.78	8.89	11.01	11.19	8.22	6.73	7.78	6.68
		F_2	8.65	8.77	10.88	11.12	8.15	7.42	7.70	6.48
		F_3	8.58	8.72	10.87	11.07	8.08	6.95	7.62	6.16
	C_2	F_1	8.37	8.51	10.73	10.87	7.92	6.65	7.41	6.67
		F_2	8.27	8.38	10.67	10.81	7.87	6.37	7.36	6.69
		F_3	7.50	7.61	10.07	10.20	7.52	6.77	6.93	5.81
	C_2	F_1	7.23	7.35	9.80	9.91	7.35	6.70	6.68	5.54
		F_2	7.08	7.18	9.61	9.73	7.30	6.12	6.62	5.89
		F_3	6.80	6.92	9.56	9.69	7.18	5.96	6.55	5.69
I_3	C_1	F_1	9.66	9.80	12.37	12.52	9.07	8.07	8.59	7.31
		F_2	9.64	9.78	12.11	12.27	8.99	7.82	8.50	7.14
		F_3	9.62	9.73	11.07	11.36	8.89	7.56	8.45	7.18
	C_2	F_1	9.57	9.75	11.99	11.98	8.75	7.35	8.32	7.24
		F_2	9.52	9.72	11.88	12.19	8.66	7.36	8.26	7.18
		F_3	9.48	9.58	11.79	12.07	8.59	7.48	8.16	6.69
	C_2	F_1	9.44	9.63	11.33	11.60	8.45	7.35	8.03	7.31
		F_2	9.37	9.55	11.27	11.52	8.42	6.89	7.96	6.54
		F_3	9.16	9.37	11.17	11.33	8.33	7.58	7.92	7.20
F test			**	**	**	**	**	**	**	**
LSD at 5%			**0.14**	**0.14**	**0.16**	**0.16**	**0.16**	**0.12**	**0.20**	**0.11**

I_1: 100% of irrigation requirement, **I_2:** 75% of irrigation requirement, **I_3:** 50% of irrigation requirement, **C_1:** Without organic fertilizer (control); **C_2:** Organic fertilizer (12 m^3 ha^{-1}), **C_3:** Organic fertilizer (24 m^3 ha^{-1}), **F_1:** Chitosan (150 mgL^{-1}), **F_2:** Yeast (5.0 gL^{-1}) and **F_3:** PEG (5.65 gL^{-1})

Scientifically, these results suggest that a combination of adequate water supply, optimal organic fertilizer application and the use of polyethylene glycol contributes to the mitigation of stress indicators in plants. The 100% of the irrigation requirements ensures ample water availability, reducing water stress-related responses. Simultaneously, organic fertilizer at the recommended rate likely provides essential nutrients, fostering healthier

plant physiology. The addition of polyethylene glycol might further contribute to stress alleviation, possibly by improving water retention and minimizing water loss.

In the context of a 75% of irrigation requirements, it's noteworthy that employing organic fertilization at 100%, combined with all foliar applications, as well as using 50% of organic fertilizer combined with polyethylene glycol, led to a reduction in the plant's content of these indicators compared to the values under 100% of irrigation requirements. Scientifically, this implies that under conditions of slightly reduced water availability, the strategic use of organic fertilization and targeted foliar applications, particularly in combination with polyethylene glycol, can still positively influence plant stress responses, resulting in lower levels of proline, MDA, PPO and POD. Similar trend was found under both investigated seasons.

Fig 2 provides a detailed exposition of the individual and combined impacts of the examined treatments on total yield of squash fruits for the growing seasons of 2023 and 2024. While Fig 3 (heat map) provides a detailed exposition of the combined impacts of the examined treatments on total yield of squash fruits for the growing seasons of 2023 and 2024, as the color intensity reflects the values obtained, with higher values taking on a darker color. The data reveal that squash plants subjected to 100% of the irrigation requirements exhibited the highest values of total yield. Conversely, these values exhibited a gradual decrease with reduced irrigation water quantities, reaching their lowest values in the treatment with 50% of irrigation requirements.

Furthermore, the data of Figs 2 and 3 illustrate a progressive increase in the values of fruit yield as the soil addition rate of organic fertilizer increased from 0 to 50 and subsequently to 100% of the recommended dosage. Regarding foliar applications, the investigated stimulants demonstrated a significant influence on the total yield, were notably affected by the applied stimulants. Among the studied treatments, polyethylene glycol (PEG) emerged as the most effective, followed by yeast and then chitosan. Concerning the interaction effects, the highest values of total yield were achieved through the combined treatment of 100% irrigation water, the complete recommended organic fertilizer dosage (100%) and the application of polyethylene glycol (PEG) as a foliar spray. Notably, it is important to highlight that the fruits yield of plants subjected to water deficit treatments (75% of irrigation requirements) and fertilized with 100% of the recommended organic dosage, combined with stimulant sprays, surpassed those under conventional irrigation (100%) in the absence of organic fertilizer. The same trend was found for both investigated seasons.

