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Enhancing Potato Growth, Yield, and Quality *via* Tuber Eye Numbers and Natural Stimulants under Egyptian Conditions

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ABSTRACT

Potato is a strategic crop in Egypt, having nutritional and economic importance. So, a field trial was conducted during the winter seasons of 2022/23 and 2023/24 using a split-plot design to evaluate the effect of eye number per tuber pieces (one, two, or three eyes) and natural stimulants, including seaweed extract (2.0 gL-1), amino acids (5 cm L-1), yeast extract (5.0 gL-1), licorice extract (10 gL-1), along with control group (without foliar applications), on potato growth and yield under Egyptian agricultural conditions in Kafr Al-Arab Village, Faraskour District, Damietta Governorate. Results showed that three-eyes per piece of tubers significantly outperformed one- and two-eye number in growth parameters, leaf chemical composition, photosynthetic pigments, yield, and quality traits. Among foliar biostimulants, amino acids had the highest positive impact for previous parameters, followed by seaweed extract. The combination of three-eye per piece of tubers with amino acids achieved the best outcomes across all metrics. It is recommended to use three-eye of tuber pieces combined with natural stimulants, particularly amino acids or seaweed extracts, to enhance potato productivity. Future research should optimize biostimulant concentrations and application schedules and explore their integration with sustainable agricultural practices for further productivity gains and environmental sustainability.

Keywords: Amino acids, Seaweed extract, Yeast extract, Licorice extract

INTRODUCTION

Potato (Solanum tuberosum) is a strategically important crop in Egypt, playing a significant role in the daily diet of the population due to its high nutritional value (Abd El-Hady et al., 2021). It is a rich source of carbohydrates, fiber, vitamins, and essential minerals such as vitamin C and potassium. Additionally, potato cultivation is of considerable economic importance, contributing to food security, providing employment opportunities in rural areas, and fulfilling the needs of both the domestic market and exports (Abd El-Hady et al., 2023). One of the key factors influencing potato production is the method of tuber cutting and the distribution of eyes on the tuber (Chae et al., 2008). Maintaining a specific number of eyes per tuber is crucial for enhancing germination rates and ensuring uniform plant growth, which directly impacts the overall yield (Kumar et al., 2015; Ibrahim, 2021). The number of eyes is determined based on the tuber size and its genetic characteristics, helping optimize the plant's growth and improving its ability to utilize available nutrients and water resources (Asnake et al., 2023).

To further improve yield and crop quality, natural stimulants play a vital role in promoting growth and increasing plant resistance to environmental stress. Among these, seaweed extract (e.g., Ascophyllum nodosum) is a potent growth promoter, enhancing root development and boosting plant resistance to environmental stress (Al-Juthery et al., 2018; Issa et al., 2019; El-Anany, 2020).

Spraying yeast extract (Saccharomyces cerevisiae) on plants offers several significant benefits that contribute to enhance growth, improve plant health (Ahmed et al., 2011), and increase productivity (Kahlel, 2014). Yeast extract helps plants better tolerate environmental stresses such as drought, high temperatures, and nutrient deficiencies (Badawy et al., 2019). It does this by promoting the synthesis of stress-related proteins and enhancing the plant's natural defense mechanisms (El-Anany, 2020). Additionally, licorice extract (Glycyrrhiza glabra) is known for its ability to mitigate oxidative stress and enhance nutrient uptake in plants (Matar et al. 2012; Dawood and Rajab, 2013). The active compounds in licorice, such as glycyrrhizin and flavonoids, have antioxidant properties that help neutralize harmful free radicals, which are often produced during periods of stress (Al-Nuaimi and Rostum, 2021). By reducing oxidative damage, licorice extract helps protect plant cells and tissues, leading to improved overall plant health (Draie and Abdul-Mohsen, 2021). Furthermore, licorice extract promotes the absorption of essential nutrients, particularly through stimulating the activity of enzymes involved in nutrient uptake and transport (Mutar et al., 2022). Finally, amino acids are essential for improving plant metabolic balance and increasing resistance to environmental challenges (Abd El-Hady et al., 2016; Kumar et al., 2018). Amino acids are fundamental components of proteins, which are essential for cell structure, enzyme activity, and various metabolic pathways (Shaheen et al., 2019).In addition to their structural role, amino acids help regulate plant physiological processes (El-Anany, 2020) such as photosynthesis, respiration, and nutrient absorption. By improving the metabolic balance within the plant, amino acids contribute to enhanced growth rates and improved stress tolerance (Draie, 2024).

The objective of this study is to evaluate the effects of eye numbers on tuber pieces as well as the impact of natural stimulants, such as seaweed extract, amino acids, yeast extract, and licorice extract, on the growth and yield of potatoes under agricultural conditions in Egypt.

MATERIALS AND METHODS

1. **Experimental Location**

A field trail was conducted during the winter growing seasons of 2022/23 and 2023/24 in Kafr Al-Arab Village, Faraskour District, Damietta Governorate, Egypt. This location is characterized by its suitable agro-climatic conditions for potato cultivation.

2. Research Methodology and Experimental Design

The experiment was laid out in a split-plot design with three replicates. The main plots included different eye numbers per tuber (one, two, or three eyes), while the sub-plots were assigned to foliar spraying treatments of natural stimulants: seaweed extract (2.0 gL-1), amino acids (5 cm L-1), yeast extract (5.0 gL-1), and licorice extract (10 gL-1), along with control group (with tap water).

3. Soil and Extract Analysis

Before planting, a detailed soil analysis was conducted to assess the physical and chemical properties of the experimental site. The analysis followed the procedures outlined by Dewis and Freitas, (1970) for soil salinity, pH, and nutrient content determination. The results are presented in Table 1.
Additionally, the chemical composition of the natural stimulants used for foliar spraying was analyzed according to Tandon (2005) and AOAC (2007) methods to ensure consistency and quality. The results are summarized in Table 2.

