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Improving Onion Productivity *via* Applying Humic Substances and Natural Stimulants under Drip Irrigation System

Mostafa A. Nassef, Mohamed A. El-Sherpiny, Amira M. Hassen and **Asmaa S. Abd El-Hady**

Soil & Water and Environment Research Institute, Agriculture Research Center, Giza, 12619 Egypt

IN EGYPT, the aim is to increase onion productivity through the application of natural and organic stimulants, harnessing sustainable agricultural practices to meet the growing demand for this essential crop. By adopting these methods, farmers strive to enhance yields while minimizing environmental impact, thus contributing to the nation's food security and economic stability. Therefore, a field experiment was executed under drip irrigation system over two consecutive seasons (2022/23 and 2023/24) to assess the efficacy of applying potassium humate and potassium fulvate at a rate of 5.0 kg per feddan. These compounds, derived from organic matter, served as the main factor alongside the control group. Additionally, natural stimulants, such as onion extract (250.0 ml L^{-1}), garlic extract (250.0 ml L^{-1}), ginger extract (2%) and moringa extract (2%), applied *via* spraying, were examined as the sub main factor alongside the control group. Various traits were assessed and quantified, including leaves chemical constituents (N, P, K, %) and chlorophyll content at 85 days after transplanting. Additionally, physical and quality characteristics of bulbs, such as bulb weight and diameter, neck diameter, total bulb yield, and marketable bulb yield, were measured. Furthermore, the bulbs' content of vitamin C, total dissolved solids, total sugar, dry matter, fiber, anthocyanin, pyruvic acid, carbohydrates and protein were determined. Concerning humic substances, the highest values for all examined traits were observed when potassium fulvate was applied, followed by potassium humate and then the control group. As for the natural stimulants, the most effective treatment was moringa extract, followed by ginger extract, garlic extract, and finally onion extract, with all natural stimulants showing better performance compared to the control group. Generally, treating onion plants with potassium fulvate in conjunction with spraying moringa extract yielded the most favorable results. By adopting sustainable agricultural practices and incorporating these effective treatments, farmers can optimize yields while minimizing environmental impact, thereby contributing to national food security and economic stability.

Keywords: Potassium humate, Potassium fulvate, Onion extract, Garlic extract, Ginger extract, Moringa extract.

1. Introduction

Introducing humic substances and natural stimulants in fertilization programs emerged as a vital approach to enhance yields and minimize the harmful environmental impact, thus playing a crucial role in bolstering food security and economic stability (**Abd El-Hady *et al.* 2024)**. Moreover, in Egypt, where agriculture plays a pivotal role in the economy, the cultivation of strategic crops like onions further underscores the importance of adopting innovative and sustainable techniques to optimize production and resource utilization (**Elshaboury and Sakara 2021)**.

Onion (*Allium cepa* L.) is more than just a flavorful addition to meals; they pack a nutritional punch that offers numerous health benefits. Rich in vitamins such as vitamin C and B6, as well as essential minerals like potassium and manganese, onions contribute to overall health and well-being (**ElGhamry *et al.* 2024)**. Their high antioxidant content, including compounds like quercetin, helps combat oxidative stress and inflammation, reducing the risk of chronic diseases such as heart disease and

*Corresponding author e-mail: m_elsherpiny2010@yahoo.com
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cancer. Additionally, the prebiotic fiber found in onions supports digestive health by nourishing beneficial gut bacteria and promoting regularity. With their potential to improve heart health, support immune function, and possibly even reduce the risk of certain cancers, onions stand as a valuable addition to any balanced diet (**Mahmoo *et al.* 2021)**.

Potassium humate and potassium fulvate stand out as key components in this endeavor. These humic substances, derived from organic matter, hold immense potential in improving soil structure, nutrient availability, and overall plant health. Their application offers a promising avenue for enhancing onion productivity while simultaneously promoting sustainable agricultural practices (**Mosa *et al.* 2020)**.

In parallel, the exploration of natural stimulants adds another dimension to sustainable cultivation practices. Among these, onion extract emerges as a notable candidate, harnessing the inherent properties of the crop itself to stimulate growth and productivity. Similarly, garlic extract, with its reputed antimicrobial and growth-promoting properties, offers intriguing possibilities for enhancing cultivation outcomes (**Elshaboury and Sakara 2021)**. Moreover, the potential benefits of ginger extract, known for its bioactive compounds and antioxidant properties, present avenues for further experimentation and optimization in sustainable agricultural contexts (**Awwad *et al.* 2022)**. Furthermore, the moringa extract holds significant promise. Moringa, celebrated for its nutritional richness and diverse applications, represents a natural stimulant with multifaceted benefits for crop enhancement. Its incorporation into cultivation practices underscores the potential synergies between traditional agricultural knowledge and modern scientific advancements, paving the way for sustainable and resilient food production systems **(Awad *et al.* 2024)**.

Against this backdrop, this research work aims to systematically evaluate the efficacy of potassium humate, potassium fulvate, and various natural stimulants in enhancing onion productivity and quality parameters, and to elucidate the synergistic effects of these interventions in the context of sustainable agricultural practices. By elucidating the mechanisms underlying these treatments and their impact on onion cultivation outcomes, this research seeks to provide valuable insights for farmers, policymakers, and stakeholders striving towards a more sustainable and food-secure future.

2. Materials and Methods

2.1 Experimental site

This work research was conducted on a private farm situated at coordinates 31°4'54"N - 31°24'4"E in Met Antar village, Talkha district, El-Dakahlia Governorate, Egypt during two consecutive seasons (2022/23 and 2023/24).