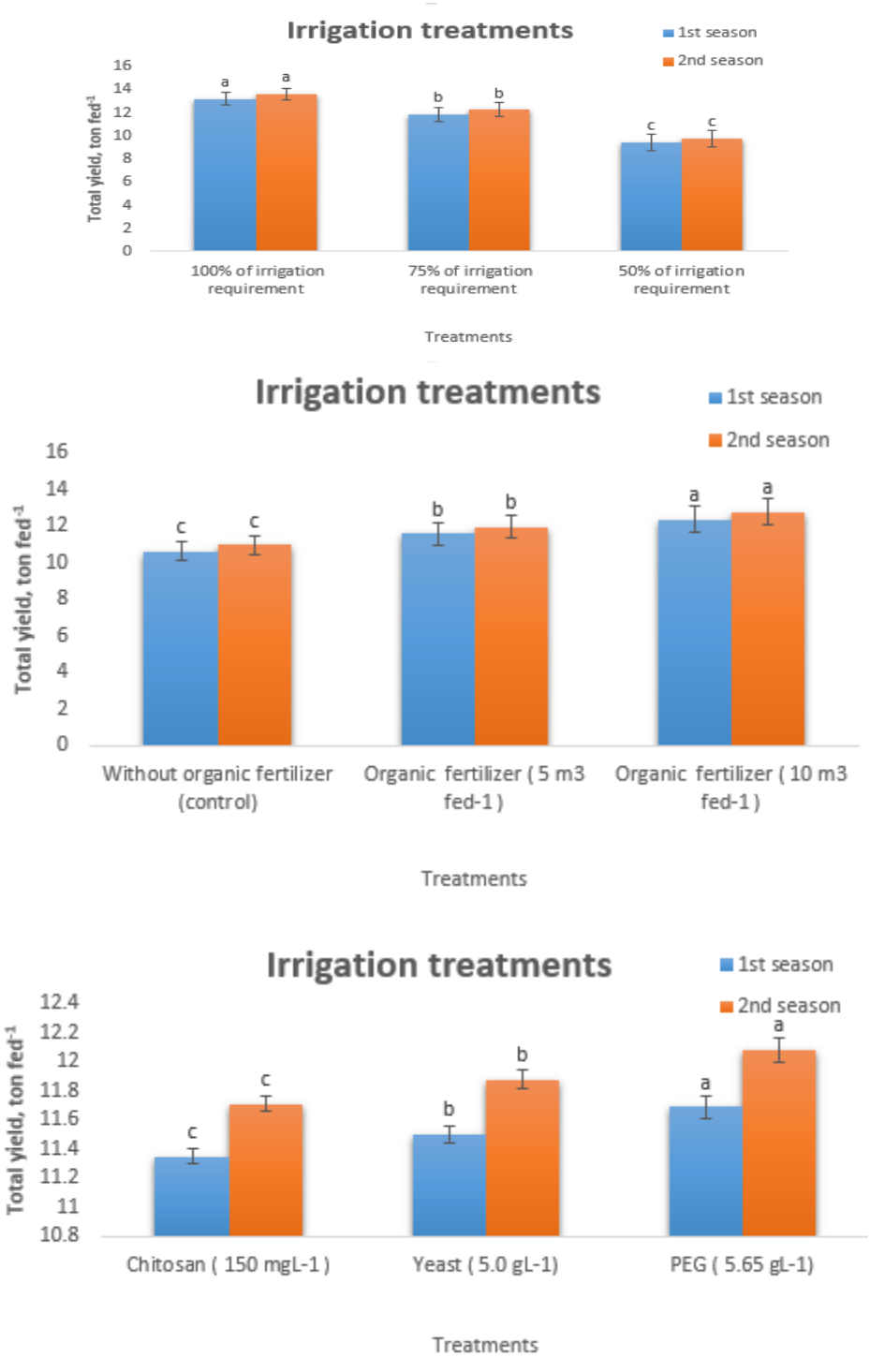

Fig 2. The individual impacts of irrigation treatments, organic fertilizer, spraying different stimulants on fruit yield during the growing seasons of 2023 and 2024