The licorice root extract was prepared following the method described by **Baek *et al.* (2008).** A total of 10 g of licorice roots were carefully weighed and placed in a suitable container. One liter of distilled water was heated to 50°C and then poured over the licorice roots. The roots were allowed to soak in the warm water for 24 hours to ensure maximum extraction of the bioactive compounds. After the soaking period, the mixture was filtered using a fine mesh or Whatman filter paper to separate the liquid extract from the solid root residues. The filtered solution was then adjusted to a final volume of 1 liter using distilled water to ensure consistency. The prepared extract was stored at 4°C until further use.

To prepare a natural yeast extract at concentrations of 5.0 g L-1, warm water was used to activate dry yeast (Saccharomyces cerevisiae), maintaining a temperature range of approximately 37-43°C (100-110°F), monitored with a thermometer. A small amount of sugar was added in equal proportions to the water to facilitate the yeast's activation. Once activation was complete, the mixture was gently stirred to ensure the yeast was evenly distributed throughout the liquid. The mixture was then left to incubate for 24 hours in a warm environment. To disrupt the yeast cells and release their bioactive components, the solution was subjected to two cycles of freezing and thawing before use **(El-Ghamriny et al., 1999).**

Both amino acid and seaweed solutions were prepared following standard protocols, as both were procured from the Egyptian commercial market.

4.Cultivation and Implementation

potato tubers (*Solanum tuberosum* L., cv. Spunta). The tubers were cut into pieces weighing approximately 50 g, each piece containing 1 or 2 or 3 eyes, depending on the studied treatments. During cutting, sharp knives were used and regularly disinfected with alcohol to prevent disease transmission.

The soil was prepared by plowing, leveling, and ridging, with ridges measuring 12 m in length and 0.85 m in width. Before planting, calcium superphosphate (15% P2O5) was applied at a rate of 100 kg P2O5 fed-1, along with farmyard manure at 15 m3 fed-1. Planting was done on 20th December, 2023, while the harvest occurred on 20th April, 2024. The foliar treatments were applied at 40, 55, and 70 days after planting. Irrigation was provided through four scheduled applications at intervals of 20 days after the initial irrigation at 30 days post-planting.

Nitrogen fertilization was applied as urea (46.5% N) at a rate of 150 kg N fed^{-1}, divided into two equal doses at 30 and 50 days after planting. Potassium fertilization was performed using potassium sulfate (48% K_2O) at a rate of 50 kg fed^{-1}, applied 50 days after planting.

Standard agricultural practices, including fungicide, insecticide, and herbicide applications, were carried out as recommended by the MASR using Metalyxyl, Mancozeb, Abamectin, and Copper Oxychloride.

Table 1: Characteristics of the initial soil

EC, dSm^{-1} (1: 5 soil suspension)	pH (1:2.5 soil suspension)	Available nutrients, mg kg^{-1}			Organic matter,%
		N	P	K	
3.45	8.00	40.3	8.95	201	1.15

Table 2. Traits of the bio stimulants

Component	Licorice E	Seaweed E	Yeast E	Amino acid
Protein	7.19 g/100g	18%	45.9%	/
Carbohydrate	/	48%	33.4%	/
Minerals	/	28%	8.6%	/
Nucleic Acids	/	/	10%	/
Lipids	/	1%	/	/
Organic mater	/	/	/	26%
Free amino acids	/	/	/	12%
Potassium	0.30%	/	/	8%
Phosphorus	2.5%	/	/	3.2%
Iron	0.01%	/	/	2%
Zinc	0.03%	/	/	7%
Magnesium	0.01%	/	/	5%

1. Measurements

5.1. Performance traits at 85 days after planting

Random samples of three plants per replicate were collected to measure growth and physiological traits:

Growth parameters

- Plant height (cm)
- No. of leaves $plant^{-1}$
- No. of branches $plant^{-1}$
- Fresh and dry weights (g $plant^{-1}$).

Leaves chemical composition

The oven-dried leaves were ground and digested with a mixture of perchloric and sulfuric acids (1:1) following **Peterburgski (1968).** Total nitrogen (N), phosphorus (P), and potassium (K) were determined using the Kjeldahl method, spectrophotometry, and flame photometry, respectively, as described by **Tandon *et al.* (2005).**

Photosynthetic pigments

Photosynthetic pigments, including chlorophyll a (mg g^{-1} F.W.), chlorophyll b (mg g^{-1} F.W.), total chlorophyll (mg g^{-1}), and carotene (mg g^{-1} F.W.), were quantified spectrophotometrically using acetone as the solvent, following the method described by **Lichtenthaler and Babani (2021).**

5.2. Yield and quality traits at harvest (120 days after planting)

Random samples of three plants per replicate were collected to evaluate yield and quality traits:

Yield parameters

- Average tuber weight (g).
- Total tuber yield (ton fed^{-1}).

Quality traits:

The levels of reducing sugar (%), non-reducing sugar (%), total sugars (%), total dissolved solids (TDS, %), dry matter (%), vitamin C (mg $100g^{-1}$), and starch (%) were analyzed following the protocols outlined by **AOAC (2007).**

6. Statistical Analysis

The data were analyzed statistically through analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at a 5% significance level, following standard procedures. Duncan's letters were used to make the analysis more clear (**Gomez and Gomez, 1984).**

RESULTS AND DISCUSSION

1. Growth criteria

Tables 3 and 4 illustrate the individual and interactive effects of tuber eye number and different foliar biostimulant treatments on potato growth parameters at 85 days after planting during the 2022/2023 and 2023/2024 seasons. The measured parameters include plant height (cm), No. of leaves $plant^{-1}$, No. of branches $plant^{-1}$, fresh and dry weights (g $plant^{-1}$).

Individual effect of eye number

Tubers with three eyes significantly outperformed those with one or two eyes in all growth parameters, recording the highest plant height, number of leaves and branches, and fresh and dry weights in both seasons. Two-eye tubers showed intermediate performance but were superior to one-eye tubers.

Increasing the number of eyes may have enhanced growth due to the higher number of active points for stem and leaf development, which may have improved photosynthesis efficiency and dry matter accumulation. Reports like **Ibrahim (2021)** confirmed that increasing the number of eyes in tubers boosts potato productivity by enhancing the number of stems and branches.