2.2 Soil sampling and analysis

Before the transplanting process, the initial soil samples (a depth of 0-25 cm) were collected for analyzing as a routine work using standard methods outlined by **Sparks *et al.* (2020) and Dane and Topp (2020).** Table 1 displays various physical and chemical characteristics of the initial soil.

2.3 Experimental design and treatments

In this study, a split-plot experimental design was employed. The main plots consisted of different treatments of humic substances: Control (without addition), potassium humate (5.0 kg per feddan), and potassium fulvate (5.0 kg per feddan). Concurrently, the subplots involved natural stimulants: Control (without foliar application), onion extract (250.0 ml L^{-1}), garlic extract (250.0 ml L^{-1}), ginger extract (2%), and moringa extract (2%). The experimental flowchart is depicted in Fig 1, illustrating the experimental treatments.

2.4 Source of humic substances

Both potassium humate and fulvate were procured from the Egyptian commercial market (Shams chemical company), and their respective characteristics are detailed in Table 2.

2.5 Preparation of natural stimulants

Onion extract: To prepare the onion extract, fresh onions were first obtained and cleaned thoroughly. They were then finely chopped or grated to increase surface area. Next, the chopped or grated onions were mixed with water, in a predetermined ratio (1:1). The mixture was allowed to steep or macerate for a specified duration to facilitate extraction of the bioactive compounds present in the onions. After the extraction period, the mixture was filtered to remove solid particles, yielding a clear onion extract solution ready for application **(Lanzotti, 2006).** A concentration of 250 mlL^{-1} was prepared specifically for use as a foliar application on onion plants in this research study.

Garlic extract: The garlic extract preparation involved several steps. Freshly harvested garlic cloves totaling 350.0 grams were immersed in a glass beaker containing 350 ml of tap water. The beaker was subjected to a freezing cycle, spending one day

in the freezer, followed by thawing at room temperature, repeated three times. After the freezing-thawing cycles, tap water was added to the mixture to make up a final volume of one liter. The resulting mixture underwent filtration to eliminate any solid residues, and the filtrate was then adjusted to a final volume of one liter, rendering it ready for utilization (**Park *et al.* 2009)**. A concentration of 250 mlL^{-1} was prepared specifically for use as a foliar application on onion plants in this research study.

Moringa extract: Moringa plants were sourced from the Experimental Farm of SWERI, ARC, Giza, Egypt. To prepare the moringa extract, 20 grams of young moringa leaves were combined with 675 mL of 80% ethanol. The mixture was then thoroughly stirred and subsequently filtered **(Mvumi *et al.* 2013)**. A concentration of 2% was prepared specifically for use as a foliar application on onion plants in this research study.

Ginger extract: To prepare the ginger extract, the ginger root underwent a series of steps. Initially, it was manually washed and then meticulously peeled using a sharp knife. Subsequently, the peeled ginger was subjected to drying in a hot air oven set at 55°C until fully dried. Once dried, the ginger was ground into a fine powder using a mill. Following this, 10 grams of the ground ginger powder were mixed with 100 mL of ethanol and left to extract overnight in a shaker at room temperature. The resultant mixture was then filtered, and the combined filtrate underwent evaporation in a rotary evaporator set below 40°C. The resulting extract, obtained after ethanol evaporation (**Salariya and Habib, 2003)**. A concentration of 2% was prepared specifically for use as a foliar application on onion plants in this research study. Table 3 shows the characteristics of all studied extracts.

2.6 Onion seedling

The onion seedlings ″Cv. Giza Red, 60 days old ″ were obtained from a private nursery.

2.7 Cultivation

On the 10th of November each season, two-month-old onion seedlings were transplanted with a spacing of 10.0 cm between plants under the drip irrigation system. The onion plants required approximately 8000 m^{-3} of water ha^{-1} under the drip irrigation system. Potassium humate and potassium fulvate were added as soil addition according to the studied treatments at the start of the trail. The NPK fertilization was done using urea (46%N), calcium super-phosphate (15.5% P_2O_5), potassium sulphate (48%K_2O), following the onion cultivation practices outlined by the Ministry of Agriculture and Land Reclamation (MASR). Foliar application of natural stimulants was conducted five times, with a volume of 1000 L ha^{-1} for each extract, using a hand sprayer. The first foliar application took place one month after transplanting, with subsequent applications occurring at 15-day intervals.

2.8 Harvest

Harvesting was carried out manually 155 days after transplanting.

2.9 Measurements

Five plants were selected after 85 days to assess chlorophyll content using the SPAD-502 device (Soil-Plant Analysis Development Section, Minolta Camera, Osaka, Japan) following the method outlined by **Castelli *et al.* (1996).** Additionally, plant samples underwent digestion with a mixture of $HClO_4$ + H_2SO_4, following the procedure detailed by Peterburgski (1968), to determine the percentage of nitrogen (N), phosphorus (P), and potassium (K) on a dry weight basis (% DW). This was achieved using Micro-Kjeldahl (for N), spectrophotometric (for P) and flame photometer (for K) methods as described by **Walinga *et al.* (2013).**

At harvest stage, other five plants were chosen to measure bulb weight (g) and diameter (cm), neck diameter (cm). Also, total bulb yield (Mg ha^{-1}) and marketable bulb yield (Mg ha^{-1}) were measured. Vitamin C (VC, mg $100g^{-1}$), total dissolved solids (TDS, %), total sugars (%), dry matter (DM, %), fiber (%), carbohydrates (%) and protein (%) were estimated at harvest stage in bulb according to **AOAC (2000).** While the anthocyanin pigment (mg $100g^{-1}$) in bulbs was determined depending on the method described by **Schoefs (2004)** and pyruvic acid (µmol g^{-1}) was estimated as described by **Anthon and Barrett (2003).**

2.10 Statistical analyses

Statistical analysis of the obtained data was done using **CoStat computer software package (Version 6.303, CoHort, USA, 1998-2004),** following the **Gomez and Gomez (1984).** Additionally, Duncan's Multiple Range Test was applied for further analysis.

