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Effect of Foliar Application with Wood Vinegar, Melatonin and some Amino Acids on Growth and Yield of Garlic (*Allium sativum*)

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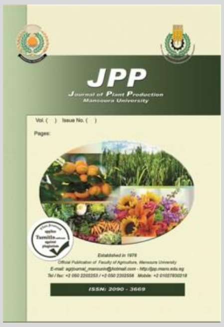

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ABSTRACT

Maximizing garlic productivity in Egypt is essential due to its high nutritional and economic value. The use of eco-friendly natural stimulants may significantly enhance garlic growth, yield, and quality while promoting sustainable agricultural practices. Therefore, this study was conducted during the 2023/24 and 2024/25 growing seasons under a randomized complete block design (RCBD) to evaluate the effects of foliar application with five biostimulants (arginine, proline, melatonin, wood vinegar and brassinolide) along with potassium silicate and a control treatment. The results demonstrated that all applied treatments significantly improved garlic growth parameters, bulb yield, and quality traits compared to the control. Brassinolide (5.0 mg L^{-1}) had the most pronounced effect, leading to significant increases in plant height, leaf area, fresh and dry biomass, bulb weight, diameter, and total yield. Wood vinegar (25 cm³ L^{-1}) ranked second, particularly enhancing leaf number, bulb size, and vitamin C content. Potassium silicate (3.0 g L^{-1}) contributed to stress tolerance and structural integrity, improving overall growth and yield. Meanwhile, melatonin, proline, and arginine showed moderate improvements, primarily in leaf area, dry weight, and bulb quality. These findings underscore the potential of biostimulants to enhance garlic productivity and quality in an environmentally friendly manner. Future research should focus on optimizing application rates and exploring synergistic effects to maximize their benefits under various environmental conditions and stress factors.

Keywords: Arginine, Proline, Melatonin, Wood-vinegar, Brassinolide

INTRODUCTION

Garlic (*Allium sativum* L.), a member of the Amaryllidaceae family, is one of the most economically and nutritionally significant crops worldwide. It is widely cultivated for its culinary, medicinal, and industrial applications (El-Batran, 2022). Rich in bioactive compounds, particularly sulfur-containing compounds, vitamins, and antioxidants, garlic is valued for its health-promoting properties, including its antimicrobial, anti-inflammatory, and cardiovascular benefits (Abdel Nabi *et al.* 2019; El Sayed *et al.* 2024). In Egypt, garlic plays a vital role in both local consumption and export markets, making it a strategic crop that contributes significantly to the agricultural economy. However, achieving high productivity and superior bulb quality remains a challenge, particularly under environmental stresses and suboptimal cultivation conditions (Ismil and Ali-Besar, 2025).

To enhance garlic growth and yield, adopting sustainable and eco-friendly agricultural practices has become essential. The application of natural bio stimulants and protective compounds in foliar spray programs presents a promising approach to improving plant performance while minimizing environmental impact.

Among these, amino acids such as arginine and proline play crucial roles in plant metabolism, stress tolerance and protein synthesis. (Awad-Allah *et al.* 2020; Heidarzadeh and Modarres-Sanavy, 2023). Arginine is a precursor for polyamines and nitric oxide, contributing to cell division, root development, and stress mitigation. Additionally it helps in nutrient absorption, promotes growth performance, improves chlorophyll production and fruit quality as well as increases plant resistance to stress (Hassanein *et al.* 2013; Wang *et al.* 2021; Almutairi *et al.* 2022), while proline functions as an osmoprotectant, enhancing water retention and antioxidant capacity under stress conditions (Siddique *et al.* 2015; Yooyongwech *et al.* 2017; Elsaied *et al.* 2024).

Melatonin, a naturally occurring hormone in plants, has gained attention for its role in regulating growth, delaying senescence, and improving plant resilience to abiotic stress. It enhances antioxidant defense mechanisms and modulates physiological processes that contribute to improved productivity and bulb quality (Hanci and Bingol, 2020; EL-Bauome *et al.* 2022&2024; Mansour *et al.* 2024).