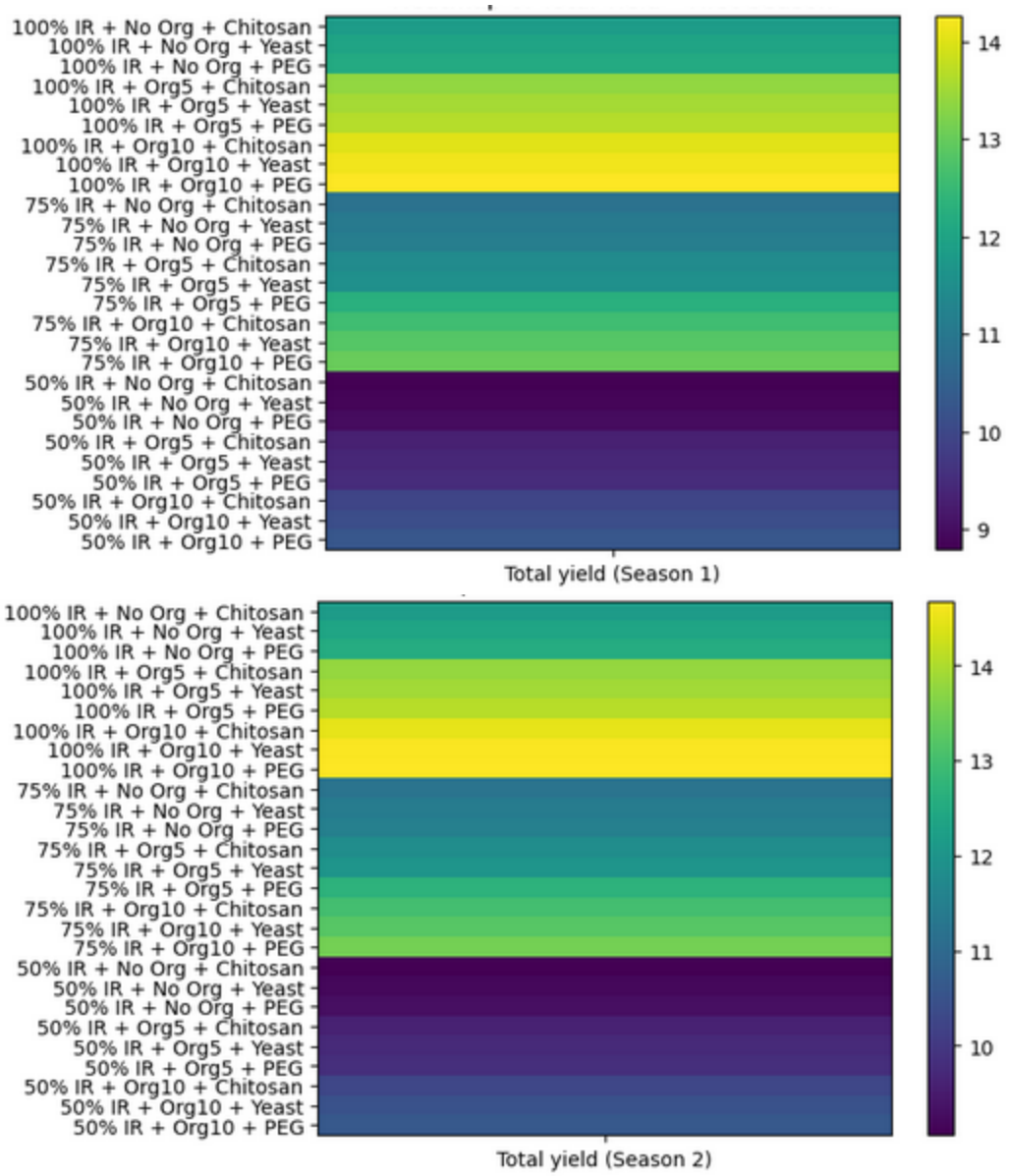

Fig 3. Heat map of total yield during the growing seasons of 2023 and 2024 showing the interaction impacts of irrigation treatments, organic fertilizer, spraying different stimulants

DISCUSSION

Concerning the individual effect of irrigation treatments on plant performance, the diminishing foliage fresh and dry weights and leaf area observed with decreasing irrigation levels can be attributed to a cascade of interconnected physiological factors. Reduced irrigation induces water stress, hindering essential processes like photosynthesis and nutrient uptake. Inadequate water availability limits cell expansion, disrupts turgor pressure and adversely affects root development, thereby compromising overall plant structure and growth (Sun *at al.* 2020).