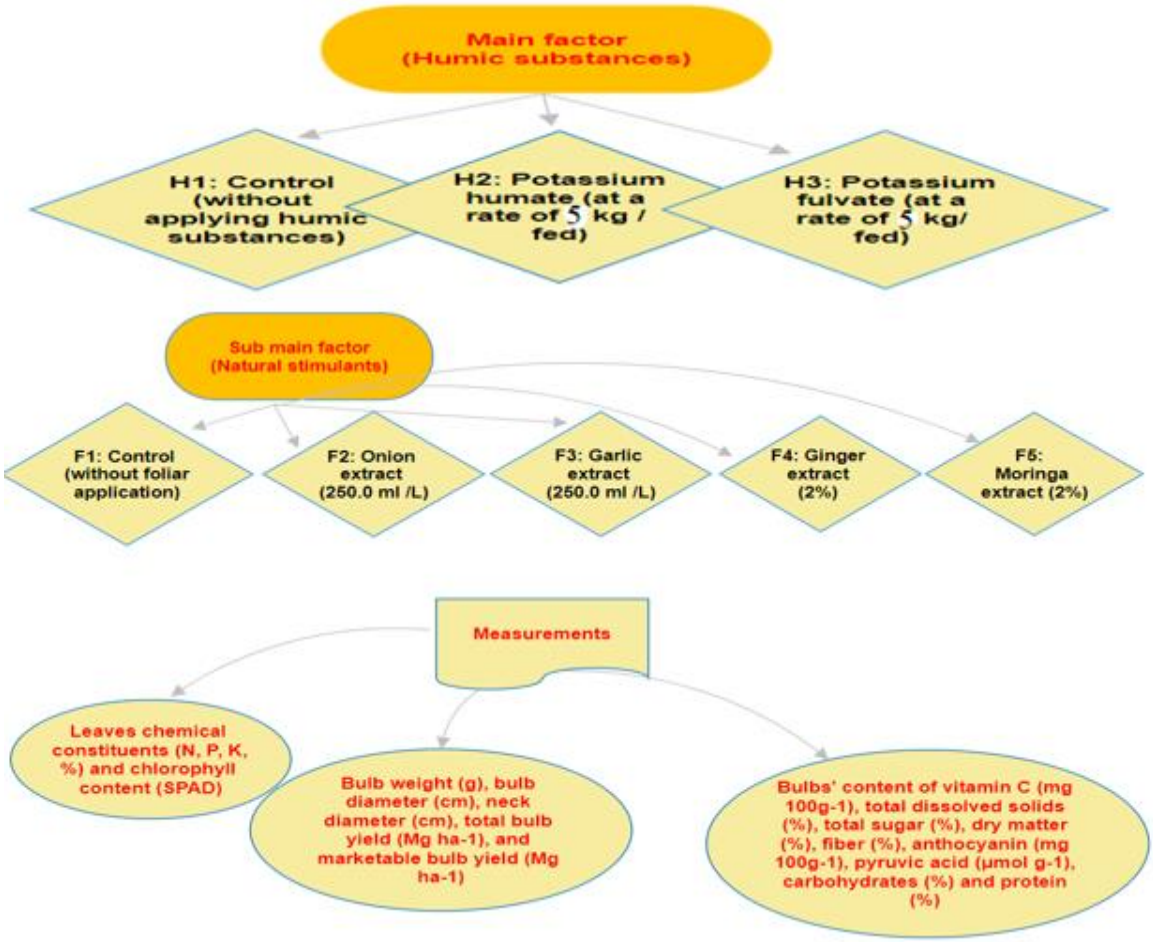

Fig. 1. Flowchart of the experiment.

Table 1. Fundamental soil characteristics.

Characteristics	Values
Available nitrogen	35.7
Available phosphorus	6.04
Available potassium	213.6
O.M, %	1.25
EC, dS m^{-1}	3.25
pH	8.12
FC	35
SP	70
The soil under study possesses a clayey texture, consisting of 50% clay particles, 25% silt particles, and 25% sand particles.	

Table 2. Characteristics of the both potassium humate and potassium fulvate.

Composition	Potassium humate	Potassium fulvate
Humic Acid (%)	66	18
Fulvic Acid (%)	13	60
pH	9.1	5.63
K, %	10	13
Solubility	Moderately soluble	Highly soluble
Molecular weight	Higher molecular weight	Lower molecular weight

Table 3. Chemical components of natural stimulants extract.

Components	Moringa extract	Garlic extract	Onion extract	Ginger extract
Super oxide dismutase (SOD, IU min $^{-1}$ mg $^{-1}$ protein)	200.3	103.2	88.9	140.5
Peroxidase (POD, IU min $^{-1}$ mg $^{-1}$ protein)	23.10	15.60	12.9	18.30
Catalase (CAT, IU min $^{-1}$ mg $^{-1}$ protein)	8.000	6.100	5.20	6.500
Phenols (mg g^{-1})	13.50	13.60	12.1	12.50
N, %	2.200	1.850	1.65	2.000
P, %	0.340	0.27	0.25	0.300
K, %	2.300	2.200	2.10	2.200

3. Results

3.1 Leaf chemical constituents and chlorophyll content

Table 4 shows the effect of applying humic substances and exogenous application of natural stimulants on onion leaves chemical constituents (N, P, K, %) and chlorophyll content (SPAD) at 85 days after transplanting during seasons of 2022/23 and 2023/24.