Similarly, wood vinegar, a byproduct of biomass pyrolysis, is rich in organic acids and phenolic compounds that stimulate root development, enhance nutrient uptake, and exhibit antimicrobial properties, thereby promoting plant health and productivity (Zhu *et al.* 2021; Abdel-Sattar *et al.* 2024; Iacomino *et al.* 2024).

Brassinolide, a plant growth regulator belonging to the brassinosteroids group, is known for its ability to enhance cell expansion, photosynthetic efficiency, and resistance to various environmental stresses. It stimulates growth at both the vegetative and reproductive stages, leading to increased biomass accumulation and improved yield quality (Abdulkadhim & Hadi, 2019; Naveen *et al.* 2021; Ruidas *et al.* 2022; Mansour *et al.* 2024).

Additionally, potassium silicate plays a crucial role in strengthening plant cell walls (Zyada & Bardisi,2018; Mohamed *et al.* 2019), enhancing resistance to pathogens, and improving drought and salinity tolerance by reducing oxidative

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stress and improving water-use efficiency (Ghazi *et al.* 2021; Panahandeh& Pahlavan Yali, 2022; Metwally *et al.* 2024).

Given the potential benefits of these natural compounds, this study aims to evaluate the effects of foliar application of arginine, proline, melatonin, wood vinegar, brassinolide, and potassium silicate on garlic growth, yield, and quality. By integrating these treatments into garlic cultivation programs, the study seeks to identify effective, environmentally friendly strategies to maximize productivity while maintaining sustainable agricultural practices.

MATERIALS AND METHODS

1.Experimental Site and Design

Afield trail was conducted at the experimental farm of the Horticultural Research Institute, located in El-Baramon, Dakahlia governorate, Egypt, during two consecutive growing seasons (2023/24 and 2024/25). The experimental design followed a randomized complete block design (RCBD) with three replications.

2.Soil Sampling

Before initiating the experiment, soil samples were collected from a depth of 0–30 cm to determine the initial physicochemical properties of the soil. The analysis was performed following the standard protocols outlined by Dane and Topp (2020) and Sparks *et al.* (2020). The soil texture was classified as clay, comprising 30.0% sand, 21.0% silt, and 49.0% clay. The chemical analysis indicated an electrical conductivity (EC) of 3.07 dSm^{-1}, a slightly alkaline pH of 8.0 (1:2.5 water extract), and organic matter content of 1.4%. The available macronutrients in the soil included 35.0 mg kg^{-1} nitrogen, 7.02 mg kg^{-1} phosphorus, and 202.2 mg kg^{-1} potassium, providing essential baseline information for assessing the impact of the applied treatments on garlic growth and yield.

3. Preparation of the studied treatments

The experiment involved the foliar application of six treatments *i.e.,* brassinolide, wood vinegar, melatonin, proline, arginine and potassium silicate, along with a control group. All materials were sourced from the Egyptian commercial market to ensure practical applicability in local agricultural conditions. Brassinolide was applied at a concentration of 5.0 mg L^{-1}. Wood vinegar, obtained through the thermal distillation (pyrolysis) of wood, was used at 25 cm^3 L^{-1}. It contains organic acids (*e.g.,* acetic acid, 5%), alcohols (*e.g.,* methanol, 1%) and phenolic compounds (*e.g.,* guaiacol, 0.5%). Potassium silicate, applied at a concentration of 3.0 g L^{-1}, is a source of potassium (K_2O 20-30%) and silica (SiO_2 50-60%). Melatonin was applied at 25 mg L^{-1}. It regulates plant responses to abiotic stress, delays senescence, and promotes root growth. Amino acid treatments included proline $C_5H_9NO_2$, (100 mg L^{-1}) and arginine $C_6H_{14}N_4O_2$ (100 mg L^{-1}). All treatment solutions were freshly prepared before each foliar spray application by dissolving the required quantities in distilled water. Surfactants were added to ensure uniform leaf coverage.

4. Plant Material and Cultivation

Garlic (*Allium sativum* L.) cv. Sids 40 was used in this study. Cloves were planted on October 15 in both growing seasons, with a growth period of 180 days, and harvested on April 15. Standard agronomic practices for garlic cultivation were followed throughout the experiment.