Individual effect of foliar biostimulants

The application of amino acids resulted in the highest values for all growth parameters, followed closely by seaweed extract. Yeast extract ranked third, while licorice extract demonstrated better performance than the control but was less effective compared to other treatments. The control treatment exhibited the lowest values across all parameters. The superiority of amino acids can be attributed to their role as biostimulants that enhance physiological processes, including protein synthesis and nutrient uptake, resulting in improved plant growth. Seaweed extract ranked second, as it contains bioactive compounds such as alginates and natural plant hormones like cytokinins, which stimulate growth and increase stress resistance. Yeast extract ranked third, given its richness in vitamins, amino acids, and micronutrients that enhance the plant's metabolic activity. Licorice extract ranked last among the biostimulants, outperforming only the control group. Its effects may be linked to its natural antioxidant content, which helps improve plant stress tolerance, although its overall impact is relatively less pronounced compared to amino acids and seaweed extract.

Studies such as **Al-Juthery *et al.* (2018)** and **El-Anany (2020)** highlighted that foliar application of amino acids and seaweed extracts significantly improves growth and yield in potatoes by enhancing the plant's physiological efficiency.

Research has shown that yeast as a biostimulant increases chlorophyll content and protein synthesis, positively influencing growth parameters **(Badawy *et al.*, 2019).**

Interaction effect

A positive interaction was observed between three-eye tubers and amino acid application, achieving the highest values for all growth parameters. Two-eye tubers combined with amino acids or seaweed extract also performed remarkably well compared to one-eye tubers.

2. Leaves chemical constituents

Tables 5 and 6 display the individual and interactive impacts of seed tuber eye number and foliar biostimulants on the nitrogen (N), phosphorus (P), and potassium (K) content of potato leaves 85 days after planting during the 2022/23 and 2023/24 growing seasons.

Individual effect of eye number

The number of eyes on tubers pieces significantly influenced the chemical composition of potato leaves. Tubers with three eyes demonstrated the highest N, P, and K percentages across both seasons, suggesting enhanced nutrient uptake and assimilation due to increased shoot and root growth. Two-eye tubers also showed considerable nutrient content but slightly lower than the three-eye treatment. Meanwhile, tubers with one eye recorded the lowest values, likely reflecting limited vegetative development and reduced nutrient absorption capacity. The obtained results are in harmony with those of **Chae *et al.* (2008); Kumar *et al.* (2015); Ibrahim (2021); Asnake *et al.* (2023).**

Individual effect of foliar biostimulants

The application of foliar biostimulants significantly enhanced the nutrient content of potato leaves. Among the treatments, amino acids resulted in the highest levels of nitrogen (N), phosphorus (P), and potassium (K), likely due to their role in improving nutrient uptake efficiency and stimulating metabolic processes. Seaweed extract ranked second, contributing to better nutrient assimilation, which can be attributed to its rich composition of plant hormones and alginates. Yeast extract followed in the third position, showing moderate improvements in nutrient content, likely due to its abundance of vitamins and amino acids. Although licorice extract improved nutrient levels compared to the control, its effects were less pronounced than those observed with amino acids, seaweed, or yeast extracts. Plants in the control group, which did not receive any biostimulant application, exhibited the lowest nutrient levels, highlighting the essential role of biostimulants in promoting plant nutrition. These findings align with those reported by **Matar *et al.* (2012), El-Anany (2020), Abd El-Hady *et al.* (2016), and Kumar *et al.* (2018).**

Interaction effect

The interaction between tuber eye number and foliar biostimulants revealed that the combination of three-eye tubers with amino acid application produced the highest nutrient levels, particularly nitrogen and potassium. This might be attributed to the combined impact of enhanced vegetative growth from multiple eyes and the physiological benefits of amino acids. Similarly, the pairing of seaweed extract with three-eye tubers yielded favorable results, likely due to the hormonal and nutrient-enriching properties of the extract. In contrast, the lowest nutrient contents were consistently observed in the one-eye control treatment, highlighting the significance of both tuber eye number and biostimulant applications in promoting optimal leaf nutrient composition in potato plants.

3. Leaves photosynthetic pigments

Tables 7 and 8 present the individual and interactive effects of tuber pieces eye number and foliar biostimulant applications on photosynthetic pigments (chlorophyll a, chlorophyll b, total chlorophyll, and carotene) of potato leaves at 85 days after planting during the 2022/2023 and 2023/2024 seasons.

Individual effect of eye number

Tubers with three eyes exhibited the highest chlorophyll a content in both seasons, followed by two-eye tubers. One-eye tubers showed the lowest chlorophyll a levels. Similar trends were observed for chlorophyll b and total chlorophyll, with three-eye tubers achieving significantly higher values compared to two- and one-eye tubers. Three-eye tubers also showed the highest carotene content, with two-eye tubers ranking second and one-eye tubers exhibiting the lowest values.

Individual effect of foliar biostimulants

Foliar application of amino acids resulted in the highest values for chlorophyll a, chlorophyll b, total chlorophyll, and carotene across both seasons. Seaweed extract showed comparable results to amino acids for all parameters, ranking as the second most effective biostimulant. Yeast extract ranked third, significantly enhancing pigment content compared to the control. Licorice extract demonstrated moderate improvement in pigment content, surpassing the control but being less effective than yeast extract. Plants in the control treatment exhibited the lowest pigment content for all parameters.