Conversely, the decline in photosynthetic pigments and chemical constituents with reduced irrigation levels (75% and 50% traditional irrigation) may be linked to water stress-induced limitations on nutrient uptake and photosynthetic efficiency. Proline, a non-

enzymatic antioxidant, is often accumulated in higher amounts under stress conditions as part of the plant's defense mechanism (Taiz *et al.,* 2015). Similarly, MDA, a biomarker of lipid peroxidation, tends to increase under conditions of oxidative stress. The drought stress negatively affected the squash plants, as it caused an increase in the production of free radicals (ROS), which are responsible for the oxidation and destruction of plant cells. The higher MDA levels observed under water deficit stress suggest an elevated degree of lipid peroxidation, indicative of membrane damage. Polyphenol oxidase and peroxidase, being enzymatic antioxidants, play roles in the plant's defense against oxidative stress. The heightened activity of these enzymes under water deficit stress reflects the plant's attempt to counteract the deleterious effects of reduced water availability (Mohr and Schopfer, 2012).

The interplay of stomatal regulation, nutrient availability and the vital role of water in biochemical reactions collectively contribute to the observed decline in squash plant parameters, with the treatment receiving 100% traditional irrigation displaying the most favorable outcomes, while the 50% irrigation treatment exhibits the lowest values (Sun *at al.* 2020).

The elevated concentrations of photosynthetic pigments (chlorophyll a, chlorophyll b and carotene) and essential chemical constituents (nitrogen, phosphorus, potassium) in squash plants irrigated with 100% traditional irrigation can be attributed to several scientific factors. Adequate water supply in the 100% irrigation treatment supports optimal photosynthetic activity, ensuring the synthesis of chlorophyll pigments crucial for light absorption and energy conversion. Additionally, sufficient irrigation contributes to improved nutrient uptake and transport, leading to higher concentrations of nitrogen, phosphorus and potassium in plant tissues (Taiz *et al.,* 2015). These nutrients are integral components of various biochemical processes, including photosynthesis and are essential for overall plant growth and development.

Overall, the observed results underscore the importance of adequate irrigation in supporting optimal physiological processes and nutrient status in squash plants (Doklega, 2018). Scientifically, the trend of indicators of oxidative stress and enzymatic antioxidants aligns with established principles of plant response to water availability. Water deficit stress, as induced by the 50% traditional irrigation treatment, typically triggers a biochemical response in plants aimed at mitigating the impact of oxidative stress.

Conversely, as the irrigation water amount increases to 100% of the traditional level, the plants experience less stress, leading to lower accumulation of proline and decreased activity of MDA, PPO and POD. This aligns with the expectation that well-hydrated plants would exhibit a reduced need for antioxidant defense mechanisms. Overall, these findings underscore the intricate relationship between water availability and the biochemical responses of plants, shedding light on the adaptive strategies employed by plants to cope with varying levels of water stress (Sun *et al.,* 2020). Regarding fruit yield, the observed pattern aligns with established principles of plant physiology and water utilization. Squash plants, when provided with an optimal water supply (100% traditional irrigation), experience improved turgor pressure, enhanced nutrient uptake and efficient metabolic processes. This, in turn, contributes to superior fruit development, reflected in increased the total yield (Mohr and Schopfer, 2012). The increased yield may be because of the enhanced vegetative growth *i.e.,* fresh and dry weights and leaf area (Table 5) and chlorophyll a, b and carotene (Table 6). Conversely, as the irrigation water decreases to

50% of the traditional level, the plants likely face water stress, resulting in compromised physiological functions. The gradual reduction in fruit yield can be attributed to the plant's adaptive response to limited water availability. Under water stress, plants often prioritize survival over reproductive and metabolic activities, leading to diminished fruit development and nutritional synthesis (Taiz *et al.,* 2015). The findings are in harmony with Dawa *et al.,* (2017) on tomato.

Regarding the effects of organic fertilization, the scientific reasons behind the observed trend of increasing vegetative growth *i.e.,* fresh and dry weights and leaf area (Table 5) and chlorophyll a, b and carotene (Table 6) and fruit yield (Table 9) with an escalating rate of organic fertilizer can be explained by several key factors. Young chicken droppings are a potent source of organic matter and nutrients, contributing to the overall fertility of the soil as shown in Table 2. Nitrogen, in particular, is abundant in chicken manure, supporting robust plant growth and leaf development (Amer *et al.,* 2009).

Chicken manure contains beneficial microorganisms that enhance soil structure and stimulate microbial activity. This fosters a healthy soil environment, promoting nutrient cycling and making essential elements more accessible to plants. The organic matter present in chicken droppings enhances the soil's water retention capacity (Aldal'in & Alhrout, 2016).