5.Foliar Treatments and Application Schedule

Foliar applications of biostimulants and potassium silicate were conducted at five growth stages: 45, 60, 75, 90, and 105 days after planting (DAP). The treatments were applied using a backpack sprayer to ensure uniform coverage. Each studied treatment was sprayed at a rate of 1000 L^3 fed^{-1}.

6.Data Collection and Measurement Intervals

At 120 DAP

Vegetative growth parameters were assessed at 120 days after planting (DAP) to evaluate the early response of garlic plants to the applied treatments. Additionally, several quality traits of garlic bulbs were evaluated at 120 DAP to assess the effects of the applied treatments on bulb composition and nutritional value.

The recorded measurements included:

- **Plant height (cm):** Measured from the base to the tip of the longest leaf using a graduated ruler.
- **Number of leaves per plant:** Counted manually to determine the impact of treatments on foliage development.
- **Fresh weight per plant (g):** Determined by weighing the whole plant immediately after removing it from the soil.
- **Dry weight per plant (g):** Obtained by drying plant samples at 70°C until a constant weight was achieved.
- **Leaf fresh weight per plant (g):** Weighed separately to assess the contribution of leaves to total plant biomass.
- **Leaf area per plant (cm²):** Measured using a leaf area meter to determine the photosynthetic surface available for growth and productivity.
- **Dry matter content (%):** Determined by drying bulb samples at 70°C until a constant weight was reached.
- **Vitamin C (mg 100 g^{-1}):** Quantified using the AOAC (2000) method to assess antioxidant properties.
- **Total soluble solids (TSS, %):** Measured using a refractometer to evaluate the concentration of soluble solids in bulb tissues.
- **Pyruvate content (µmol mL^{-1}):** Estimated as an indicator of pungency and flavor intensity.
- **Oil content (mg g^{-1}):** Determined following AOAC (2000) procedures.
- **Macronutrient content:** To analyze the nutrient composition of garlic bulbs, the macronutrient content, including nitrogen (N), phosphorus (P), and potassium (K), was determined after sample digestion. Clove samples were digested using a mixture of concentrated sulfuric acid and perchloric acid following the procedure described by Peterburgski (1968). The concentrations of N, P and K were measured according to the methods outlined by Walinga *et al.* (2013).

These assessments provided critical insights into the impact of bio stimulants and potassium silicate on the growth performance, biochemical composition and nutritional quality of garlic bulbs.

At 180 DAP

At 180 days after planting (DAP), garlic plants were harvested, and several yield-related parameters were measured to evaluate the effects of different treatments on final productivity and bulb characteristics. The assessed parameters included:

- **Average bulb weight (g):** Determined by weighing a representative sample of bulbs from each treatment.
- **Bulb diameter (cm):** Measured across the widest part of the bulb using a digital caliper.
- **Neck diameter (cm):** Assessed to determine bulb maturity and storage potential.

- **Bulbing ratio:** Calculated as the ratio of bulb diameter to neck diameter, serving as an indicator of bulb compactness.
- **Number of cloves per bulb:** Counted to evaluate bulb segmentation and commercial quality.
- **Total bulb yield (ton fed^{-1}):** The total harvested yield per feddan (ton fed^{-1}) was recorded to determine overall productivity.
- **Marketable yield (ton fed^{-1}):** The weight of bulbs meeting commercial standards (size, shape, and quality) was measured to assess the economic feasibility of the applied treatments.

These parameters provided a comprehensive evaluation of the impact of foliar-applied bio stimulants and potassium silicate on garlic yield and marketable quality.

Statistical Analysis

All collected data were statistically analyzed to determine the effects of the applied treatments on garlic growth, yield, and quality using Duncan's Multiple Range Test according to Gomez and Gomez, (1984).