Interaction effect

Combining three eyes + amino acids produced the highest values for all photosynthetic pigments, emphasizing the synergistic effect of increased eye number and amino acid application. A similar trend was observed regarding the combination of three Eyes + seaweed extract, with slightly lower values than the amino acid combination. These combinations of two eyes + amino acids or seaweed extract also resulted in high pigment content, outperforming most other interactions. Combining one Eye + control yielded the lowest pigment content, highlighting the negative impact of low eye number and lack of biostimulant application. Higher eye numbers may have enhanced photosynthetic capacity by increasing the number of leaves and leaf area, which facilitates greater pigment synthesis **(Ibrahim, 2021)**. Amino acids, ranked first among the biostimulants, likely stimulated enzyme activities involved in chlorophyll synthesis, thereby enhancing pigment content. Seaweed extract, ranked second, contains growth-promoting substances such as cytokinins and micronutrients, which boost chlorophyll and carotene synthesis. Yeast extract, ranked third, provides essential vitamins and nutrients that improve chloroplast development and pigment content. Licorice extract, ranked last among the biostimulants but outperforming the control, may include antioxidants that enhance stress tolerance and chlorophyll stability, although it is less effective than amino acids or seaweed extract. Carotenoids play a critical role in protecting chlorophyll from oxidative damage. The higher carotene levels observed in three-eye tubers treated with biostimulants highlight improved stress tolerance and enhanced photosynthetic efficiency. The obtained results are in agreements with those of **Abd El-Hady *et al.* (2016); Kumar *et al.* (2018); El-Anany, (2020); Al-Nuaimi and Rostum (2021); Draie (2024).**

4. Tuber yield

Tables 9 and 10 show the individual and interactive impacts of seed tuber eye number and foliar biostimulant application on tuber yield of potato at 120 days after planting during the 2022/23 and 2023/24 seasons.

Individual effect of eye number

The number of eyes on seed tubers significantly influenced both average tuber weight and total yield across the two growing seasons.

One-eye of tubers piece produced the lowest average tuber weight and total yield, with values of 310.06 g and 319.55 g, and yields of 13.85 ton fed^{-1} and 14.28 ton fed^{-1} in the first and second seasons, respectively. This indicates that fewer eyes limit the plant's ability to produce sufficient foliage, leading to reduced photosynthetic activity and lower productivity.

Two-eye tubers showed a marked improvement, with average tuber weights of 355.34 g and 366.55 g and total yields of 15.27 ton fed^{-1} and 15.78 ton fed^{-1} in the first and second seasons, respectively. This reflects enhanced leaf area and photosynthetic capacity, resulting in better growth and productivity.

Three-eye tubers recorded the highest performance, with average tuber weights of 360.05 g and 372.65 g and total yields of 15.56 ton fed^{-1} and 16.14 ton fed^{-1} for the two seasons, respectively. Three-eye tubers recorded the highest values for tuber weight and yield, as the increased number of eyes promoted greater leaf development, boosting photosynthetic efficiency and overall productivity.

The differences were statistically significant at a 5% level, confirming the advantage of higher eye numbers for yield-related traits. The obtained results are in harmony with those of **Chae *et al.* (2008)**; **Kumar *et al.* (2015); Ibrahim (2021);Asnake *et al.* (2023).**

Individual effect of foliar biostimulants

Biostimulant application had a significant impact on tuber yield and weight. Amino acids consistently ranked highest, with average tuber weights of 351.18 g and 362.98 g and total yields of 15.49 ton fed^{-1} and 16.04 ton fed^{-1} in the first and second seasons, respectively. Seaweed extract followed closely, showing comparable performance to amino acids in tuber weight (348.69 g and 358.94 g) and yield (15.30 ton fed^{-1} and 15.82 ton fed^{-1}).

Yeast extract and licorice extract ranked third and fourth, respectively, in both seasons. Although they enhanced tuber weight and yield compared to the control, their effects were less pronounced than amino acids and seaweed extract. The control group consistently exhibited the lowest values for tuber weight and yield.

Amino acids ranked first, as they stimulated enzymatic activities involved in chlorophyll synthesis, enhanced photosynthesis, and improved nutrient uptake, resulting in superior tuber weight and yield. Seaweed extract showed a performance close to that of amino acids, as it contains natural growth-promoting hormones like cytokinins and micronutrients, which enhanced plant growth and productivity. Yeast extract ranked third, contributing to better chloroplast development and photosynthetic pigment content due to its vitamins and nutrients, resulting in moderate yield improvement. Licorice extract had the least effect among the biostimulants but outperformed the control group. Its antioxidant properties may have contributed to stress tolerance and chlorophyll stability, albeit with less pronounced effects compared to the other biostimulants. The control group recorded the lowest values, highlighting the critical role of biostimulants in boosting potato yield under experimental conditions (**Abd El-Hady *et al.*, 2016; Kumar *et al.*, 2018**; **El-Anany, 2020; Al-Nuaimi and Rostum, 2021; Draie, 2024)**.

Interaction effect

Regarding the interaction between the number of eyes and foliar biostimulants, the three-eye tubers treated with amino acids recorded the best results, with the highest average tuber weight (371.09 g and 383.94 g) and total yield (16.31 ton fed^{-1} and 16.89 ton fed^{-1}) across both seasons. Seaweed extract applied to three-eye tubers also demonstrated superior performance, closely following amino acids in tuber weight and yield.

In contrast, the lowest yields and tuber weights were recorded in one-eye tubers under control conditions. The interaction effects were statistically significant at a 5% level, further emphasizing the synergistic impact of higher eye numbers and biostimulant applications on tuber yield.

5. Tuber quality

Tables 11 and 12 illustrate the individual and interactive effects of tuber eye number and foliar biostimulant applications on potato tuber quality parameters, specifically reducing sugar, non-reducing sugar, and total sugars percentages, measured at 120 days after planting during the 2022/23 and 2023/24 growing seasons. The table highlights the main effects of different eye numbers (one, two, and three) and various biostimulants (control, amino acids, seaweed extract, yeast extract, and licorice extract) as well as their interactions.

Tables 13 and 14, on the other hand, focuses on additional tuber quality parameters, including total dissolved solids (TDS), dry matter content, vitamin C content, and starch percentage, evaluated under the same experimental conditions. This table also presents the individual and combined impacts of eye number and biostimulants on these parameters.

Individual effect of eye number

Table 11 shows that tubers derived from seed tubers with three eyes exhibited significantly higher levels of reducing sugar, non-reducing sugar, and total sugars compared to those with fewer eyes. This trend was consistent across both seasons, with the highest values recorded for the three-eye treatment (*e.g.,* total sugar at 6.37% and 6.51% for the first and second seasons, respectively). Similarly, Table 13 reveals that increasing the number of eyes significantly improved TDS, dry matter, vitamin C, and starch content. Tubers with three eyes recorded the highest vitamin C content (21.80 and 22.21 mg 100g^{-1}) and starch percentage (19.76 and 20.20%) in the first and second seasons, respectively, indicating better overall quality and nutritional value.