Concerning humic substances, the highest values for N, P, K and chlorophyll (SPAD) content were observed when potassium fulvate was applied, followed by that of plants treated with potassium humate and then that of the corresponding plants grown under the control group (without humic substances). As for the natural stimulants, the most effective treatment was moringa extract, followed by ginger extract then garlic extract and finally onion extract, with all natural stimulants showing better performance compared to the control group. Generally, the most favorable results in terms of N, P, K and chlorophyll contents were obtained when onion plants were treated with potassium fulvate in combination with spraying moringa extract. The same trend was observed during both studied seasons.

3.2 Quantitative yield

Table 5 illustrates the impact of utilizing humic substances and externally applying natural stimulants on bulb weight (g), bulb diameter (cm), neck diameter (cm), total bulb yield (Mg ha^{-1}, **Fig 2**), and marketable bulb yield (Mg ha^{-1}**)** at the harvest stage across the 2022/23 and 2023/24 seasons.

Regarding humic substances, the most effective treatment for achieving the highest values in quantitative yield traits was the application of potassium fulvate. Potassium humate followed as the second-best treatment, while the control treatment (without humic substances) ranked last in performance.

Concerning the natural stimulants, the most superior treatment was moringa extract, while the lowest values were recorded under the control treatment. In other words, the sequence order from the most effective natural stimulants to less was as follows; moringa extract > ginger extract>garlic extract > onion extract> control.

In terms of the interaction effect, it is evident that the highest values for bulb weight (g), bulb diameter (cm), neck diameter (cm), total bulb yield (Mg ha^{-1}), and marketable bulb yield (Mg ha^{-1}) were achieved when onion plants were subjected to a combination treatment of potassium fulvate along with spraying moringa extract. This consistent trend was observed throughout both studied seasons.

3.3 Qualitative yield

Tables 6 and 7 present the influence of employing humic substances and externally administering natural stimulants on the bulbs' content of vitamin C (mg 100g^{-1}), total dissolved solids (%), total sugar (%), dry matter (%), fiber (%), anthocyanin (mg 100g^{-1}), pyruvic acid (µmol g^{-1}), carbohydrates (%) and protein (%) at the harvest stage over the 2022/23 and 2023/24 seasons. Concerning the studied natural stimulants, it's noteworthy that all studied natural stimulants exhibited superior performance compared to the control group. Moringa extract proved to be the most effective treatment for achieving the highest values in qualitative yield traits, followed by ginger extract, garlic extract, and finally onion extract.

Regarding the interaction effect, it is clear that the highest levels of vitamin C (mg 100 g^{-1}), total dissolved solids (%), total sugar (%), dry matter (%),

fiber (%), anthocyanin (mg 100 g^{-1}), pyruvic acid (µmol g^{-1}), carbohydrates (%) and protein (%) in the bulbs were attained when onion plants received a combined treatment of potassium fulvate along with the application of moringa extract. This consistent pattern was observed consistently throughout both studied seasons.

Table 4. Effect of humic substances (potassium humate and fulvate) and various natural stimulants on the leaf chemical constitutes and chlorophyll content of onion plants at 85 days after transplanting during seasons of 2022/23 and 2023/24.

Treatments		N, %		P, %		K, %		Chlorophyll, SPAD reading	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Humic substances treatments									
H_1		2.54c	2.61c	0.293c	0.305c	2.18c	2.23c	39.35c	39.79c
H_2		2.94b	3.03b	0.338b	0.352b	2.52b	2.59b	40.30b	40.79b
H_3		3.41a	3.52a	0.388a	0.404a	2.85a	2.91a	41.33a	41.95a
LSD at 5%		**0.04**	**0.03**	**0.005**	**0.003**	**0.02**	**0.02**	**0.41**	**0.77**
Natural stimulants treatments									
F_1		2.80e	2.89e	0.321e	0.335e	2.37e	2.42e	39.88c	40.42c
F_2		2.85d	2.95d	0.329d	0.343d	2.43d	2.49d	40.11bc	40.68bc
F_3		2.96c	3.04c	0.342c	0.356c	2.54c	2.60c	40.36ab	40.82abc
F_4		3.04b	3.14b	0.351b	0.365b	2.60b	2.66b	40.57ab	41.05ab
F_5		3.14a	3.24a	0.357a	0.372a	2.65a	2.71a	40.72a	41.26a
LSD at 5%		**0.04**	**0.04**	**0.004**	**0.005**	**0.03**	**0.03**	**0.47**	**0.50**
Interaction									
H_1	**F_1**	2.43	2.51	0.278	0.289	2.05	2.10	38.95	39.31
	F_2	2.45	2.53	0.283	0.295	2.08	2.12	39.13	39.72
	F_3	2.49	2.56	0.293	0.306	2.19	2.24	39.37	39.80
	F_4	2.61	2.69	0.303	0.316	2.25	2.30	39.56	39.91
	F_5	2.71	2.79	0.310	0.322	2.33	2.39	39.72	40.20
H_2	**F_1**	2.78	2.87	0.318	0.333	2.37	2.42	39.86	40.32
	F_2	2.85	2.94	0.328	0.342	2.46	2.53	40.13	40.56
	F_3	2.94	3.03	0.340	0.354	2.54	2.61	40.29	40.78
	F_4	3.01	3.09	0.349	0.363	2.60	2.67	40.51	41.02
	F_5	3.12	3.21	0.357	0.371	2.66	2.72	40.70	41.29
H_3	**F_1**	3.20	3.30	0.368	0.382	2.70	2.76	40.82	41.63
	F_2	3.27	3.38	0.376	0.391	2.74	2.81	41.05	41.74
	F_3	3.45	3.55	0.392	0.408	2.88	2.95	41.42	41.89
	F_4	3.52	3.64	0.400	0.416	2.95	3.01	41.64	42.21
	F_5	3.60	3.72	0.405	0.423	2.97	3.04	41.73	42.28
LSD at 5%		**0.07**	**0.07**	**0.008**	**0.008**	**0.06**	**0.06**	**0.82**	**0.86**

