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(Original Article)

Foliar Application of Plant Growth Hormones to Improve Growth and Yield of Drip-Irrigated Cucumber (*Cucumis sativus* L.) under Full and Deficit Irrigation

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Abstract

A field experiment was conducted at the vegetable research farm, Faculty of Agriculture, Assiut University for three summer seasons 2020, 2021 and 2022. The study aimed to improve the growth and productivity of cucumber under different water regimes using foliar application of six plant bio-stimulants during the plant growth stages. The cucumber cultivar 'F1 Hayal' was planted under three water regimes 100%, 75% and 50% of irrigation water requirements. Plant bio-stimulants were sprayed at different growth stages using the recommended concentrations of Salicylic Acid (SA at 10uM), Glycine Betaine (GlyBet at 50mM/L), Indole Acetic Acid (IAA at 100 uM), Proline at 1 mM/L, Potassium Silicate (PS at 1mM/L) and Humic Acid (HA at 1g/L). The results showed that the tested growth hormones enhanced the growth and yield parameters of cucumber under a 100% water regime. Under deficit irrigation (water regimes 75% and 50%), foliar application of PS at 1 mM/L increased length of cucumber plants (cm), plant fresh and dry weights (g), leaf area (cm2), number and weight of marketable fruits/plant, and total yield of marketable fruits (ton/fedd., 1 fedd. = 4200m^2). Proline application at 1 mM/L and GlyBet at 50 mM/L came second. Plants of control treatment (sprayed with distilled water) illustrated significant reduction in growth and yield parameters under all tested water regimes (100%, 75% and 50%) as compared to the plants treated by stimulants. Potassium Silicate spraying could be recommended as a natural, environmentally friendly material during the growth stages of cucumbers that may increase growth, production, and fruit quality.

Keywords: *Cucumber, Deficit irrigation, Drip irrigation, Growth hormone, Growth, yield*

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Introduction

The world faces the major challenge of providing food for approximately 9.7 billion people due to the shortage of usable water and the lack of arable land. This challenge will peak in the year 2050, when the planet's population will reach about 11.5 billion persons in addition to climate change and global rising temperature. The lack of usable water represents the most important obstacle facing the expansion of agriculture, both in plant and animal production.

Also, climate changes have affected basic agricultural resources, such as soil fertility, quality, and arable water in many regions of the world. This had a significant impact on the cultivated areas, production quantities, and ensuring the availability of food (Raza *et al*., 2019; Wang *et al*., 2023). One of the important agricultural practices that helps to continue growing crops and maintain production is deficit irrigation, which is one of the potential irrigation practices to conserve water. That is supplying plants with lower amounts of irrigation water than their full needs, at specific growth stages or during the entire cultivation period (Gupta *et al*., 2020). This exposes plants to partial water stress which extremely affects the biochemical and physiological processes of plants (Parkash and Singh, 2020). Such processes include respiration and photosynthesis, which leads to lack of growth and productivity (Yuan *et al*., 2016; Sharma *et al*., 2019; Gupta *et al*., 2020, Metwaly *et al*., 2022).

The growth and development of crops are controlled by genotypes, growth environments and cultivating practices including the exogenous application of plant growth regulators (PGR) (Elotmani *et al.*, 2000). PGRs, both natural and synthetic, have been widely used in horticulture to manipulate plant growth and development to meet market demands (Elotmani *et al*., 2000; Metwaly *et al*., 2022). There are more than twenty types of PGRs belonging to five major classes that include auxins, gibberellins, cytokinins, ethylene, and abscisic acid. These compounds are active at all plant growth stages from vegetative to reproductive growth. They are used to improve fruit color, suppress plant overgrowth, promote flower differentiation, protect flowers and fruits, accelerate fruit ripening, and promote the production of seedless fruits (Prajapati *et al.*, 2017). The application of PGRs can also be used to increase yields and make crops available for markets during the off season. At the cellular level, the growth hormones protect cellular components through: a) maintain osmotic equilibrium, b) stabilize the quaternary structures of complex proteins, c) regulate a number of physiological and biochemical processes, and d) maintain turgor pressure and enhancing net CO^2 assimilation rate (Hasanuzzaman *et al*., 2019; Dustgeer *et al*., 2021; Yang *et al*., 2022).