RESULTS AND DISCUSSION

Table 1 presents the effect of foliar application of the studied stimulants including arginine, proline, melatonin, potassium silicate, wood vinegar and brassinolide, along with the control group on the growth parameters of garlic plants at 120 days after planting during the 2023/24 and 2024/25 seasons. The evaluated parameters include plant height, number of leaves per plant, fresh weight per plant, dry weight per plant, leaves fresh weight and leaf area. The different treatments were compared with the control (untreated) using the Least Significant Difference (LSD) test at a 5% significance level. All bio stimulant treatments improved growth parameters compared to the control, with brassinolide (5.0 mg L^{-1}) and wood vinegar (25 cm^3 L^{-1}) exhibiting the most significant enhancements in all aforementioned growth criteria in both seasons, as there weren't significant difference between brassinolide and wood vinegar treatments. This highlights its strong growth-promoting effects.

Table 1. Effect of foliar application of stimulants on growth criteria of garlic plants at 120 days from planting during seasons of 2023/24 and 2024/25

Treatments	Plant height,cm		No. of leavesplant^{-1}		Fresh weight,g plant^{-1}	
	1stseason	2ndseason	1stseason	2ndseason	1stseason	2ndseason
Control (without)	50.77e	53.10b	3.00b	3.33b	56.44c	58.60c
Arginine (100 mgL^{-1})	51.53e	54.10ab	3.67ab	4.00ab	56.68c	58.55c
Proline (100 mgL^{-1})	54.40d	54.27ab	4.00ab	4.67ab	57.01bc	58.83c
Melatonin (25 mgL^{-1})	55.43cd	54.70ab	4.33ab	5.00ab	57.48bc	59.76bc
Potassium silicate (3.0 gL^{-1})	56.60bc	55.20ab	4.67ab	5.00ab	58.14b	60.40ab
Wood vinegar (25 cm^3 L^{-1})	57.40ab	56.77a	5.00a	5.33a	60.94a	60.79ab
Brassinolide (5.0 mgL^{-1})	58.27a	57.07a	5.33a	5.67a	61.43a	61.36a
LSD $_{at 5\%}$	1.32	3.29	2.02	1.79	1.42	1.40

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

Table 1. Cont.

Treatments	Dry weight,g plant^{-1}		Leaves fresh weight, g plant^{-1}		Leaf area,cm^2 plant^{-1}	
	1stseason	2ndseason	1stseason	2ndseason	1stseason	2ndseason
Control (without)	12.07b	12.55a	23.07d	23.12d	235.00c	231.67d
Arginine (100 mgL^{-1})	12.19ab	12.62a	23.11d	23.54cd	239.67bc	246.00cd
Proline (100 mgL^{-1})	12.56ab	12.73a	23.49d	23.64cd	244.00bc	249.67c
Melatonin (25 mgL^{-1})	12.65ab	12.78a	24.53c	23.93c	250.67b	256.33bc
Potassium silicate (3.0 gL^{-1})	12.70ab	12.91a	24.84bc	25.03b	265.00ab	268.00ab
Wood vinegar (25 cm^3 L^{-1})	12.76ab	13.00a	25.27ab	25.16b	269.00a	273.67a
Brassinolide (5.0 mgL^{-1})	12.83a	13.14a	25.52a	26.24a	276.33a	281.67a
LSD $_{at 5\%}$	0.75	N.S*	0.57	0.57	13.86	15.55

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
N.S*= no significant

Potassium silicate (3.0 g L^{-1}) also had a significant positive impact, particularly in plant height, number of leaves and fresh weight, suggesting its role in stress tolerance and structural reinforcement of plant tissues. Melatonin (25 mg L^{-1}) significantly increased the number of leaves and leaf area, likely due to its role in regulating plant physiological responses and reducing oxidative stress. Proline (100 mg L^{-1}) and Arginine (100 mg L^{-1}) moderately improved leaf number, leaf area, and dry weight, but their effects were less pronounced compared to the other treatments. The control (untreated plants) recorded the lowest values in all growth parameters, emphasizing the importance of bio stimulant applications in enhancing garlic plant development.