This is particularly beneficial under water deficit stress, as it helps plants better withstand dry conditions. Chicken manure contributes to pH regulation in the soil. While it is initially acidic, its decomposition releases compounds that help balance soil pH, creating a more favorable environment for plant growth. The organic matter in chicken droppings improves soil structure by preventing soil compaction and promoting aeration (Abou El-Goud and Yousry, 2019).

This allows for better root penetration, nutrient absorption and water movement within the soil. In summary, the application of organic fertilizer at increasing rates positively influences plant growth parameters by providing essential nutrients, enhancing photosynthesis, improving water retention and stimulating root development (Khanuma *et al.,* 2021). The enhanced availability of these nutrients in organic fosters optimal physiological functions, leading to increased chlorophyll synthesis, improved photosynthetic efficiency and heightened nutrient content in plant tissues. Consequently, the application of organic at the recommended dosage (100%) ensures a robust nutrient supply, positively influencing both photosynthetic pigments and chemical constituents in squash plants and thereby promoting overall plant health and growth (Behdarnejad *et al.,* 2023). This pattern aligns with the influence of organic fertilization on plant biochemical responses. The control treatment, devoid of organic fertilizer, likely prompted a higher accumulation of proline, indicative of a stress response. MDA, as a marker for lipid peroxidation, might have been elevated due to the absence of additional nutrients provided by organic fertilization, potentially leading to oxidative stress and membrane damage (Serri *et al.,* 2021).

The decline in the levels of proline, MDA, PPO and POD with increasing amounts of organic fertilizer can be explained by the improved nutrient status of the soil. Organic fertilizers contribute essential nutrients, promoting healthier plant growth and reducing the need for stress-related responses. Proline accumulation, often associated with stress conditions, may decrease as the plant experiences improved nutrient availability. Polyphenol oxidase and peroxidase, being enzymatic antioxidants, may also be influenced

by the availability of nutrients. Higher nutrient levels from organic fertilization may enhance the overall antioxidant capacity of the plant, reducing the need for increased enzymatic activity. Therefore, the observed decrease in proline, MDA, PPO and POD with organic fertilization suggests a positive impact on plant health, reflecting a more favorable nutritional environment (Poozesh & Amirahmadi, 2024).

The treatment involving 100% of the recommended fertilizer level demonstrated superiority in influencing these fruit yield. This observed trend aligns with the principles of nutrient availability and its impact on plant growth and productivity. Chick-droppings, being an organic fertilizer, contribute essential nutrients to the soil, fostering improved plant nutrition and metabolic activities. The incremental increase in the values of fruit characteristics and nutritional components with higher fertilizer levels suggests that the plants are responding positively to enhance nutrient availability (Amer *et al.,* 2009). In particular, the treatment involving 100% of the recommended organic fertilizer level appears to provide the optimum nutrient concentration for squash plants, resulting in superior fruit yield development. This may be attributed to the balanced and adequate supply of essential nutrients, promoting robust growth, efficient photosynthesis and enhanced biosynthesis of vitamins, carbohydrates, sugars and proteins (Abou El-Goud and Yousry, 2019). As shown in Table 2, the studied organic fertilizer contained 41% organic matter and many macro- and microelements, and this led to improved plant performance. The obtained results are in agreement with those of Ibrahim *et al.,* (2023) on coriander plant.

Concerning the effects of spraying treatments on plant performance, the favorable effects of applied foliar substances on plant growth performance can be attributed to the distinct roles each stimulant plays in enhancing physiological processes.

Polyethylene glycol (PEG) likely contributes to improved growth by promoting water uptake and retention, thus alleviating water stress and enhancing turgor pressure (Munir and Aftab, 2009). Yeast, with its potential to stimulate nutrient mobilization and support metabolic activities, may enhance overall plant vigor and contribute to increased biomass (Abdelaal *at al.* 2017). Chitosan, known for its biostimulant properties, might induce plant defense mechanisms and improve nutrient uptake efficiency (Katiyar *et al.,* 2015). Each stimulant appears to exert its effects through different mechanisms, collectively influencing plant height, foliage fresh and dry weights and leaf area, with polyethylene glycol emerging as the most effective in promoting these growth parameters.

The obtained results suggests that PEG, as a stimulant, plays a primary role in enhancing growth criteria, photosynthetic efficiency, nutrient uptake and fruit yield in squash plants (Hajihashemi and Sofo, 2018). Yeast; with its potential to stimulate metabolic processes, follows closely, contributing to improved growth criteria, photosynthetic efficiency, nutrient uptake and fruit yield (Abdelaal *at al.*2017). As shown in Table 3, the studied yeast extract contained many macro- and microelements as well as vitamins, and this led to improved plant performance, as it came in the second order after PEG.