The improved quality with higher eye numbers can be attributed to enhanced photosynthetic efficiency and nutrient uptake due to a larger canopy resulting from increased eye numbers. This promotes carbohydrate synthesis and allocation to tubers (**Kumar *et al.*, 2015; Ibrahim, 2021; Asnake *et al.*, 2023).**

Individual effect of foliar biostimulants

The application of biostimulants positively influenced all studied parameters. Amino acid treatments consistently produced the highest values across most quality traits. For instance, Table 11 highlights that amino acids increased total sugar content to 6.31% and 6.50% in the first and second seasons, respectively. Similarly, Table 13 shows that amino acids enhanced vitamin C to 21.76 and 22.03 mg 100g^{-1}, starch content to 19.70 and 20.13% in the first and second seasons, respectively. Seaweed extract followed as the second most effective treatment, while yeast and licorice extracts showed moderate improvements.

Amino acids likely promoted enzymatic activity and nitrogen metabolism, leading to improved carbohydrate and protein synthesis. Seaweed extract, rich in phytohormones and micronutrients, enhanced overall metabolic activity, contributing to tuber quality (**Abd El-Hady *et al.*, 2016; Kumar *et al.*, 2018**; **El-Anany, 2020; Al-Nuaimi and Rostum, 2021; Draie, 2024)**.

Interaction effect

The interaction between eye number and biostimulants significantly influenced tuber quality. In Table 12, tubers from three-eye tubers treated with amino acids recorded the highest total sugars content (6.85% and 7.01% for the first and second seasons, respectively). Table 14 further emphasizes that the combination of three eyes and amino acids resulted in the highest TDS (7.67 and 8.01%), dry matter (22.89 and 23.40%), and vitamin C (22.63 and 23.08 mg 100g^{-1}) in the first and second seasons, respectively.

This synergistic effect may be due to the complementary roles of increased canopy size (from three eyes) and biostimulants in optimizing photosynthetic activity, nutrient assimilation, and metabolic processes. The improvements in tuber quality traits can be attributed to the physiological roles of biostimulants and the morphological advantage of higher eye numbers. Amino acids and seaweed extract enhance cellular metabolism and stress tolerance, while the larger leaf area from three-eye seed tubers ensures efficient light capture and nutrient use. These factors collectively boost the synthesis and accumulation of sugars, starch, and vitamins in the tubers, ultimately improving their quality and nutritional profile.

Table 3. Individual impact of tuber eye number and foliar biostimulant applications on potato growth parameters at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments	Plant height, cm		No. of leaves $plant^{-1}$		No. of branches $plant^{-1}$		Fresh weight, g $plant^{-1}$		Dry weight, g $plant^{-1}$	
	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes										
One eye	41.17b	43.11c	13.80b	14.13b	3.80b	4.20b	304.57c	313.59c	51.38c	53.02c
Two eyes	46.67a	49.00b	15.53a	15.93a	5.20a	5.73a	336.92b	346.74b	54.97b	56.91b
Three eyes	47.23a	49.56a	15.80a	16.20a	5.53a	6.07a	343.41a	354.51a	55.72a	57.65a
LSD at 5%	**0.81**	**0.01**	**0.86**	**1.07**	**0.44**	**0.49**	**2.63**	**4.47**	**0.71**	**0.54**
Sub main factor: Bio stimulants										
Control	43.61b	45.80b	14.33d	14.78c	4.11c	4.56c	313.02d	322.47e	52.27d	53.98d
Amino acids	46.32a	48.58a	15.78a	16.11a	5.44a	6.00a	341.58a	352.49a	55.63a	57.59a
Seaweed .E	45.97a	48.23a	15.44ab	15.78ab	5.22ab	5.78a	337.57a	347.40b	55.10a	57.00a
Yeast. E	45.29a	47.44a	15.00bc	15.33abc	4.78abc	5.33ab	328.47b	338.27c	53.97b	55.73b
Licorice .E	43.92b	46.07b	14.67cd	15.11bc	4.67bc	5.00bc	320.86c	330.80d	53.15c	55.00c
LSD at 5%	**1.30**	**1.24**	**0.62**	**0.82**	**0.72**	**0.73**	**4.37**	**4.79**	**0.77**	**0.65**

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

Table 4. Interactive impact of tuber eye number and foliar biostimulant applications on potato growth parameters at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments		Plant height,		No. of leaves		No. of branches $plant^{-1}$		Fresh weight, g $plant^{-1}$		Dry weight, g $plant^{-1}$	
		1st season	2nd	1st season	2nd	1st season	2nd	1st season	2nd	1st season	2nd
One eye	**Control**	39.34	41.43	13.33	13.67	3.33	3.67	295.72	304.83	50.24	51.72
	Amino acids	42.57	44.65	14.33	14.67	4.33	4.67	312.76	322.54	52.41	54.08
	Seaweed .E	42.15	44.20	14.00	14.33	4.00	4.33	308.82	317.95	52.00	53.72
	Yeast. E	42.05	43.51	13.67	14.00	3.67	4.33	304.92	313.68	51.37	52.99
	Licorice .E	39.75	41.74	13.67	14.00	3.67	4.00	300.64	308.98	50.88	52.61
Two eyes	**Control**	45.66	47.86	14.67	15.00	4.33	5.00	319.15	328.59	53.01	54.87
	Amino acids	47.85	50.13	16.33	16.67	5.67	6.33	351.02	361.53	56.66	58.80
	Seaweed .E	47.23	49.55	16.00	16.33	5.67	6.33	347.61	357.28	56.17	58.11
	Yeast. E	46.69	49.20	15.67	16.00	5.33	5.67	337.91	347.52	54.99	56.81
	Licorice .E	45.93	48.24	15.00	15.67	5.00	5.33	328.92	338.79	54.05	55.95
Three eyes	**Control**	45.83	48.09	15.00	15.67	4.67	5.00	324.19	333.98	53.58	55.34
	Amino acids	48.56	50.97	16.67	17.00	6.33	7.00	360.96	373.40	57.80	59.89
	Seaweed .E	48.55	50.95	16.33	16.67	6.00	6.67	356.28	366.96	57.15	59.18
	Yeast. E	47.13	49.60	15.67	16.00	5.33	6.00	342.60	353.60	55.56	57.40
	Licorice .E	46.08	48.22	15.33	15.67	5.33	5.67	333.01	344.62	54.53	56.43
LSD at 5%		**2.26**	**2.14**	**1.06**	**1.42**	**1.24**	**1.26**	**7.56**	**8.30**	**1.34**	**1.12**