These findings demonstrate the beneficial effects of stimulants in enhancing plant physiological processes, leading to improved growth performance. The superior performance of brassinolide can be attributed to its ability to stimulate cell division, enhance nutrient uptake, and increase photosynthetic efficiency, resulting in greater vegetative growth and expanded leaf area. The impact of wood vinegar is likely due to its content of phenolic compounds and organic acids, which may stimulate enzymatic activity and enhance nutrient absorption. Similarly, Potassium silicate contributed to cell wall reinforcement and improved stress tolerance, promoting overall plant growth. Melatonin plays a crucial role in modulating plant metabolism and mitigating oxidative stress, explaining its positive effects on leaf development and plant height (Hanci and Bingol, 2020; Mansour *et al.* 2024). Meanwhile, proline and Arginine support stress adaptation mechanisms and protein synthesis (Awad-Allah *et al.* 2020; Heidarzadeh and Modarres-Sanavy, 2023), but their effects were relatively moderate compared to the other treatments.

These results align with previous studies indicating that brassinolide enhances vegetative growth and yield in garlic (Mansour *et al.* 2024). Additionally, research has shown that wood vinegar improves nutrient uptake and photosynthetic efficiency (Zhu *et al.* 2021), while potassium silicate strengthens plant tolerance to environmental stressors and enhances growth (Ghazi *et al.* 2021).

Tables 2 and 3 present the effects of foliar application of different stimulants on the quality and nutritional composition of garlic bulbs at 120 days from planting during the 2023/24 and 2024/25 growing seasons.

Table 2. Effect of foliar application of stimulants on bulb quality parameters of garlic plants at 120 days from planting during seasons of 2023/24 and 2024/25

Treatments	Dry matter, %		Vitamin C, mg 100g^{-1}		TSS*, %		Purvate content, πmol.ml^{-1}		Oil, mg g^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control (without)	19.04b	18.24b	11.95d	11.41c	20.11d	19.79c	9.78e	9.56d	14.49e	14.27d
Arginine (100 mgL^{-1})	19.33ab	18.58ab	12.16d	11.56c	20.40cd	20.13bc	9.89de	9.70cd	14.77de	14.50d
Proline (100 mgL^{-1})	19.34ab	18.59ab	12.21cd	11.61c	20.48bcd	20.22bc	10.08cd	9.83bc	15.11cd	14.87c
Melatonin (25 mgL^{-1})	19.55a	18.67ab	12.49bc	11.94b	20.68abc	20.41ab	10.10cd	9.90bc	15.39c	15.14c
Potassium silicate (3.0 gL^{-1})	19.71a	18.64ab	12.58b	11.95ab	20.85abc	20.49ab	10.30bc	10.06b	15.77b	15.48b
Wood vinegar (25 cm^3 L^{-1})	19.76a	18.98a	12.77ab	12.15ab	20.97ab	20.86a	10.53ab	10.32a	16.05ab	15.75b
Brassinolide (5.0 mgL^{-1})	19.78a	19.02a	12.92a	12.27a	21.11a	20.87a	10.62a	10.34a	16.40a	16.09a
LSD at 5%	0.45	0.46	0.30	0.31	0.50	0.51	0.26	0.26	0.36	0.32

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
TSS*= Total Soluble Solid

Table 3. Effect of foliar application of stimulants on bulb nutritional content of garlic plants at 120 days from planting during seasons of 2023/24 and 2024/25

Treatments	Nitrogen,%		Phosphorus,%		Potassium,%	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control (without)	2.11d	2.08e	0.309e	0.297d	2.42e	2.38f
Arginine (100 mgL^{-1})	2.14d	2.13de	0.316e	0.304d	2.47de	2.46e
Proline (100 mgL^{-1})	2.20cd	2.17d	0.324d	0.312c	2.55cde	2.53d
Melatonin (25 mgL^{-1})	2.28bc	2.24c	0.328cd	0.316c	2.60bcd	2.58cd
Potassium silicate (3.0 gL^{-1})	2.32abc	2.30b	0.332bc	0.319bc	2.68abc	2.64bc
Wood vinegar (25 cm^3 L^{-1})	2.37ab	2.34ab	0.337b	0.324ab	2.74ab	2.68ab
Brassinolide (5.0 mgL^{-1})	2.45a	2.39a	0.345a	0.331a	2.80a	2.73a
LSD at 5%	0.14	0.06	0.007	0.008	0.16	0.06

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

Table 2 shows the impact on bulb quality parameters, including dry matter percentage, vitamin C content, total soluble solids (TSS), pyruvate content and oil content. The results indicate significant differences among treatments, with brassinolide (5.0 mg L^{-1}) consistently leading across most parameters, followed by wood vinegar (25 cm³ L^{-1}) and potassium silicate (3.0 g L^{-1}). Noting that there weren't significant difference between brassinolide and wood vinegar treatments in terms of dry mater content and TSS in both seasons as well as purvate content in the 2nd season and oil content in the 1st season. The control (untreated plants) recorded the lowest values in all parameters.