Cucurbitaceae is the largest vegetable family in the plant kingdom. It includes many economical edible crops, with high market value, particularly in the Egyptian market, due to its lofty nutritional values as well as its richness in all types of vitamins (Janick *et al*., 2007; Fiume *et al*., 2014; Muruganantham *et al*., 2016; Saaed *et al*., 2017; Ibitoye *et al*., 2018). Cucurbits (summer squash, melon, cucumber, and watermelon) are warm season crops and most of them require relatively high temperatures for germination.

Cucumber (*Cucumis sativus*) is one of the most cultivated vegetable crops in the world (Amer *et al*., 2009). The area under cucumber cultivation is around 2,174,347 hectares and production is around 94,718,396 tons (FAO, 2022). In Egypt, the total area cultivated with cucumber was 20,403ha with a total production of 237,427 tons (FAO, 2022). There are numerous studies on the effect of deficit irrigation in cucumber (Wang *et al*., 2009; Al-Omran and Louki, 2011; Hnilička *et al*., 2013). Most of these studies are concerned with the effect of deficit irrigation on the yield and water use efficiency (WUE) of cucumbers. Moreover, the majority of these studies were conducted in controlled conditions. Open field studies investigating the effects of growth hormones on the alleviation of adverse effects of deficit irrigation are limited especially under arid and semi-arid conditions. Therefore, the present study aimed to explore the role of growth hormones, Salicylic Acid (SA at 10uM), Glycine Betanine (GlyBet at 50mM/L), Indole Acetic Acid (IAA at 100uM), Proline at 1 mM/L, Potassium Silicate (PS at 1mM/L) and Humic Acid (HA at 1g/L) on alleviating the adverse effects of deficit irrigation on growth and yield of the cucumber cultivar 'F1 Hayel'.

Materials and Methods

Plant materials

Seeds of the open-field cucumber cultivar *Cucumis sativus* var 'F1 Hayel' were obtained from the agricultural market of Cairo, Egypt. The cucumber cultivar 'F1 Hayel is for open field production, vigorous vegetative growth, high yield and fruit quality, and tolerant to several plant viruses. A germination test was conducted in the lab of vegetable crops, Department of Vegetables to evaluate the seed's vigor and viability.

Growth hormone treatments (GH)

The chemicals were obtained from Al-Gomhouria Company for Trading Medicines, Chemicals, and Medical Supplies, Cairo, Egypt. The plant growth hormones were Salicylic Acid (SA) at 100 uM, Glycine betaine (GlyBet) at 50 mM/L, Indole Acetic Acid (IAA) at 100 µM, Proline at 1 mM/L, Potassium Silicate (PS) at 1 mM and Humic acid (HA) at 1g/L. The growth hormones were sprayed three times at their recommended concentrations. The application started at the third true leaves stage (15 days from planting), at flowering time, and after the first fruit harvest. The cucumber plants of the control treatment were sprayed with distilled water.

Irrigation Water Regimes (IWR)

After full germination and at the fourth true leaves, the cucumber plants were subjected to three different water regimes as follows:

- Plants received 100% irrigation water.
- Plants received 75% of irrigation water.
- Plants received 50% of irrigation water.

The plants were supplied with irrigation water using a surface drip irrigation system, where each water regime treatment was controlled using a 2-inch valve. The second author designed, installed, and manage the drip irrigation system.

Experimental Design and layout

The experiments were conducted in three successful summer seasons of the years 2020, 2021, and 2022 in the research farm of the Department of Vegetable Crops, Faculty of Agriculture, Assiut University. The experiments were laid out in split-plot arrangement using 4 replicates. The Irrigation Water regime treatments (IWR) were in the main plots, where the Growth Hormone treatments (GH) were randomly distributed over the sub-plots following the Randomized Complete Block Design (RCBD). The plot size was 3 m × 4 m, and the planting distance was 0.5 m between plants and 1 m between rows.

Measurements

The growth parameters were measured at the end of the season and included, plant length (cm), and plant fresh and dry weight (g). Leaf length and width of cucumber plant, as used in the Cho *et al.*, (2007) model. Leaf length was measured from the lamina tip to the intersection of the lamina and petiole along the lamina midrib. Leaf width was measured from tip to tip between the widest lamina lobes. The yield parameters included: the number of fruits/plant, weight of fruits/plant, and total yield of marketable fresh fruits. The fruit quality parameters were measured at the third harvest and included fruit length (cm) and diameter (cm)

Data Analysis

Analysis of variance relevant to split-plot experiments as described by Gomez and Gomez (1984) was used. The data of the growth hormones and water regimes gave some error degrees of freedom suitable to conduct a valid 'F' significance test. In such a case, 'The Least Significant Difference' (LSD 0.05) was used for means comparisons (Steel and Torrie, 1980).