Means within a column followed by a different letter (s) are statistically different at 5%

Where, H_1: Control (without applying humic substances), **H_2:** Potassium humate **(**at a rate of 5.0 kg per feddan), **H_3:** Potassium fulvate **(**at a rate of 5.0 kg per feddan**), F_1:** Control (without foliar application), **F_2:** Onion extract (250.0 ml L^{-1}), **F_3:** Garlic extract (250.0 ml L^{-1}), **F_4:** Ginger extract (2%) and **F_5:** Moringa extract (2%)

Table 5. Effect of humic substances (potassium humate and fulvate) and various natural stimulants on the quantitative yield of onion plants at harvest stage during seasons of 2022/23 and 2023/24.

Treatments		Bulb weight, g		Bulb diameter, cm		Neck diameter, cm		Total bulb yield, Mg ha^{-1}		Marketable bulb yield, Mg ha^{-1}	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Humic substances treatments											
H_1		84.54c	85.98c	4.19c	4.27c	0.89c	0.93c	32.19c	32.74c	30.68c	30.97c
H_2		95.29b	96.97b	5.26b	5.36b	1.39b	1.45b	36.29b	36.93b	34.24b	34.66b
H_3		106.09a	107.69a	6.44a	6.57a	2.13a	2.19a	40.40a	41.01a	37.93a	38.16a
LSD at 5%		**0.79**	**1.36**	**0.17**	**0.07**	**0.05**	**0.05**	**0.30**	**0.52**	**0.56**	**1.11**
Natural stimulants treatments											
F_1		91.24d	92.76c	4.82e	4.92e	1.26e	1.31e	34.74d	35.32c	32.80e	33.10d
F_2		94.32c	96.05b	5.06d	5.17d	1.37d	1.41d	35.91c	36.58b	33.58d	33.87cd
F_3		95.66b	97.36b	5.34c	5.46c	1.45c	1.52c	36.43b	37.07b	34.27c	34.61bc
F_4		97.24a	98.78a	5.53b	5.64b	1.59b	1.63b	37.03a	37.62a	35.04b	35.34ab
F_5		98.08a	99.45a	5.71a	5.81a	1.69a	1.74a	37.35a	37.87a	35.73a	36.07a
LSD at 5%		**1.26**	**1.38**	**0.15**	**0.07**	**0.07**	**0.07**	**0.48**	**0.52**	**0.40**	**0.97**
Interaction											
	F_1	81.11	82.37	3.79	3.87	0.76	0.78	30.89	31.37	29.22	29.28
	F_2	84.55	86.16	3.94	4.00	0.82	0.85	32.20	32.81	29.94	30.17
H_1	**F_3**	84.71	86.18	4.21	4.30	0.87	0.95	32.25	32.82	30.64	30.98
	F_4	85.09	86.43	4.41	4.50	0.95	0.98	32.40	32.92	31.49	31.80
	F_5	87.26	88.74	4.60	4.68	1.06	1.09	33.23	33.79	32.10	32.62
	F_1	92.45	94.17	4.78	4.88	1.13	1.19	35.21	35.86	32.81	33.30
	F_2	93.95	95.67	5.07	5.18	1.25	1.29	35.77	36.43	33.52	33.99
H_2	**F_3**	94.53	96.30	5.26	5.36	1.32	1.39	36.00	36.67	34.32	34.70
	F_4	97.73	99.27	5.44	5.53	1.55	1.59	37.22	37.80	34.94	35.36
	F_5	97.77	99.43	5.73	5.83	1.71	1.78	37.24	37.86	35.63	35.97
	F_1	100.14	101.75	5.90	6.02	1.89	1.95	38.14	38.75	36.36	36.72
	F_2	104.45	106.32	6.18	6.33	2.03	2.10	39.77	40.49	37.29	37.44
H_3	**F_3**	107.75	109.59	6.56	6.70	2.17	2.21	41.03	41.73	37.86	38.15
	F_4	108.91	110.63	6.75	6.89	2.26	2.33	41.48	42.13	38.68	38.85
	F_5	109.21	110.17	6.79	6.92	2.31	2.36	41.59	41.95	39.47	39.64
LSD at 5%		**2.18**	**2.38**	**0.26**	**0.12**	**0.12**	**0.13**	**0.83**	**0.91**	**0.70**	**1.69**

Means within a column followed by a different letter (s) are statistically different at 5%

Where, H_1: Control (without applying humic substances), **H_2:** Potassium humate **(**at a rate of 5.0 kg per feddan), **H_3:** Potassium fulvate **(**at a rate of 5.0 kg per feddan**), F_1:** Control (without foliar application), **F_2:** Onion extract (250.0 ml L^{-1}), **F_3:** Garlic extract (250.0 ml L^{-1}), **F_4:** Ginger extract (2%) and **F_5:** Moringa extract (2%)

Table 6. Effect of humic substances (potassium humate and fulvate) and various natural stimulants on the qualitative yield traits (vitamin C, total dissolved solids, total sugar and dry matter) of onion plants at harvest stage during seasons of 2022/23 and 2023/24.