Chitosan, though still beneficial, exhibits a comparatively lower impact on photosynthetic pigments and chemical constituents (Sharif *et al.,* 2018). The observed hierarchy underscores the distinct effectiveness of these foliar-applied stimulants in promoting the physiological and nutritional aspects of squash plants, with PEG exhibiting the most pronounced effects.

The observed results for indicators of oxidative stress and enzymatic antioxidants can be attributed to the different effects of chitosan, yeast and polyethylene glycol on the plant's stress responses and biochemical processes. Regarding fruit yield, the observed impact of the foliar applications can be attributed to the specific properties and functions of each stimulant. Polyethylene glycol (PEG), known for its role in enhancing water retention and mitigating water stress, likely contributed to improved fruit development by maintaining optimal hydration levels (Munir and Aftab, 2009). Yeast, recognized for its potential to stimulate plant growth and metabolism, may have influenced various physiological processes leading to enhanced fruit traits and nutritional content (Doklega, 2018). Chitosan, with its reported effects on plant defense mechanisms and stress tolerance, also played a role, albeit to a lesser extent (Ibraheim and Mohsen, 2015) compared to PEG and yeast.

CONCLUSION

Finally, the comprehensive investigation into the interplay of water deficit conditions, organic fertilizers and stress-alleviating substances in squash plants has provided valuable insights. The complete organic fertilizer dosage and polyethylene glycol (PEG) foliar application, under water deficit conditions, consistently recorded superior results across various parameters, outperforming conventional irrigation (100%) without these substances. This approach positively affected growth criteria, photosynthetic pigments, oxidative stress indicators and fruit yield. The findings underscore the potential of holistic strategies to mitigate the adverse effects of water scarcity on crop performance. Recommendations for sustainable agricultural practices include the incorporation of organic fertilizers like organic at recommended dosages and strategic foliar applications of stress-alleviating substances, with particular emphasis on polyethylene glycol, to enhance overall crop resilience and productivity in water-limited environments. Further research could explore the underlying biochemical mechanisms and long-term effects of these strategies, facilitating their wider implementation in crop management practices.

CONFLICT OF INTEREST

Authors have declared that no competing interests exist. The authors contributed equally to put the research methodology and implementing it at all stages.

Formatting of funding sources: The research was funded by personal efforts of the authors.

REFERENCES

Abd El-Nabi, A., El-Shal, Z. S. A., Doklega, S., & Abdel Razek, M. E. A. (2022). Effect of water deficit, organic fertilization and some soil additions on potato productivity. *Journal of Plant Production, 13(8),* 611-619. https://doi.org/10.21608/jpp.2022.153832.1151

Abdelaal, K. A., Hafez, Y. M., El Sabagh, A., & Saneoka, H. (2017). Ameliorative effects of Abscisic acid and yeast on morpho-physiological and yield characteristics of maize plant (*Zea mays* L.) under water deficit conditions. *Fresenius Environmental Bulletin, 26(12),* 7372-7383.

Abou El-Goud, A. K., & Yousry, M. M. (2019). Organic summer squash production using chicken manure, compost and AMF for enhancing soil fertility. *Current Science International, ISSN*, 2077-4435. https://doi.org/10.36632/csi/2019.8.4.12

Ahmed, H. M. I., Dawa, K. K., El-Nabi, A., & Makeen, A. (2019). Influence of some irrigation levels and foliar application of some antitranspirants on vegetative growth, leaf chemical constitutes and seed yield of squash plants. *Journal of Plant Production, 10(7*), 505-510. https://doi.org/10.21608/jpp.2019.53544

Aldal'in, H. K. H., & Alhrout, H. H. (2016). Effect of NPK and chicken manure on the productivity and some growth components of squash (*Cucurbita pepo* L.). *Journal of Agricultural and Biological Science*, 11, 61-65.

Alici, E. H ., & Arabaci, G. (2016). Determination of SOD, POD, PPO and cat enzyme activities in *Rumex obtusifolius* L. *Annual Research and Review in Biology,* 1-7. https://doi.org/10.9734/arrb/2016/29809

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome, 300(9), D05109. https://doi.org/10.1061/40499(2000)125

Amer, K. H., Midan, S. A., & Hatfield, J. L. (2009). Effect of deficit irrigation and fertilization on cucumber. *Agronomy Journal, 101(6),* 1556-1564. https://doi.org/10.2134/agronj2009.0112

Baque, A., Nahar, M., Yeasmin, M., Quamruzzaman, M., Rahman, A., Azad, M. J. and Biswas, P. K. (2016). Germination behavior of wheat (*Triticum aestivum* L.) as influenced by polyethylene glycol (PEG). *Universal J. Agril. Res, 4(3),* 86-91. https://doi.org/10.13189/ujar.2016.040304

Behdarnejad, M., Piri, H., & Delbari, M. (2023). The effect of combined use of vermicompost and poultry manure on the growth and yield of cucumber plants in different conditions of deficit irrigation. *Water and Soil, 37(2),* 237-259. http://doi.org/10.22067/jsw.2023.79296.1215

CoStat version 6.303 copyright (1998-2004). "CoHort Software 798 Lighthouse Ave". PMB 320, Monterey, CA, 93940, USA.