Results

Plant Length (cm)

The data of plant length (cm) of cucumber cultivar 'F1 hayel' as affected by foliar application of growth hormones (GH) and irrigation water regimes (IWR) were presented in Table (1). The heights of cucumber plants were significantly affected by applying GH and IWR and their interaction. The tallest cucumber plants were observed when PS was foliar applied at 1 mM/l under 100% irrigation water with 149.6, 143.2, and 137.5 cm in 2020, 2021, and 2022, respectively.

The application of water deficit to 75% and foliar application of PS at 1 mM/l produced the tallest cucumber plants as compared to the other applied GH and control treatment (Table 1). The cucumber plants with reduced heights were observed when the plants were sprayed with IAA at 100 uM and supplied with 50% irrigation water in 2020 (64.74 cm), 2021 (96.23 cm) and 2022 (68.21 cm). The shortest plants were observed in the control treatment in all seasons (Table 1).

Table 1. Plant Length (cm) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR), and their interactions in the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	111.9	121.6	137.5	130.0	127.8	115.4	108.8	121.9
75%	89.62	98.81	106.3	103.2	101.1	94.62	84.72	96.91
50%	64.74	71.23	80.76	77.23	74.96	68.23	61.53	71.24
Mean	88.75	97.21	108.2	103.5	101.3	92.75	85.02	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			***			2.16		
Growth Hormones (GH)			*			2.41		
IWR x GH			*			2.65		
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	131.7	138.6	149.6	144.3	141.2	134.2	129.1	138.4
75%	112.1	119.4	128.4	126.2	122.7	116.7	110.4	119.4
50%	96.23	102.8	107.3	105.2	104.3	98.32	94.21	101.2
Mean	113.3	120.3	128.4	125.2	122.7	116.4	111.2	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			*			1.87		
Growth Hormones (GH)			*			1.95		
IWR x GH			*			2.04		
	2022							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	115.4	131.6	143.2	138.7	134.3	127.8	112.3	129.0
75%	90.32	99.62	110.5	107.2	103.8	94.65	88.65	99.25
50%	68.21	74.61	86.21	81.63	78.65	71.31	63.31	74.85
Mean	91.31	101.9	113.3	109.2	105.6	97.92	88.09	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			***			2.08		
Growth Hormones (GH)			**			2.37		
IWR x GH			*			2.51		

Plant Fresh weight (kg)

Plant fresh weight of cucumber plants of the cultivar 'F1 Hayel' parameter as affected by IWR and foliar application of GH and their interaction was presented in Table (2). The results indicated significant differences between IWR and GH treatments and their interaction.

In 2021, 2022, and 2023, except for the GH treatments in 2021. The results illustrated that increased fresh weights of cucumber plants were observed when PS was foliar applied at 1 mM/l under 100%, 75% and 50% irrigation water regimes in 2020, 2021, and 2022, followed by Proline at 1 mM/l and GlyBet at 50 uM (Table 2). Among the tested GH, foliar application of IAA at 100 uM and HA at 1 g/l recorded the minimum fresh weight of cucumber plants under IWR 100%, 75% and 50%, respectively. In addition, the control treatment showed the least fresh weight of cucumber plants in all growing seasons (Table 2).

Table 2. Fresh weight (kg) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR), and their interaction in the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	1.695	1.789	1.962	1.876	1.821	1.732	1.681	1.794
75%	1.389	1.487	1.657	1.581	1.557	1.431	1.295	1.485
50%	0.976	1.144	1.312	1.287	1.196	1.113	0.936	1.138
Mean	1.353	1.473	1.644	1.581	1.525	1.425	1.304	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				*			0.067	
Growth Hormones (GH)				NS			NS	
IWR x GH				*			0.079	
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	1.802	1.904	2.090	1.998	1.939	1.842	1.787	1.909
75%	1.476	1.582	1.764	1.683	1.657	1.522	1.377	1.580
50%	1.037	1.217	1.396	1.369	1.272	1.183	0.995	1.210
Mean	1.438	1.568	1.750	1.683	1.623	1.516	1.386	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				*			0.072	
Growth Hormones (GH)				*			0.079	
IWR x GH				*			0.081	
	2022							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	1.751	1.850	2.031	1.941	1.884	1.790	1.737	1.855
75%	1.435	1.537	1.714	1.635	1.610	1.479	1.338	1.535
50%	1.008	1.183	1.357	1.331	1.236	1.150	0.967	1.176
Mean	1.398	1.523	1.701	1.636	1.577	1.473	1.347	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				*			0.062	
Growth Hormones (GH)				*			0.066	
IWR x GH				*			0.069	