Table 3 illustrates the effect on bulb nutritional content, specifically nitrogen (N), phosphorus (P), and potassium (K) concentrations. Again, brassinolide treatment outperformed all others, while the control showed the lowest nutrient accumulation.

Overall, the effectiveness of the treatments, based on the results from both tables, follows a descending order. Brassinolide (5.0 mg L^{-1}) demonstrated the highest performance across all parameters, making it the most effective treatment. Wood vinegar (25 cm³ L^{-1}) ranked second, particularly excelling in enhancing vitamin C content, total soluble solids (TSS), and nutrient accumulation. Potassium silicate (3.0 g L^{-1}) followed in third place, showing significant improvements in bulb quality and nutrient uptake. Melatonin (25 mg L^{-1}) provided moderate enhancements in both bulb quality and nutrient content, while proline (100 mg L^{-1}) also contributed positively but was slightly outperformed by melatonin. Arginine (100 mg L^{-1}) exhibited some beneficial effects but ranked lower than proline. Finally, the control (untreated plants) recorded the lowest values across all measured traits, confirming the positive impact of biostimulant applications on garlic bulb quality and nutritional content.

Brassinolide superiority can be attributed to its role as a plant growth regulator that enhances physiological and biochemical processes, including nutrient absorption, antioxidant activity, and carbohydrate metabolism, which contribute to increased dry matter, oil content, and nutrient accumulation. Wood vinegar ranked second due to its bioactive compounds, which improve nutrient availability and metabolic activity, leading to enhanced vitamin C content, TSS, and pyruvate levels. Potassium silicate may have improved bulb quality by strengthening plant cell walls and enhancing stress tolerance, which positively influenced pyruvate and oil content. Melatonin may have contributed to bulb quality due to its antioxidant properties, which mitigate oxidative stress and improve metabolic efficiency. Proline enhanced garlic quality by functioning as an osmoprotectant, supporting cell integrity and metabolic processes under stress. Arginine showed improvements due to its role in nitrogen metabolism and polyamine synthesis, which contribute to better growth and nutrient accumulation.The control treatment resulted in the lowest values across all traits, emphasizing the importance of biostimulant applications in improving garlic quality and nutrient content. The obtained results are in harmony with those of Nasibi *et al.* (2011); Awad-Allah *et al.* (2020); Hanci and Bingol, (2020); Ghazi *et al.* (2021); Naveen *et al.* (2021); Zhu *et al.* (2021); Heidarzadeh and Modarres-Sanavy, (2023); Mansour *et al.* (2024).

Table 4 illustrates the effect of different foliar-applied stimulants on various garlic bulb yield parameters at 180 days from planting (harvest stage) during the 2023/24 and 2024/25 growing seasons. The parameters measured include average bulb weight, bulb diameter, neck diameter, bulbing ratio, number of cloves per bulb, total bulb yield and marketable yield.

The results of Table 4 show that the application of stimulants significantly influenced all studied parameters, with notable improvements compared to the control (untreated plants). Among the treatments, brassinolide (5.0 mg L^{-1}) and wood vinegar (25 cm^3 L^{-1}) consistently exhibited the highest values across most parameters, particularly in bulb weight, diameter and yield. The significant increase in garlic bulb yield parameters due to foliar application of stimulants can be attributed to their roles in enhancing physiological and biochemical processes in plants.