Table 5. Individual impact of tuber eye number and foliar biostimulant applications on leaves chemical constituents of potato at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments	Nitrogen,%		Phosphorus,%		Potassium,%	
	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes						
One eye	2.72b	2.80c	0.341b	0.355c	2.37c	2.49c
Two eyes	3.10a	3.19b	0.388a	0.404b	2.82b	2.97b
Three eyes	3.15a	3.25a	0.397a	0.413a	2.91a	3.05a
LSD at 5%	**0.09**	**0.06**	**0.010**	**0.009**	**0.08**	**0.06**
Sub main factor: Bio stimulants						
Control	2.81d	2.90e	0.353d	0.368d	2.46d	2.58e
Amino acids	3.14a	3.24a	0.396a	0.412a	2.89a	3.03a
Seaweed .E	3.10a	3.19b	0.389a	0.405a	2.83a	2.97b
Yeast. E	3.01b	3.09c	0.375b	0.390b	2.72b	2.86c
Licorice .E	2.90c	2.99d	0.364c	0.379c	2.60c	2.74d
LSD at 5%	**0.09**	**0.04**	**0.009**	**0.010**	**0.06**	**0.03**

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

Table 6. Interactive impact of tuber eye number and foliar biostimulant applications on leaves chemical constituents of potato at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments		Nitrogen,%		Phosphorus,%		Potassium,%	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
One eye	**Control**	2.58	2.65	0.330	0.343	2.25	2.37
	Amino acids	2.84	2.93	0.354	0.369	2.47	2.59
	Seaweed .E	2.79	2.88	0.348	0.362	2.40	2.52
	Yeast. E	2.74	2.81	0.339	0.354	2.40	2.51
	Licorice .E	2.67	2.74	0.336	0.348	2.34	2.46
Two eyes	**Control**	2.92	3.01	0.362	0.380	2.52	2.64
	Amino acids	3.26	3.36	0.411	0.427	3.05	3.19
	Seaweed .E	3.21	3.29	0.401	0.418	2.99	3.15
	Yeast. E	3.11	3.20	0.390	0.405	2.86	3.01
	Licorice .E	3.00	3.09	0.375	0.390	2.70	2.85
Three eyes	**Control**	2.95	3.04	0.368	0.382	2.62	2.74
	Amino acids	3.33	3.43	0.424	0.440	3.16	3.32
	Seaweed .E	3.30	3.40	0.419	0.436	3.10	3.26
	Yeast. E	3.17	3.27	0.395	0.410	2.92	3.05
	Licorice .E	3.03	3.14	0.381	0.399	2.76	2.90
LSD at 5%		**0.15**	**0.06**	**0.015**	**0.017**	**0.11**	**0.06**

Table 7. Individual impact of tuber eye number and foliar biostimulant applications on leaves photosynthetic pigments of potato at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments	Chlorophyll a, mg g^{-1} F.W		Chlorophyll b, mg g^{-1} F.W		Total chlorophyll, mg g^{-1}		Carotene, mgg^{-1} F.W	
	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes								
One eye	0.850c	0.884c	0.585c	0.602c	1.435c	1.486c	0.292c	0.297c
Two eyes	0.955b	0.993b	0.659b	0.682b	1.614b	1.675b	0.349b	0.355b
Three eyes	0.972a	1.012a	0.669a	0.691a	1.641a	1.703a	0.360a	0.368a
LSD at 5%	**0.013**	**0.013**	**0.009**	**0.007**	**0.020**	**0.008**	**0.007**	**0.009**
Sub main factor: Bio stimulants								
Control	0.873d	0.908c	0.602c	0.621c	1.475d	1.529c	0.308d	0.315e
Amino acids	0.977a	1.016a	0.675a	0.697a	1.652a	1.713a	0.362a	0.369a
Seaweed .E	0.965a	1.003a	0.668a	0.688a	1.632a	1.690a	0.345b	0.352b
Yeast. E	0.916b	0.953b	0.627b	0.648b	1.543b	1.601b	0.331bc	0.337c
Licorice .E	0.897c	0.934b	0.618bc	0.638bc	1.515c	1.572b	0.322cd	0.327d
LSD at 5%	**0.013**	**0.023**	**0.016**	**0.021**	**0.020**	**0.041**	**0.016**	**0.008**

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

Table 8. Interactive impact of tuber eye number and foliar biostimulant applications on leaves photosynthetic pigments of potato at 85 days after planting during the 2022/23 and 2023/24 seasons

Treatments		Chlorophyll a, mg g^{-1} F.W		Chlorophyll b, mg g^{-1} F.W		Total chlorophyll, mg g^{-1}		Carotene, mgg^{-1} F.W	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
One eye	**Control**	0.824	0.855	0.565	0.583	1.389	1.438	0.275	0.282
	Amino acids	0.880	0.912	0.608	0.626	1.488	1.538	0.313	0.320
	Seaweed .E	0.868	0.903	0.602	0.621	1.470	1.524	0.293	0.299
	Yeast. E	0.847	0.881	0.576	0.593	1.424	1.474	0.292	0.297
	Licorice .E	0.833	0.866	0.572	0.589	1.405	1.455	0.285	0.290
Two eyes	**Control**	0.891	0.927	0.616	0.637	1.507	1.564	0.322	0.327
	Amino acids	1.013	1.056	0.701	0.724	1.714	1.780	0.379	0.385
	Seaweed .E	1.000	1.039	0.693	0.714	1.694	1.753	0.362	0.368
	Yeast. E	0.946	0.982	0.649	0.672	1.595	1.654	0.348	0.355
	Licorice .E	0.923	0.960	0.638	0.661	1.561	1.621	0.336	0.341
Three eyes	**Control**	0.905	0.942	0.624	0.643	1.529	1.585	0.329	0.336
	Amino acids	1.037	1.079	0.716	0.741	1.753	1.820	0.393	0.402
	Seaweed .E	1.026	1.066	0.707	0.728	1.733	1.794	0.380	0.389
	Yeast. E	0.954	0.997	0.656	0.678	1.610	1.675	0.354	0.361
	Licorice .E	0.936	0.975	0.643	0.665	1.579	1.641	0.345	0.350
LSD at 5%		**0.022**	**0.040**	**0.027**	**0.037**	**0.035**	**0.072**	**0.028**	**0.014**