Plant dry weight (g)

Plant dry weight of cucumber plants of the cultivar 'F1 Hayel' as affected by IWR and foliar application of GH and their interaction was presented in Table (3). The results indicated significant differences between IWR and GH treatments and their interactions concerning plant dry weight (g). The highest dry weight of cucumber plants was observed when PS was foliar applied at 1 mM/l under 100%, 75% and 50% irrigation water regimes in 2020, 2021, and 2022, followed by Proline at 1 mM/l and GlyBet at 50 uM (Table 2,3). Contrarily, foliar application of IAA at 100 uM and HA at 1 g/l showed the minimum dry weight of cucumber plants under IWR 100%, 75% and 50%, respectively. In addition, the control treatment showed the least fresh dry weight of cucumber plants in all growing seasons (Table 3).

Table 3. Dry weight (g) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR) and their interaction in the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	169.5	178.9	196.2	187.6	182.1	173.2	168.1	179.4
75%	138.9	148.7	165.7	158.1	155.7	143.1	129.5	148.5
50%	97.6	114.4	131.2	128.7	119.6	111.3	93.6	113.8
Mean	135.3	147.3	164.4	158.1	152.5	142.5	130.4	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			2.13		
Growth Hormones (GH)			**			3.43		
IWR x GH			NS			NS		
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	180.2	190.4	209	199.8	193.9	184.2	178.7	190.9
75%	147.6	158.2	176.4	168.3	165.7	152.2	137.7	158.0
50%	103.7	121.7	139.6	136.9	127.2	118.3	99.5	121.0
Mean	143.8	156.8	175.0	168.3	162.3	151.6	138.6	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			4.22		
Growth Hormones (GH)			*			5.17		
IWR x GH			*			5.94		
	2022							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 mM/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	175.1	185	203.1	194.1	188.4	179	173.7	185.5
75%	143.5	153.7	171.4	163.5	161	147.9	133.8	153.5
50%	100.8	118.3	135.7	133.1	123.6	115.0	96.7	117.6
Mean	139.8	152.3	170.1	163.6	157.7	147.3	134.7	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			3.76		
Growth Hormones (GH)			*			4.78		
IWR x GH			**			5.13		

Leaf area (cm^2)

The mean values of the cucumber plant's leaf area (cm^2) under different IWR and GH are presented in Table (4). Under 100% IWR, the maximum leaf area of cucumber plants of the cultivar 'F1 Hayel' was recorded when PS was foliar applied at 1 mM/l with 210.1 cm^2 (summer season of 2020), 205.6 cm^2 (winter season of 2021), and 193.6 cm^2 (summer season of 2022). This was followed by Proline at 1 mM/l with 178.6 cm^2 (2020), 193.8 cm^2 (2021), and 189.7 cm^2 (2022), and GlyBet at 50 mM with 171.5 cm^2, 186.0 cm^2, and 182.1 cm^2 in 2020, 2021, and 2023 seasons, respectively. The leaf area of cucumber plants was significantly reduced under deficit irrigation of 75%, and an extreme reduction of leaf area was observed at deficit irrigation of 50% (Table 3). However, Foliar application of SC at 1 mM/l enhanced leaf area (cm^2) under deficit irrigation of 75% and 50% as compared to other tested GH, while the cucumber plants that sprayed IAA at 100uM recorded the minimum leaf area cm^2 (Table 4).