Treatments		Vitamin C, mg 100g^{-1}		Total dissolved solids, %		Total sugar, %		Dry matter, %	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Humic substances treatments									
H_1		10.88c	11.06c	9.67c	9.86c	5.43c	5.53c	10.22c	10.36c
H_2		12.11b	12.28b	10.72b	10.96b	5.74b	5.85b	11.53b	11.68b
H_3		13.10a	13.29a	11.62a	11.88a	6.07a	6.20a	12.53a	12.69a
LSD at 5%		**0.10**	**0.11**	**0.15**	**0.09**	**0.07**	**0.08**	**0.14**	**0.14**
Natural stimulants treatments									
F_1		11.56e	11.73e	10.28e	10.50e	5.61c	5.72c	10.96e	11.09e
F_2		11.84d	12.02d	10.48d	10.70d	5.69b	5.80b	11.23d	11.37d
F_3		12.05c	12.24c	10.66c	10.88c	5.73b	5.85b	11.45c	11.60c
F_4		12.24b	12.42b	10.88b	11.13b	5.83a	5.95a	11.63b	11.79b
F_5		12.46a	12.64a	11.06a	11.29a	5.87a	5.98a	11.87a	12.02a
LSD at 5%		**0.15**	**0.15**	**0.15**	**0.14**	**0.08**	**0.06**	**0.16**	**0.17**
Interaction									
	F_1	10.40	10.59	9.25	9.43	5.30	5.41	9.77	9.88
	F_2	10.63	10.83	9.46	9.64	5.37	5.47	10.01	10.12
H_1	**F_3**	10.89	11.11	9.68	9.83	5.42	5.52	10.22	10.36
	F_4	11.08	11.22	9.88	10.09	5.49	5.61	10.42	10.58
	F_5	11.40	11.56	10.10	10.30	5.54	5.64	10.70	10.83
	F_1	11.57	11.74	10.30	10.52	5.58	5.69	10.93	11.08
	F_2	11.99	12.16	10.50	10.73	5.67	5.78	11.35	11.50
H_2	**F_3**	12.15	12.31	10.69	10.93	5.71	5.83	11.58	11.72
	F_4	12.33	12.53	10.97	11.26	5.84	5.95	11.78	11.91
	F_5	12.50	12.66	11.16	11.36	5.88	6.00	12.00	12.18
	F_1	12.72	12.86	11.29	11.53	5.93	6.05	12.17	12.30
	F_2	12.89	13.06	11.49	11.74	6.01	6.15	12.34	12.48
H_3	**F_3**	13.11	13.31	11.61	11.89	6.07	6.19	12.54	12.73
	F_4	13.31	13.50	11.79	12.03	6.15	6.28	12.70	12.89
	F_5	13.48	13.70	11.93	12.19	6.18	6.31	12.90	13.05
LSD at 5%		**0.26**	**0.25**	**0.26**	**0.25**	**0.13**	**0.11**	**0.28**	**0.29**

Means within a column followed by a different letter (s) are statistically different at 5%

Where, H_1: Control (without applying humic substances), **H_2:** Potassium humate **(**at a rate of 5.0 kg per feddan), **H_3:** Potassium fulvate **(**at a rate of 5.0 kg per feddan**), F_1:** Control (without foliar application), **F_2:** Onion extract (250.0 ml L^{-1}), **F_3:** Garlic extract (250.0 ml L^{-1}), **F_4:** Ginger extract (2%) and **F_5:** Moringa extract (2%)

Table 7. Effect of humic substances (potassium humate and fulvate) and various natural stimulants on the qualitative yield traits (fiber, anthocyanin, pyruvic acid, carbohydrates and protein) of onion plants at harvest stage during seasons of 2022/23 and 2023/24.

Treatments		Fiber, %		Anthocyanin, mg 100 g^{-1}		Pyruvic acid, µmol g^{-1}		Carbohydrates, %		Protein, %	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Humic substances treatments											
H_1		2.79c	2.85c	25.23c	25.66c	5.32c	5.48c	15.38c	15.67c	7.46c	7.77c
H_2		3.38b	3.46b	26.65b	27.07b	6.30b	6.48b	16.63b	16.98b	8.04b	8.36b
H_3		3.97a	4.06a	27.76a	28.15a	7.13a	7.36a	17.78a	18.14a	8.58a	8.93a
LSD at 5%		**0.07**	**0.05**	**0.57**	**0.25**	**0.07**	**0.21**	**0.15**	**0.21**	**0.07**	**0.11**
Natural stimulants treatments											
F_1		3.15e	3.21e	26.05d	26.51d	5.87e	6.06c	16.11d	16.43c	7.81c	8.13c
F_2		3.23d	3.32d	26.28cd	26.67cd	6.09d	6.28b	16.35c	16.70b	7.90c	8.24c
F_3		3.39c	3.48c	26.59bc	26.96bc	6.24c	6.42b	16.58b	16.90b	8.05b	8.37b
F_4		3.51b	3.58b	26.80ab	27.23ab	6.43b	6.63a	16.88a	17.21a	8.14ab	8.48ab
F_5		3.61a	3.69a	27.02a	27.42a	6.61a	6.80a	17.06a	17.43a	8.23a	8.56a
LSD at 5%		**0.04**	**0.05**	**0.33**	**0.32**	**0.08**	**0.18**	**0.19**	**0.24**	**0.10**	**0.11**
Interaction											
H_1	**F_1**	2.57	2.63	24.75	25.16	4.96	5.12	14.87	15.12	7.24	7.55
	F_2	2.66	2.71	24.96	25.36	5.12	5.27	15.15	15.46	7.36	7.68
	F_3	2.78	2.85	25.21	25.59	5.33	5.48	15.37	15.65	7.47	7.78
	F_4	2.92	2.98	25.46	25.93	5.52	5.69	15.65	15.96	7.57	7.90
	F_5	3.01	3.07	25.76	26.25	5.68	5.84	15.84	16.17	7.66	7.96
H_2	**F_1**	3.13	3.19	26.08	26.66	5.85	6.03	16.10	16.44	7.78	8.13
	F_2	3.21	3.29	26.32	26.69	6.17	6.36	16.35	16.73	7.88	8.22
	F_3	3.43	3.51	26.75	27.12	6.28	6.46	16.59	16.91	8.10	8.40
	F_4	3.52	3.61	26.97	27.39	6.49	6.67	16.98	17.31	8.17	8.49
	F_5	3.62	3.70	27.13	27.48	6.69	6.87	17.14	17.53	8.26	8.57
H_3	**F_1**	3.74	3.81	27.32	27.72	6.81	7.03	17.36	17.74	8.39	8.71
	F_2	3.84	3.94	27.56	27.98	6.99	7.21	17.56	17.90	8.46	8.82
	F_3	3.96	4.06	27.79	28.18	7.11	7.33	17.77	18.13	8.57	8.91
	F_4	4.08	4.16	27.97	28.35	7.30	7.53	18.01	18.36	8.69	9.04
	F_5	4.22	4.30	28.17	28.54	7.46	7.71	18.20	18.59	8.76	9.15
LSD at 5%		**0.07**	**0.09**	**0.57**	**0.55**	**0.13**	**0.31**	**0.34**	**0.42**	**0.17**	**0.19**