Davey, M. W., Stals, E., Panis, B., Keulemans, J., & Swennen, R. L. (2005). High-throughput determination of malondialdehyde in plant tissues. *Analytical biochemistry, 347(2),* 201-207. https://doi.org/10.1016/j.ab.2005.09.041

Dewis, J., & Freitas, F. (1970). "*Physical and chemical methods of soil and water analysis*". FAO soils Bulletin, (10).

Dietz, T., Shwom, R. L., & Whitley, C. T. (2020). Climate change and society. Annual Review of Sociology, 46(1), 135-158. https://doi.org/10.1146/annurev-soc-121919-054614

Doklega, S. (2018). Impact of irrigation intervals, organic fertilizer and foliar application with some antioxidants on summer squash. *Journal of Plant Production, 9(1),* 143-151. https://doi.org/10.21608/jpp.2018.35271

Economic Affairs Sector (2023). Area, yield and production of summer vegetable crops. Ministry of Agricultural, Egypt.

Elsherpiny, M. A., & Helmy, A. (2022). Response of maize plant grown under water deficit stress to compost and melatonin under terraces and alternate furrow irrigation techniques. *Egyptian Journal of Soil Science, 62(4),* 383-394. https://doi.org/10.21608/ejss.2022.165573.1544

Farhan, K. J., AlGabbar, M. S. A., & Alkhateb, B. A. (2021). The role of poultry manure and humic acid in the water consumption, nitrogen availability and the summer squash plant (*Cucurbita pepo* L.) yield. *Annals of the Romanian Society for Cell Biology, 25(6),* 8671-8678.

Gee, G. W., & Bauder, J. W. (1986). Particle-size analysis. Methods of soil analysis: Part 1 Physical and mineralogical methods, 5, 383-411. https://doi.org/10.2136/sssabookser5.1.2ed.c15

Gholami, F., Amerian, M. R., Asghari, H. R. and Ebrahimi, A. (2023). Assessing the effects of 24-epibrassinolide and yeast extract at various levels on cowpea's morphophysiological and biochemical responses under water deficit stress. *BMC Plant Biology, 23(1),* 593. https://doi.org/10.1186/s12870-023-04548-6

Gomez and K. A., & Gomez, A.A (1984). "*Statistical Procedures for Agricultural Research*". John Wiley and Sons, Inc., New York.pp:680. https://doi.org/10.1017/s0014479700014496

Hajihashemi, S., & Sofo, A. (2018). The effect of polyethylene glycol-induced drought stress on photosynthesis, carbohydrates and cell membrane in Stevia rebaudiana grown in greenhouse. *Acta Physiologiae Plantarum, 40(8),* 142. https://doi.org/10.1007/s11738-018-2722-8

Hassnain, M., Alam, I., Ahmad, A., Basit, I., Ullah, N., Alam, I., & Ain, N. (2020). Efficacy of chitosan on performance of tomato (*Lycopersicon esculentum* L.) plant under water stress condition. *Pak. J. Agric. Res, 33(1),* 27-41. https://doi.org/10.17582/journal.pjar/2020/33.1.27.41

Ibraheim, S. K. A., & Mohsen, A. A. M. (2015). Effect of chitosan and nitrogen rates on growth and productivity of summer squash plants. Middle East J. Agric. Res, 4(4), 673-681.

Ibrahim, F. R., El-Sherpiny, M. A., & Ghazi, D. A. (2023). The effects of compost and magnesium on the productivity of coriander plant. *Asian Journal of Plant and Soil Sciences*, 21-31. https://doi.org/10.56557/ajopss/2023/v8i198

Katiyar, D., Hemantaranjan, A., & Singh, B. (2015). Chitosan as a promising natural compound to enhance potential physiological responses in plant: a review. *Indian Journal of Plant Physiology,* 20, 1-9. https://doi.org/10.1007/s40502-015-0139-6

Khanuma, M. M., Nuruzzamana, M., Hudab, M. S., & Muzahidc, M. A. A. A. (2021). Effect of organic manures and planting time on growth, yield, quality and economics of squash under medium high land condition of Dinajpur region. *Sustainability Food Agric*, 2, 40-43. https://doi.org/10.26480/sfna.01.2021.40.43

Mohr, H., & Schopfer, P. (Eds.). (2012). *Plant physiology.* Springer Science and Business Media.