Table 4. Leaf area (cm^2) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR) and their interaction in the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	**HA 1 g/l**	**PS 1mM/l**	**Proline 1 mM/l**	**GlyBet 50mM**	**SA 100uM**	**Control**	**Mean**
100%	151.6	162.1	193.6	178.6	171.5	165.2	147.2	167.1
75%	122.4	128.4	153.6	141.9	137.1	125.8	117.6	132.4
50%	104.8	110.8	123.4	119.4	114.7	107.1	99.78	111.4
Mean	126.3	133.8	156.9	146.6	141.1	132.7	121.5	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				**			3.71	
Growth Hormones (GH)				*			4.65	
IWR x GH				NS			NS	
	2021							
	IAA 100uM	**HA 1 g/l**	**PS 1mM/l**	**Proline 1 mM/l**	**GlyBet 50mM**	**SA 100uM**	**Control**	**Mean**
100%	164.2	175.7	210.1	193.8	186.0	179.0	159.5	181.2
75%	132.5	139.2	166.6	153.9	148.6	136.3	127.4	143.5
50%	113.5	120.1	133.8	129.4	124.3	116.0	108.0	120.7
Mean	136.7	145.0	170.2	159.0	153.0	143.8	131.6	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				**			2.17	
Growth Hormones (GH)				**			3.22	
IWR x GH				**			4.05	
	2022							
	IAA 100uM	**HA 1 g/l**	**PS 1mM/l**	**Proline 1 mM/l**	**GlyBet 50mM**	**SA 100uM**	**Control**	**Mean**
100%	160.7	172.0	205.6	189.7	182.1	175.2	156.1	177.3
75%	129.7	136.2	163.1	150.6	145.5	133.4	124.7	140.4
50%	111.0	117.5	131.0	126.7	121.7	113.5	105.7	118.2
Mean	133.8	141.9	166.6	155.6	149.7	140.7	128.8	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				*			2.98	
Growth Hormones (GH)				*			3.12	
IWR x GH				*			4.07	

Number of fresh fruits/plant

The number of fresh fruits per plant was significantly influenced by the tested GH and IWR and their interaction (Table 5). Among the tested GH and IWR, the maximum number of marketable fruits per plant was observed when the cucumber plants were supplied with 100% IWR and spared with PS at 1 mM, followed by Proline 1mM and BG at 50mM in 2020, 2021 and 2022 growing seasons. Applying the deficit irrigation at 75% significantly reduced the number of fruits/ plant for all tested GH. However, the plants sprayed with PS at 100uM recorded the greatest number of fruits/ plant in all growing seasons. Regardless of the effects of spared GH, exposing cucumber plants to deficit irrigation by up to 50% results in the lowest number of fruits / plant, while the PS treatment at 1mM was able to produce the highest number of fruits/plant. The GHs that produced the minimum number of fruits/plant, as the result of applying deficit irrigation of 50%, were IAA at 100uM, HA at 1g/l and SA at 100 uM during all growing seasons. Moreover, the control treatments produced the lowest number of fresh fruits/ plant under all applied IWR in the 2020, 2021 and 2022 growing seasons (Table 5).

Table 5. Number of fresh fruits/ plant of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR) and their interaction with the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	11.75	13.25	14.62	13.93	13.45	12.15	11.45	12.94
75%	9.75	10.04	11.52	10.87	10.25	9.85	9.55	10.26
50%	8.05	8.34	9.61	8.91	8.56	8.05	7.65	8.453
Mean	9.85	10.54	11.92	11.24	10.75	10.02	9.55	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				**			0.878	
Growth Hormones (GH)				**			0.964	
IWR x GH				*			1.06	
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	Glybet 50mM	SA 100uM	Control	Mean
100%	13.31	15.03	16.60	15.81	15.26	13.77	12.98	14.68
75%	11.05	11.38	13.07	12.33	11.62	11.16	10.82	11.63
50%	9.12	9.46	10.90	10.10	9.71	9.12	8.67	9.58
Mean	11.16	11.96	13.52	12.75	12.20	11.35	10.82	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				**			0.972	
Growth Hormones (GH)				**			07.1	
IWR x GH				*			1.14	
	2022							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	Glybet 50mM	SA 100uM	Control	Mean
100%	12.84	14.50	16.01	15.25	14.72	13.29	12.52	14.16
75%	10.66	10.98	12.61	11.90	11.21	10.77	10.44	11.22
50%	8.80	9.12	10.52	9.75	9.36	8.80	8.36	9.24
Mean	10.77	11.53	13.05	12.30	11.77	10.95	10.44	
F test and LSD 0.05				F test			LSD 0.05	
Irrigation Water regimes (IWR)				**			1.02	
Growth Hormones (GH)				**			1.09	
IWR x GH				*			1.16	

Weight of fresh fruits/ plant (g)