Means within a column followed by a different letter (s) are statistically different at 5%

Where, H_1: Control (without applying humic substances), **H_2:** Potassium humate **(**at a rate of 5.0 kg per feddan), **H_3:** Potassium fulvate **(**at a rate of 5.0 kg per feddan**), F_1:** Control (without foliar application), **F_2:** Onion extract (250.0 ml L^{-1}), **F_3:** Garlic extract (250.0 ml L^{-1}), **F_4:** Ginger extract (2%) and **F_5:** Moringa extract (2%).

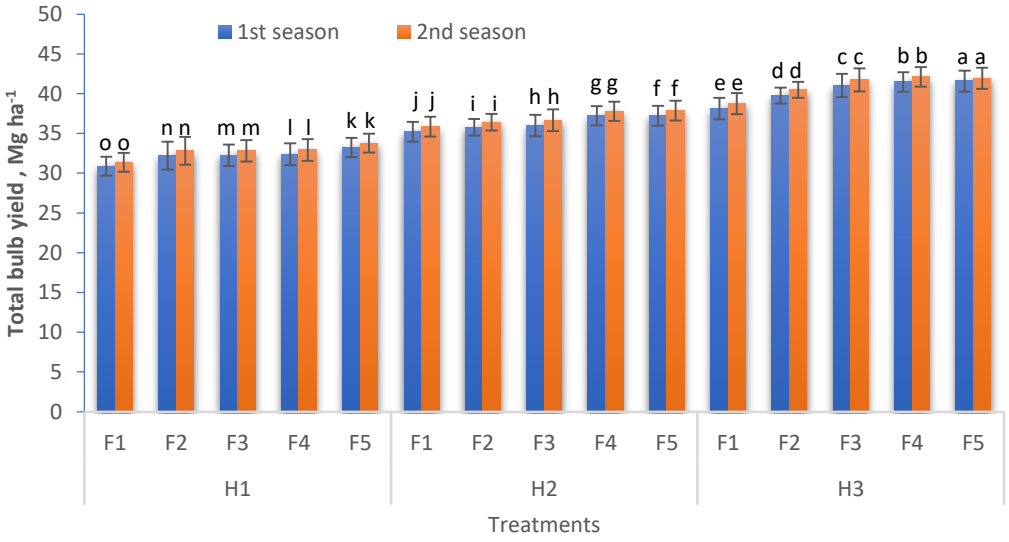

Fig. 2. Effect of humic substances (potassium humate and fulvate) and various natural stimulants on the total bulb yield of onion plants at harvest stage during seasons of 2022/23 and 2023/24.

Where, H_1: Control (without applying humic substances), **H_2:** Potassium humate **(**at a rate of 5.0 kg per feddan), **H_3:** Potassium fulvate **(**at a rate of 5.0 kg per feddan**), F_1:** Control (without foliar application), **F_2:** Onion extract (250.0 ml L^{-1}), **F_3:** Garlic extract (250.0 ml L^{-1}), **F_4:** Ginger extract (2%) and **F_5:** Moringa extract (2%)

4. Discussion

The observed positive effects of potassium humate and potassium fulvate on onion performance and productivity can be attributed to their inherent composition and molecular characteristics. Both substances are organic in nature (**Mosa *et al.* 2020)**. When applied through drip irrigation, they facilitate the uptake of essential nutrients by the onion plants, thereby enhancing their growth and development (**Elshaboury and Sakara 2021)**.

Potassium humate and potassium fulvate act as organic chelators, forming complexes with soil nutrients such as nitrogen, phosphorus, and potassium, making them more readily available to the onion plants. Additionally, these humic substances may have improved soil structure, water retention, and microbial activity, creating a favorable environment for onion growth (**Abd El-Hady *et al.* 2024)**.

The examined humic substances likely exerted a positive impact on both the physical and chemical characteristics of the soil, as well as directly influencing the essential functions of onion plants and higher microorganisms. This influence was consequently reflected in the performance and productivity of onions (**Vasilievich et al. 2021)**. Humic acids may have engaged with the soil, enhancing its chemical and physico-chemical attributes. When introduced, they disperse ions and persist in the soil, thereby being absorbed by the onion plants. Once absorbed, humic acid integrates into the metabolic processes of the onion, enhancing oxygen availability and elevating its vital functions (**Amiri-Forotaghe *et al.* 2022)**.

Potassium fulvate, in particular, exhibits superior effectiveness compared to potassium humate. This is likely due to its smaller molecular size and higher solubility, allowing for better absorption and utilization by the onion plants. As a result, onion plants treated with potassium fulvate demonstrate enhanced nutrient uptake, leading to improved productivity and quality compared to those treated with potassium humate (**Jin *et al.* 2024)**.