Table 4. Effect of foliar application of stimulants on bulb yield parameters of garlic plants at 180 days from planting (harvest stage) during seasons of 2023/24 and 2024/25

Treatments	Average bulb weight, g		Bulb diameter, cm		Neck diameter, cm		Bulbing ratio	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control (without)	32.21c	31.69d	2.95c	2.82c	0.88a	0.75a	0.30a	0.27a
Arginine (100 mgL^{-1})	32.77c	32.27d	2.99c	2.84c	0.87a	0.73ab	0.29a	0.26a
Proline (100 mgL^{-1})	32.86c	32.39cd	3.02c	2.92bc	0.85ab	0.72ab	0.28ab	0.25ab
Melatonin (25 mgL^{-1})	33.70b	33.10bc	3.06c	2.95abc	0.82bc	0.70bc	0.27bc	0.24b
Potassium silicate (3.0 gL^{-1})	33.78b	33.19b	3.09bc	2.98abc	0.80c	0.68cd	0.26cd	0.23bc
Wood vinegar (25 cm^3 L^{-1})	34.78a	34.03a	3.27ab	3.08ab	0.79c	0.66de	0.24cd	0.21cd
Brassinolide (5.0 mgL^{-1})	35.05a	34.63a	3.33a	3.13a	0.67d	0.65e	0.20e	0.21d
LSD at 5%	0.79	0.76	0.19	0.19	0.04	0.03	0.02	0.02

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
N.S*= no significant

Table 4. Cont.

Treatments	No. of cloves $bulb^{-1}$		Total bulb yield, ton fed^{-1}		Marketable yield, ton fed^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control (without)	12.00c	11.67b	5.15c	5.07d	4.23f	4.13f
Arginine (100 mgL^{-1})	12.33bc	11.67b	5.25c	5.16d	4.29ef	4.23ef
Proline (100 mgL^{-1})	12.67bc	12.00ab	5.26c	5.18cd	4.36de	4.29de
Melatonin (25 mgL^{-1})	13.00abc	12.33ab	5.39b	5.30bc	4.47cd	4.35cd
Potassium silicate (3.0 gL^{-1})	13.33abc	12.67ab	5.41b	5.31b	4.54bc	4.46bc
Wood vinegar (25 cm^3 L^{-1})	13.67ab	13.33ab	5.56a	5.45a	4.61ab	4.55ab
Brassinolide (5.0 mgL^{-1})	14.33a	13.67a	5.61a	5.54a	4.69a	4.61a
LSD at 5%	1.57	1.75	0.13	0.12	0.11	0.11

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

The control treatment recorded the lowest average bulb weight (32.21 g and 31.69 g in the first and second seasons, respectively), while the highest was observed with brassinolide (35.05 g and 34.63 g). Noting that there weren't significant difference between brassinolide and wood vinegar treatments in terms of average bulb weight and total bulb yield in both seasons. This indicates that brassinolide promotes cell expansion and biomass accumulation, likely due to its role in regulating plant growth and stress tolerance (Naveen *et al.* 2021; Mansour *et al.* 2024). Wood vinegar also resulted in a significant increase in bulb weight (34.78 g and 34.03 g), suggesting its potential in enhancing nutrient uptake and metabolic activity in garlic (Zhu *et al.* 2021).

Bulb diameter followed a similar trend, with brassinolide and wood vinegar producing the largest bulbs (3.33 cm and 3.27 cm, respectively in 1st season and3.13 cm and 3.08 cm, respectively in 2nd season). The increase in bulb diameter is critical for market value, as larger bulbs are generally preferred in commercial production.

Neck diameter is an important factor affecting bulb maturity and storability. The lowest values were recorded with brassinolide (0.67 cm and 0.65 cm in both studied seasons respectively), indicating its role in strengthening cell walls and improving bulb firmness.

The bulbing ratio, which reflects the efficiency of the plant in forming bulbs, was significantly affected by all stimulants. The number of cloves per bulb, a key determinant of yield, was highest in the brassinolide treatment (14.33 and 13.67 cloves per bulb), further supporting its positive effects on reproductive growth. The total bulb yield was significantly enhanced by foliar application of stimulants, with brassinolide achieving the highest yield (5.61 ton fed^{-1} and 5.54 ton fed^{-1}). Wood vinegar also showed a substantial increase compared to the control. Marketable yield followed the same pattern, emphasizing the importance of these stimulants in improving both yield quantity and quality.