The data presented in Table (6) reflects the response of the cucumber cultivar 'F1 Hayel' to irrigation water regimes and the spray of different growth hormones concerning the weight of marketable fruits/ plant (g) during three growing seasons from 2020 to 2022. There were observed significant effects of the tested IWR and GH and their interaction with the weight of marketable fruits/ plant (g). The results showed that the cucumber plants that received 100% IWR and spared with PS at 1 mM produced the greatest weight of marketable fruits per plant in the 2020, 2021 and 2022 growing seasons. The weight of fruits per plant was significantly reduced when supplying the cucumber plants with deficit irrigation of 75% and an extreme reduction was observed at 50% deficit irrigation for all applied GH treatments during all growing seasons. However, spray PS at 100uM recorded the greatest weight of fresh fruits/ plant under 75% and 50% deficit irrigation as compared to the other applied GH (Table 6). Among the tested GH, IAA at 100uM, HA at 1g/l and SA at 100 uM produced the minimum weight of fresh fruits/ plant under full (100%) and deficit irrigation treatments (75% and 50%) in 2020, 2021 and 2022 growing seasons. Moreover, the control treatments produced the lowest number of fresh fruits/ plant under all applied IWR in the 2020, 2021 and 2022 growing seasons (Table 6).

Table 6. Weight of fresh fruits/ plant (g) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR) and their interaction in the three growing seasons

Irrigation Water regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	Glybet 50mM	SA 100uM	Control	Mean
100%	965.6	980.4	1140.3	1093.3	1055.2	999.6	957.2	1027.4
75%	773.2	828.4	920.2	885.1	871.2	801.7	761.9	834.5
50%	489.2	539.9	659.8	615.2	589.0	514.8	478.2	555.2
Mean	742.7	782.9	906.8	864.5	838.5	772.0	732.4	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			6.41		
Growth Hormones (GH)			*			7.57		
IWR x GH			*			8.12		
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	1002.4	1018.8	1186.1	1136.9	1097.0	1038.2	993.9	1067.6
75%	802.5	860.5	956.7	919.9	905.3	832.5	790.9	866.9
50%	507.6	560.8	685.7	639.1	611.9	534.5	496.3	576.5
Mean	770.8	813.4	942.9	898.6	871.4	801.7	760.3	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			7.65		
Growth Hormones (GH)			*			8.22		
IWR x GH			*			9.11		
	2022							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	Glybet 50mM	SA 100uM	Control	Mean
100%	994.7	1011.0	1177.0	1128.2	1088.5	1030.2	986.2	1059.4
75%	796.3	853.9	949.4	912.8	898.3	826.1	784.8	860.2
50%	503.7	556.5	680.5	634.2	607.1	530.3	492.5	572.1
Mean	764.9	807.1	935.6	891.7	864.7	795.5	754.5	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			8.23		
Growth Hormones (GH)			*			9.51		
IWR x GH			*			10.13		

Total yield of fresh fruits (ton/fedd)

There were observed significant effects of the tested IWR and GH and their interaction for the total yield of marketable fruits (ton/fedd.). The results indicated that under full IWR (100%) and foliar application of PS at 1 mM the cucumber plants produced the greatest yield of marketable fruits (ton/fedd.) for all growing seasons. Despite the yield of marketable fruits (ton/fedd.) being significantly reduced under deficit irrigation of 75% and extremely reduced at 50% deficit irrigation, the growth hormone treatment PS at 1mM significantly enhanced the yield of fresh fruits (ton/fedd.). Among the tested Growth hormones treatments, GH, IAA at 100uM, HA at 1g/l and SA at 100 uM produced the lowest yield of fresh fruits (ton/fedd.) under full (100%) and deficit irrigation treatments (75% and 50%) in 2020, 2021 and 2022 growing seasons. Moreover, the control treatments produced the lowest yield of fresh fruits (ton/fedd.) under all applied IWR in 2020, 2021 and 2022 growing seasons (Table 7).

Table 7. Total yield of fresh fruits/ plant (ton/fedd) of the cucumber cultivar 'F1 Hayel' as affected by foliar application of growth hormones (GH), irrigation water regimes (IWR) and their interaction in the three growing seasons