Table 9. Individual impact of tuber eye number and foliar biostimulant applications on tuber yield of potato at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments	Average tuber weight, g		Total yield, ton fed^{-1}	
	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes				
One eye	310.06c	319.55c	13.85c	14.28c
Two eyes	355.34b	366.55b	15.27b	15.78b
Three eyes	360.05a	372.65a	15.56a	16.14a
LSD at 5%	**1.99**	**5.02**	**0.21**	**0.09**
Sub main factor: Bio stimulants				
Control	329.93c	341.21c	14.22d	14.68e
Amino acids	351.18a	362.98a	15.49a	16.04a
Seaweed .E	348.69a	358.94a	15.30a	15.82b
Yeast. E	341.36b	352.52b	14.90b	15.38c
Licorice .E	337.91b	348.93b	14.56c	15.08d
LSD at 5%	**4.04**	**4.34**	**0.18**	**0.18**

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

Table 10. Interactive impact of tuber eye number and foliar biostimulant applications on tuber yield of potato at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments		Average tuber weight, g		Total yield, ton fed^{-1}	
		1st season	2nd Season	1st season	2nd Season
One eye	**Control**	301.96	311.96	13.37	13.72
	Amino acids	318.30	328.03	14.28	14.81
	Seaweed .E	315.67	325.02	14.11	14.61
	Yeast. E	308.59	317.99	13.84	14.23
	Licorice .E	305.77	314.76	13.65	14.01
Two eyes	**Control**	341.79	353.87	14.52	14.99
	Amino acids	364.14	376.98	15.88	16.41
	Seaweed .E	362.49	373.49	15.75	16.27
	Yeast. E	355.29	364.85	15.31	15.76
	Licorice .E	352.97	363.56	14.91	15.49
Three eyes	**Control**	346.05	357.81	14.76	15.34
	Amino acids	371.09	383.94	16.31	16.89
	Seaweed .E	367.92	378.30	16.06	16.58
	Yeast. E	360.20	374.72	15.56	16.15
	Licorice .E	354.99	368.48	15.14	15.74
LSD at 5%		**7.00**	**7.53**	**0.32**	**0.32**

Table 11. Individual impact of seed tuber eye number and foliar biostimulant application on leaves tuber quality of potato (reducing sugar, non-reducing sugar and total sugars) at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments	Reducing sugar, %		Non Reducing sugar, %		Total sugar, %	
	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes						
One eye	2.43b	2.51c	2.82b	2.93b	5.26c	5.44c
Two eyes	2.81a	2.86b	3.39a	3.46a	6.19b	6.33b
Three eyes	2.88a	2.96a	3.49a	3.55a	6.37a	6.51a
LSD at 5%	**0.08**	**0.07**	**0.20**	**0.16**	**0.12**	**0.09**
Sub main factor: Bio stimulants						
Control	2.52d	2.58d	3.00d	3.07d	5.53e	5.65e
Amino acids	2.87a	2.94a	3.44a	3.56a	6.31a	6.50a
Seaweed .E	2.82a	2.91a	3.37a	3.46a	6.19b	6.37b
Yeast. E	2.71b	2.78b	3.22b	3.30b	5.94c	6.07c
Licorice .E	2.61c	2.68c	3.13c	3.18c	5.74d	5.86d
LSD at 5%	**0.08**	**0.08**	**0.08**	**0.11**	**0.07**	**0.09**

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

Table 12. Interactive impact of tuber eye number and foliar biostimulant applications on leaves tuber quality of potato (reducing sugar, non-reducing sugar and total sugars) at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments		Reducing sugar, %		Non Reducing sugar, %		Total sugar, %	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
One eye	**Control**	2.32	2.39	2.76	2.83	5.08	5.22
	Amino acids	2.55	2.60	2.90	3.11	5.45	5.71
	Seaweed .E	2.49	2.59	2.88	3.02	5.36	5.61
	Yeast. E	2.44	2.52	2.79	2.87	5.23	5.39
	Licorice .E	2.37	2.46	2.79	2.81	5.16	5.27
Two eyes	**Control**	2.58	2.64	3.08	3.13	5.66	5.77
	Amino acids	2.98	3.04	3.65	3.74	6.63	6.78
	Seaweed .E	2.93	3.01	3.55	3.64	6.48	6.65
	Yeast. E	2.83	2.88	3.38	3.45	6.21	6.33
	Licorice .E	2.71	2.76	3.27	3.35	5.98	6.11
Three eyes	**Control**	2.67	2.71	3.17	3.25	5.83	5.96
	Amino acids	3.09	3.19	3.77	3.82	6.85	7.01
	Seaweed .E	3.04	3.14	3.68	3.72	6.72	6.86
	Yeast. E	2.87	2.93	3.50	3.57	6.37	6.50
	Licorice .E	2.75	2.81	3.33	3.40	6.09	6.21
LSD at 5%		**0.13**	**0.14**	**0.15**	**0.19**	**0.12**	**0.15**