The observed improvements in garlic bulb yield parameters due to foliar-applied stimulants can be attributed to their physiological effects:

Brassinolide is a well-documented plant growth regulator that enhances cell elongation, photosynthetic efficiency, and stress tolerance (Mansour *et al.* 2024).Wood vinegar contains beneficial organic acids and phenolic compounds that stimulate root development and nutrient uptake (Zhu *et al.* 2021). Potassium silicate plays a crucial role in strengthening cell walls, improving drought resistance, and enhancing enzymatic activities related to growth and stress response (Ghazi *et al.* 2021). Melatonin and proline are known to act as antioxidants and osmoprotectants, mitigating oxidative stress and improving plant metabolism under variable environmental conditions (Hanci and Bingol, 2020).

CONCLUSION

Depending on the obtained results, it can be concluded that the foliar application of eco-friendly biostimulants and potassium silicate significantly enhances garlic growth, yield and quality under Egyptian conditions. Among the tested treatments, brassinolide exhibit the most pronounced positive effects on plant growth parameters, bulb yield, and quality traits, followed by wood vinegar and potassium silicate, which improved stress tolerance and nutrient uptake. Other biostimulants, including melatonin, proline, and arginine, contributed to moderate improvements in physiological and quality attributes. These findings highlight the potential of biostimulants as sustainable alternatives to synthetic agrochemicals for enhancing garlic productivity. Future research should focus on optimizing application rates and investigating possible synergistic effects between different biostimulants under varying environmental conditions.

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تأثير الرش الورقي بإستخدام خل الخشب والميلاتونين وبعض الأحماض الأمينية على النمو والمحصول لنبات الثوم

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الملخص

تعظيم إنتاجية الثوم في مصر أمرًا ضروريًا نظرًا لقيمته الغذائية والاقتصادية العالية. وقد يساهم استخدام المنشطات الحيوية الطبيعية الصديقة للبيئة بشكل كبير في تحسين نمو الثوم وإنتاجيته وجودته، مع تعزيز ممارسات الزراعة المستدامة. لذا، أُجريت هذه الدراسة خلال موسمي ٢٠٢٣/٢٠٢٤ و٢٠٢٤/٢٠٢٥ وفق تصميم القطاعات العشوائية الكاملة (RCBD) لتقييم تأثير الرش الورقي لخمس منشطات حيوية (الأرجينين، البرولين، الميلاتونين، خل الخشب، والبراسينولايد) إلى جانب سيليكات البوتاسيوم ومعاملة الكنترول. أظهرت النتائج أن جميع المعاملات المدروسة حسّنت بشكل ملحوظ معايير النمو وإنتاجية رؤس الثوم وصفاتها مقارنة بمعاملة الكنترول. كان للبراسينولايد (٥,٠ ملجم لتر$^{-1}$) التأثير الأكثر وضوحًا، حيث أدى إلى زيادة معنوية في طول النبات، والمساحة الورقية، والوزن الطازج والجاف، ووزن رؤس الثوم، وقطرها، والمحصول الكلي. جاء خل الخشب (٢٥ سم^{3} لتر$^{-1}$) في المرتبة الثانية، حيث عزز بشكل خاص عدد الأوراق، وحجم رؤس الثوم، ومحتوى فيتامين C. أما سيليكات البوتاسيوم (٣,٠ جم لتر$^{-1}$) فقد ساهمت في تحسين تحمل الإجهاد وتعزيز السلامة الهيكلية للنبات، مما أدى إلى تحسين النمو والإنتاج. بينما أظهرت الميلاتونين، والبرولين، والأرجينين تحسينات متوسطة، خاصة في المساحة الورقية، والوزن الجاف، وجودة رؤس الثوم. تؤكد هذه النتائج الإمكانات الكبيرة للمنشطات الحيوية في تحسين إنتاجية وجودة الثوم بطريقة صديقة للبيئة. لذا، ينبغي أن تركز الأبحاث المستقبلية على تحسين معدلات التطبيق، واستكشاف التأثيرات المحفزه المتداخله لتعظيم الفوائد تحت ظروف بيئية مختلفة وعوامل الإجهاد المتعددة.