On the other hand, the exceptional performance of moringa extract in promoting onion productivity and quality can be attributed to its rich content of antioxidants and essential nutrients (**Awad *et al.* 2024)**. Moringa extract contains high levels of vitamins, minerals, and phytochemicals such as vitamin C, β-carotene, and flavonoids, which exert antioxidant properties and support onion plant growth and development. Moringa played a pivotal role in enhancing the productivity and quality of onions due to its rich array of beneficial compounds and nutrients (**Aljabary, 2023).** With its abundant reserves of antioxidants, vitamins, and minerals, moringa served as a potent natural stimulant for onion plant growth and development. The antioxidants present in moringa, such as vitamins C and E, along with flavonoids and polyphenols, may have helped to combat oxidative stress and protect onion plants from damage caused by environmental factors like UV radiation and pests **(Yaseen and Hájos 2020).** Furthermore, moringa's high content of essential nutrients, including nitrogen, phosphorus, and potassium, may have provided crucial support for onion growth, root development, and overall vigor. Moreover, moringa exhibits bio-stimulant properties that enhance nutrient uptake and assimilation in onion plants, leading to improved nutrient efficiency and utilization. This results in increased onion yields and enhanced nutritional quality of the bulbs (**Zulfiqar *et al.* 2020)**.

Ginger extract, which ranked second among the natural stimulants, is known for its bioactive compounds. Ginger extract may have played a crucial role in enhancing onion productivity and quality owing to its rich composition of bioactive compounds and beneficial properties. With its potent antioxidant, anti-inflammatory, and antimicrobial properties, ginger extract served as an effective natural stimulant for promoting plant growth and health **Salariya and Habib 2003)**. The presence of bioactive compounds such as gingerol and shogaol contributes to the enhancement of root development, nutrient uptake, and overall plant vigor in onions. Furthermore, ginger extract acts as a natural defense mechanism for onion plants, protecting them against various biotic and abiotic stresses. Its antioxidant properties help to mitigate oxidative stress caused by environmental factors such as UV radiation, heat, and pests, thereby reducing plant damage and improving resilience **(Naser and Ibadi 2022).** Additionally, ginger extract's anti-inflammatory properties can alleviate stress-induced inflammation in onion plants, allowing them to allocate more resources towards growth and development. Moreover, ginger extract stimulates hormone production and signaling pathways in onion plants, promoting growth and flowering processes. This leads to increased onion bulb formation, size, and weight, ultimately enhancing overall yield and productivity (**Awwad *et al.* 2022)**.

Similarly, garlic extract, ranking third, contains sulfur-containing compounds such as allicin, which have been shown to enhance plant growth and resistance to pathogens (**Hayat *et al.* 2018)**. Garlic extract played a pivotal role in enhancing onion productivity and quality due to its potent array of

bioactive compounds and beneficial properties. Rich in sulfur-containing compounds such as allicin, garlic extract served as a natural stimulant for promoting onion plant growth and health. Allicin, along with other sulfur compounds, may have contributed to improved root development, nutrient uptake, and overall plant vigor in onions. Furthermore, garlic extract exhibits strong antimicrobial properties, helping to suppress soil-borne pathogens and reduce disease incidence in onion plants (**Mahmood *et al.* 2020)**. Its antioxidant properties also play a crucial role in mitigating oxidative stress and protecting onion plants from environmental stressors. Additionally, garlic extract stimulates hormonal pathways in onion plants, leading to increased bulb formation, size, and weight, thereby enhancing overall yield and productivity (**Mohamed *et al.* 2020)**.

Onion extract, although ranking last among the natural stimulants, still exhibits beneficial effects on onion productivity. It contains bioactive compounds such as quercetin and sulfur compounds, which contribute to plant growth and stress tolerance. Although it may rank lower compared to other natural stimulants, onion extract still offers valuable benefits for onion cultivation. Rich in compounds such as quercetin and sulfur-containing compounds, onion extract contributes to improved root growth, nutrient uptake, and overall onion plant vigor (**Li *et al.* 2020)**. Its antioxidant properties may have helped to protect onion plants from oxidative stress caused by environmental factors, enhancing their resilience and health. Additionally, onion extract contains phytochemicals that stimulate hormonal pathways, and this may have promoted bulb formation and development. While it may not exhibit the same potency as other extracts, onion extract still plays a vital role in supporting onion growth and contributing to overall productivity and quality (**Elshaboury and Sakara 2021)**.

The synergistic effect of potassium fulvate and moringa extract further enhances onion productivity by optimizing nutrient uptake and utilization. Potassium fulvate improves nutrient availability in the soil, while moringa extract provides essential nutrients and antioxidants directly to the plants. This combined treatment results in improved onion growth, yield, and quality, highlighting the importance of employing integrated approaches for sustainable crop management. The obtained results are in harmony with those of **Mahmood *et al.* (2020)**; **Elshaboury and Sakara (2021); Awwad *et al.* (2022).**

5. Conclusion

The findings of this study found that potassium fulvate was the most effective humic substance, and among the natural stimulants, moringa extract provided the most substantial improvements, to enhance onion productivity in Egypt. By adopting sustainable agricultural practices and incorporating these effective treatments, farmers can optimize yields while minimizing environmental impact, thereby contributing to national food security and economic stability. Moving forward, it is recommended that further research be conducted to explore optimal application rates and timing for these stimulants, as well as their long-term effects on soil health and crop resilience. Additionally, extension programs should be developed to disseminate knowledge and encourage widespread adoption of these innovative techniques among onion growers in Egypt.

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