Table 13. Individual impact of tuber eye number and foliar biostimulant applications on leaves tuber quality of potato (TDS, dry matter, vitamin C, starch) at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments	TDS, %		Dry matter, %		Vitamin C, mg 100g^{-1}		Starch, %	
	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor: Number of eyes								
One eye	6.26c	6.43c	20.35c	21.05c	20.01c	20.62b	18.08c	18.44b
Two eyes	7.15b	7.33b	21.81b	22.28b	21.50b	22.01a	19.49b	19.93a
Three eyes	7.31a	7.53a	22.11a	22.58a	21.80a	22.21a	19.76a	20.20a
LSD at 5%	**0.07**	**0.05**	**0.21**	**0.12**	**0.14**	**0.26**	**0.15**	**0.38**
Sub main factor: Bio stimulants								
Control	6.52e	6.72e	20.76d	21.18d	20.35d	20.87d	18.42d	18.86c
Amino acids	7.21a	7.47a	22.03a	22.71a	21.76a	22.30a	19.70a	20.13a
Seaweed .E	7.11b	7.32b	21.82a	22.49a	21.52a	21.95b	19.51a	19.90a
Yeast. E	6.94c	7.10c	21.42b	21.96b	21.11b	21.49c	19.12b	19.49b
Licorice .E	6.76d	6.89d	21.09c	21.51c	20.76c	21.44c	18.79c	19.24b
LSD at 5%	**0.06**	**0.07**	**0.25**	**0.26**	**0.27**	**0.31**	**0.25**	**0.27**

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

Table 14. Interactive impact of tuber eye number and foliar biostimulant applications on leaves tuber quality of potato (TDS, dry matter, vitamin C, starch) at 120 days after planting during the 2022/23 and 2023/24 seasons

Treatments		TDS, %		Dry matter, %		Vitamin C, mg 100g^{-1}		Starch, %	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
One eye	**Control**	6.02	6.20	20.04	20.37	19.49	20.24	17.61	17.93
	Amino acids	6.47	6.76	20.69	21.74	20.47	21.29	18.48	18.86
	Seaweed .E	6.36	6.48	20.53	21.53	20.26	20.69	18.31	18.70
	Yeast. E	6.28	6.41	20.35	21.07	20.05	20.42	18.12	18.50
	Licorice .E	6.17	6.31	20.15	20.55	19.77	20.44	17.87	18.24
Two eyes	**Control**	6.69	6.95	20.99	21.44	20.64	21.05	18.73	19.13
	Amino acids	7.47	7.64	22.50	23.00	22.17	22.54	20.13	20.63
	Seaweed .E	7.40	7.56	22.24	22.80	21.95	22.36	19.93	20.28
	Yeast. E	7.22	7.39	21.85	22.28	21.55	21.94	19.52	19.90
	Licorice .E	6.97	7.09	21.45	21.86	21.17	22.15	19.14	19.73
Three eyes	**Control**	6.86	7.00	21.24	21.73	20.91	21.31	18.93	19.53
	Amino acids	7.67	8.01	22.89	23.40	22.63	23.08	20.49	20.91
	Seaweed .E	7.58	7.91	22.69	23.15	22.36	22.81	20.28	20.71
	Yeast. E	7.33	7.48	22.07	22.51	21.74	22.13	19.72	20.08
	Licorice .E	7.12	7.26	21.67	22.12	21.33	21.72	19.36	19.77
LSD at 5%		**0.11**	**0.11**	**0.43**	**0.45**	**0.47**	**0.53**	**0.44**	**0.46**

3.3.a. Interactions effect

CONCLUSION

The study revealed that increasing the number of eyes per tuber combined with the application of natural stimulants significantly improved potato growth and yield. Among the tested stimulants, amino acids and seaweed extract showed exceptional potential for enhancing productivity under the study's conditions then yeast extract and lately licorice extract. Based on these findings, it is recommended to adopt a planting strategy utilizing tubers with three eyes and to incorporate foliar applications of amino acids, seaweed extract, or yeast extract into potato cultivation practices.

Generally, future research should aim to optimize the concentration levels and application schedules of these natural stimulants for various potato cultivars. Furthermore, examining the synergistic effects of natural stimulants with other sustainable agricultural practices could provide additional benefits, enhancing productivity while reducing environmental impact.

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الملخص العربي

تحسين نمو وجودة وإنتاجية البطاطس من خلال عدد عيون الدرنات والمحفزات الطبيعية تحت الظروف المصرية

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يُعد محصول البطاطس من المحاصيل الإستراتيجية في مصر لما له من أهمية غذائية واقتصادية. ولذلك، تم إجراء تجربة حقلية خلال موسمي الشتاء 2023/2022 و2024/2023 باستخدام تصميم القطع المنشقة، لدراسة تأثير عدد العيون في قطعة الدرنة الواحدة (عين واحدة، عينان، أو ثلاث عيون) والمحفزات الطبيعية، والتي شملت مستخلص الطحالب البحرية (2.0 جرام/لتر)، الأحماض الأمينية (5 سم/لتر)، مستخلص الخميرة (5.0 جرام/لتر)، ومستخلص العرقسوس (10 جرام/لتر)، بالإضافة إلى الكنترول (الماء العادى)، على نمو البطاطس وإنتاجيتها تحت الظروف الزراعية المصرية بقرية كفر العرب مركز فارسكور بمحلفظة دمياط. أظهرت النتائج أن قطع الدرنات ذات الثلاث عيون تفوقت بشكل ملحوظ على قطع الدرنات ذات العين الواحدة أو العينين في صفات النمو، وتركيب الأوراق الكيميائي، وصبغات التمثيل الضوئي، والإنتاجية، وخصائص الجودة. وكان للأحماض الأمينية التأثير الإيجابي الأكبر بين المحفزات الحيوية المستخدمة، تلاها مستخلص الأعشاب البحرية. وقد حقق الجمع بين قطع الدرنات ذات الثلاث عيون مع الأحماض الأمينية أفضل النتائج في جميع الصفات المدروسة. يوصى باستخدام قطع درنات ذات الثلاث عيون مع المنشطات الطبيعية، خاصة الأحماض الأمينية أو مستخلص الأعشاب البحرية، لتحسين إنتاجية البطاطس. وينبغي أن تركز الأبحاث المستقبلية على تحسين تركيزات المحفزات الحيوية وجدولة تطبيقها، واستكشاف دمجها مع ممارسات الزراعة المستدامة لتحقيق مكاسب إنتاجية إضافية وضمان استدامة بيئية.