Irrigation Water Regimes (IWR)	Growth Hormones (GH)							
	2020							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	8.163	9.170	10.36	9.850	9.415	8.750	7.896	9.086
75%	6.932	7.113	7.750	7.657	7.420	7.030	6.756	7.237
50%	6.075	6.227	6.650	6.412	6.327	6.115	5.870	6.239
Mean	7.057	7.503	8.253	7.973	7.721	7.298	6.841	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			0.674		
Growth Hormones (GH)			**			0.751		
IWR x GH			**			0.823		
	2021							
	IAA 100uM	HA 1 g/l	PS 1mM/l	Proline 1 m/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	8.760	9.850	11.14	10.59	10.12	9.394	8.475	9.760
75%	7.437	7.638	8.329	8.226	7.970	7.546	7.249	7.771
50%	6.516	6.686	7.144	6.886	6.794	6.563	6.297	6.698
Mean	7.571	8.058	8.871	8.567	8.294	7.834	7.340	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			0.725		
Growth Hormones (GH)			**			0.815		
IWR x GH			**			0.921		
	2022							
	IAA 100uM	HA 1 g/l	SC 1mM/l	Proline 1 m/l	GlyBet 50mM	SA 100uM	Control	Mean
100%	8.596	9.667	10.93	10.39	9.929	9.219	8.317	9.579
75%	7.299	7.496	8.174	8.073	7.821	7.405	7.114	7.626
50%	6.395	6.561	7.011	6.758	6.667	6.440	6.180	6.573
Mean	7.430	7.908	8.706	8.407	8.139	7.688	7.204	
F test and LSD 0.05			F test			LSD 0.05		
Irrigation Water regimes (IWR)			**			0.689		
Growth Hormones (GH)			**			0.727		
IWR x GH			**			0.789		

Discussion

Cucumber is one of the important cucurbit crops grown in greenhouses and open fields, and it generates daily income for small-scale farmers (Jamir and Sharma, 2014). Expanding cucumber production in open fields faces many challenges, such as the fact that cucumbers are sensitive to insect and disease infestations, high temperatures, water and soil salinity, and drought (Metwaly *et al*., 2022). The negative effect of drought can reduce crop productivity by approximately 70% through a direct effect on photosynthesis and inhibition of biochemical processes and molecular interactions in the cell such as water absorption, and accumulation of reactive oxygen species (ROS) (Shafiq *et al*., 2021; Alam *et al*., 2022; Eid *et al*., 2022; Farouk and Al-Huqail, 2020; Farouk and

Al-Ghamdi, 2021; Shemi *et al*., 2021; Yadav *et al*., 2022).

In the current study, the growth and yield parameters were significantly reduced by applying deficit irrigation regimes at 75% and 50% as compared to 100%. It also indicated that deficit irrigation at 75% and 50% significantly decreased plant length, fresh and dry weights (g), and leaf area (cm^2) (Tables 1,2,3, and 4). This could be attributed to the loss of leaf pigments, especially chlorophyll, which lead to the reduction of photosynthetic rates (Shafiq *et al*., 2021; Shime *et al*., 2021; Alam *et al*., 2022). The reduction in photosynthetic rates results from one or more of the following: a) Preventing assimilation of chlorophyll pigments which are encoded by the cabin genes, b) destroy the chloroplast defense and light harvesting systems, and c) damage of membranes of chloroplast and lamellae vacuolation and the formation of plastoglobulus in the cells (Haider *et al*., 2017; Farouk and El-Metwally, 2019; Farouk and Omar, 2020). Moreover, drought stress slows down the process of cell growth and elongation by increasing the concentration of Abscisic Acid (ABA), which disrupts the synthesis of endogenous growth hormones in plants (González-Villagra *et al*., 2018).

The current findings demonstrated that spraying the growth hormones at the recommended concentrations mitigated the adverse effects of deficit irrigation (75% and 50%) on cucumber growth and yield parameters. A significant increase on cucumber growth parameters under deficit irrigation (75% and 50%) and as well as the 100% full water irrigation was observed when Potassium Silicate (PS), Proline and GlycineBetain (GlyBet) were foliar applied at different growth stages (Tables 1,2,3, and 4). Previous studies indicated that the use of GlyBet led to a significant increase in the pigments chlorophyll and carotene, thus increasing the rate of photosynthesis (Shafiq *et al*., 2021; Shemi *et al*., 2021; Dustgeer *et al*., 2021; Tisarum *et al*., 2019). Carotenoids act as photoreceptors and protect cells against reactive oxygen species (ROS), while the accumulation of chlorophyl pigments increases the number of chloroplast (Hassanuzaman *et al*., 2019). Prolin foliar application enhanced water use efficiency (WUE), growth, and yield of onion under deficit irrigation (Semida *et al*., 2020).