Mukherjee, A., Verma, J. P., Gaurav, A. K., Chouhan, G. K., Patel, J. S., & Hesham, A. E. L. (2020). Yeast a potential bio-agent: future for plant growth and postharvest disease management for sustainable agriculture. *Applied Microbiology and Biotechnology, 104(4),* 1497-1510. https://doi.org/10.1007/s00253-019-10321-3

Munir, N., & Aftab, F. (2009). The role of polyethylene glycol (PEG) pretreatment in improving sugarcane's salt (NaCl) tolerance. Turkish journal of botany, 33(6), 407-415. https://doi.org/10.3906/bot-0806-6

Mustamu, N. E., Tampubolon, K., Basyuni, M., Al-Taey, D. K., Janabi, H. J. K. A., & Mehdizadeh, M. (2023). Drought stress induced by polyethylene glycol (PEG) in local maize at the early seedling stage. Heliyon, 9(9). https://doi.org/10.1016/j.heliyon.2023.e20209

Okasha, E. M., Hashem, F. A., & El-Metwally, I. M. (2020). Effect of irrigation system and irrigation intervals on the water application efficiency, growth, yield, water productivity and quality of squash under clay soil conditions. *Plant Archives, 20(2),* 3266-3275. https://doi.org/10.21608/ejss.2020.48343.1404

Peterburgski, A. V. (1968). "*Hand Book of Agronomic Chemistry*". Kolas Publishing House Moscow, (in Russian).

Poozesh, V., & Amirahmadi, A. (2024). The Impact of Organic and Inorganic Fertilizers on Some Phytochemical and Antioxidant Properties in *Zingiber Officinale Rosc*. Journal of *Chemical Health Risks,* 14(3).

Rajput, R. D., & Patil, R. P. (2017). The comparative study on spectrophotometric analysis of chlorophyll and carotenoids pigments from non-leguminous fodder crops. International Journal of Innovative Science, *Engineering and Technology, 4(7),* 140-148. https://doi.org/10.7717/peerj.20823/table-5

Serri, F., Souri, M. K., & Rezapanah, M. (2021). Growth, biochemical quality and antioxidant capacity of coriander leaves under organic and inorganic fertilization programs. *Chemical and Biological Technologies in Agriculture*, *8*(1), 33. https://doi.org/10.1186/s40538-021-00232-9

Sharif, R., Mujtaba, M., Ur Rahman, M., Shalmani, A., Ahmad, H., Anwar, T., & Wang, X. (2018). The multifunctional role of chitosan in horticultural crops and a review. *Molecules, 23(4),* 872. https://doi.org/10.3390/molecules23040872

Sun, Y., Wang, C., Chen, H. Y., & Ruan, H. (2020). Response of plants to water stress: a meta-analysis. *Frontiers in Plant Science*, 11, 978. https://doi.org/10.3389/fpls.2020.00978

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). Plant physiology and development (No. Ed. 6). Sinauer Associates Incorporated. https://doi.org/10.1093/hesc/9780197614204.001.0001

Tandon, H. L. S. (2005). *Methods of analysis of soils, plants, waters, fertilizers and organic manures*. Fertilizer Development and Consultation Organization.

Vieira, E. F., Carvalho, J., Pinto, E., Cunha, S., Almeida, A. A., & Ferreira, I. M. (2016). Nutritive value, antioxidant activity and phenolic compounds profile of brewer's spent yeast extract. *Journal of Food Composition and Analysis, 52*, 44-51. https://doi.org/10.1016/j.jfca.2016.07.006

Waleed, A. (2016). Amelioration of growth and crop performance of cabbage by chitosan foliar spraying under water deficit stress conditions. Sciences, 6(04), 1180-1192.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W., & Novozamsky, I. (2013). *Plant analysis manual*. Springer Science and Business Media.

Wang, X., Sun, H., Lian, X., Feng, J., Zhao, J., Wang, Y., & Liu, Y. (2024). Physiological and biochemical characteristics of cucumber seedlings under different levels of drought stress (PEG 6000 concentrations). *Horticultural Science*, 51(3). https://doi.org/10.17221/53/2023

Watson, D. J. (1952). The physiological basis of variation in yield. Advances in agronomy, 4, 101-145. https://doi.org/10.1016/s0065-2113(08)60307-7