It was reported that Potassium Silicate application improved the growth and yield of cucumber under water deficit of 85% ETc as compared to the untreated plants. Application of Potassium Silicate causing an increase of 20, 51, and 156% in plant height, chlorophyll and fruit yield, respectively, compared to untreated plants (Al-Saeed *et al*., 2019). Moreover, the current results demonstrated significant increase in number of fruits/plant, weight of fruits/plant(g), and total yield of fresh fruits (ton/fedd.) (Tables 5, 6, and 7). Also, foliar application of Potassium Silicate, proline, and GlyBet significantly increased number and weight of fruits/plant, and total yield of marketable fruits (ton/fedd). These findings were in line with that reported in cucumber (Miyake and Takahashi, 1983; Al-Saeed *et al*., 2019; Metwaly *et al*., 2022), lettuce (Yildirim *et al*., 2015), in wheat (Neu *et al*., 2017), and in rice (Cuong *et al*., 2017).

The increased yield components and yield of cucumber occurred by Potassium Silicate application could be attributed to the impact of Potassium

Silicate on water uptake and the availability, uptake, and transport of essential elements for growth and development such as Ca, N, P, and K (Kafi *et al*., 2011; Chen *et al*., 2018; Al-Saeed *et al*., 2019). Additionally, Potassium Silicate increases production of phytohormones such as GA1 and GA4, promotes cell elongation, increases activity of antioxidant enzymes, and enhances the number of chloroplast (Liang *et al*., 2006; Neu *et al*., 2017; Al-Saeed *et al*., 2019).

Conclusion

The present work demonstrated the impact of growth hormones on alleviating the adverse effects of deficit irrigation on growth and yield of open field cucumber. It could be concluded that the foliar application of Potassium Silicate followed by Prolin, and GlyBet enhanced the growth, yield components, and yield of cucumber under deficit irrigation of 75% and 50% and as well under 100% full irrigation.

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الرش الورقي بهرمونات النمو النباتية لتحسين نمو ومحصول الخيار (*Cucumis sativus* L.) المروي بالتنقيط تحت ظروف الري الكامل والمتناقص

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الملخص

أجريت التجارب الحقلية بمزرعة الخضر البحثية بكلية الزراعة جامعة أسيوط خلال ثلاثة مواسم صيفية 2020، 2021، 2022 بهدف تحسين نمو وإنتاجية الخيار تحت أنظمة مائية مختلفة من خلال الرش الورقي لبعض هرمونات النمو النباتية خلال المراحل المختلفة لنمو النبات.. تمت زراعة صنف الخيار 'F1 هايال' تحت ثلاث أنظمة ري 100%، 75%، 50% من مياه الري خلال دورة حياة النبات. تم رش نباتات الخيار خلال مراحل النمو المختلفة بالتركيزات الموصي بها من حمض الساليسيليك (SA عند 10 ميكرومولر)، جليساين البيتين (GlyBet عند 50 مل مولر / لتر)، حامض الإندول أسيتيك (IAA عند 100 ميكرومولر)، البرولين عند 1 مل مولر / لتر، سليكات البوتاسيوم (PS عند 1 ملي مول/لتر) وحامض الهيوميك (HA عند 1 جم/لتر). نفذت التجربة بتصميم القطع المنشقة باستخدام أربع مكررات حيث وزعت مستويات مياه الري في القطع الرئيسية وتم توزيع الهرمونات النمو النباتية على القطع الثانوية باستخدام نظام القطاعات كاملة العشوائية (RCBD). أظهرت النتائج أن هرمونات النمو المختبرة عززت صفات النمو والصفات المحصولية للخيار تحت مستوي الري الكامل 100%. وقد أدى الرش الورقي باستخدام سليكات البوتاسيوم (PS) بتركيز 1 مل مولر / لتر إلى زيادة صفات طول النبات، الوزن الطازج والجاف ومساحة سطح الورقة، وعدد ووزن الثمار للنبات والمحصول الكلي للخيار تحت ظروف الري المتناقص (أنظمة المياه 75%، 50%) يليه البرولين عند 1 مل مولر / لتر والجليساين بيتين (GelyBet) عند 50 مل مولر / لتر وذلك مقارنة بمنظمات النمو الأخرى. أظهرت معاملة الكنترول انخفاضًا في صفات النمو والإنتاج في ظل أنظمة المياه المختبرة الثلاثة 100%، 75%، 50%. ويمكن من نتائج هذه الدراسة التوصية برش سليكات البوتاسيوم باعتباره مادة طبيعية صديقة للبيئة خلال مراحل نمو الخيار مما قد يزيد من النمو والإنتاج وجودة الثمار.

الكلمات المفتاحية: *الخيار، الري بالتنقيط، الري المتناقص، المحصول، النمو، هرمونات النمو.*