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EFFECT OF FOLIAR APPLICATION OF NPK AND AMINO ACID ON THE GROWTH AND YIELD-RELATED TRAITS OF BROCCOLI (*BRASSICA OLERACEA* VAR. ITALICA)

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SUMMARY

A field experiment materialized during the winter of 2022 at the College of Agriculture, University of Kerbala, to determine the effect of foliar spraying of several concentrations of NPK and amino acids on growth characteristics and yield of broccoli plants (*Brassica oleracea* var. Italica). The study implemented a randomized complete block design (RCBD) with two factorial experiments and three replications. The first factor included three concentrations of NPK (0, 1.5, and 2.5 g L^{-1}), and the second with three concentrations of amino acids (0, 1, and 2 ml L^{-1}). The findings demonstrated notable disparities, with the third concentration of NPK (2.5 g L^{-1}) exhibiting superior performance, giving a plant height of 63.78 cm, leaves per plant (18.076 leaves $plant^{-1}$), stem diameter (3.326 mm), flower disc weight per plant (510.84 g $plant^{-1}$), and the flower holder diameter (18.671 mm). Regarding the impact of amino acid, the concentration at 2 ml L^{-1} appeared with maximum values across traits, i.e., plant height (62.50 cm), number of leaves (17.477 leaf $plant^{-1}$), stem diameter (3.241 mm), flower disc weight (485.49 g), and the diameter of the flower container (15.972 mm). The interaction between the two factors displayed significant effects, with the highest interaction between the third concentration of NPK (2.5 g L^{-1}) and the concentration of amino acid (2 ml L^{-1}) arising in most traits.

Keywords: Broccoli (*Brassica oleracea*), NPK doses, amino acid, growth and yield traits

Key findings: In broccoli (*Brassica oleracea*), NPK at 2.5 g L^{-1} provided better results than other doses for plant height, leaf count, stem diameter, floral disc weight, and flower stand diameter. Similarly, the highest averages for plant height, leaf count, stem diameter, floral disc weight, and flower stand diameter emerged with the amino acid at 2 ml L^{-1}.

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INTRODUCTION

The cruciferous family encompasses a variety of substantial vegetables, and one of the most important is broccoli (*Brassica oleracea*). Winter vegetable crops are significantly relevant due to their wide distribution across various regions worldwide. This category encompasses over 350 genera and over 4000 species. According to past studies, the plants exhibit optimal growth in cold and humid climatic conditions while displaying limited resilience to sudden temperature fluctuations and frost and have a low tolerance to high temperatures (Ghazal and Al-Nussairaw, 2022).

Broccoli is characteristic of notable nutritional composition, encompassing numerous essential elements, vitamins, proteins, lipids, and carbohydrates. Moreover, it is remarkable due to its high content of glycosides, validating to have anti-cancer properties (Hanson, 2000). Regular eating of broccoli, more than once a week—has proven to reduce the risk of prostate cancer by 45% (Gad and Abd-El-Moez, 2011).

According to statistics from the Food and Agriculture Organization (FAO, 2018), broccoli production worldwide has reached more than 26.5 million metric tons. Likewise, producing this vegetable in Iraq amounted to 112,000 metric tons. From obtained information by this research, the produced amount by the Iraqi firm accounts for less than 0.4% of global production.

Plants need nitrogen as a primary and vital ingredient at every stage of their development. It is essential for creating proteins, enzymes, protoplasm, and the chemicals with them—NADH, NADPH, and ATP, the energy unit. Auxins, cytokinins, alkaloids, and the development of the chlorophyll molecule are just a few of the plant growth regulators it is essential for, along with the synthesis of several vitamins, including those in the vitamin B group like niacin (also called dicotonic acid). One vital component of a plant's metabolic activities is acquiring the energy needed for crucial processes like photosynthesis and respiration (Al-Nuaimi, 2011).

An essential component for the growth and development of plants is phosphorus (P). Plant roots absorb phosphate (Pi), often as H2PO-4, from the rhizosphere solution to get phosphorus (Hammond and White, 2008). Pi is usually prevalent in the soil solution at low concentrations (2–10 μM). As such, Pi requires delivery to the root surface via diffusion-mediated means slowly (Marschner, 1995). Therefore, phosphorus (P) is considerably one of the lesser mineral elements in the soil, which frequently acts as a limiting factor in plant growth (Tiessen, 2008).

Phosphorus is a primary nutrient for plants. It is crucial in the processes of energy transfer and storage in plants, contributing to metabolism and root transport. It also affects root growth and the formation of DNA and other nucleic acids, directly affecting plant development and production (Mohamed *et al.,* 2021). Similarly, potassium is a vital nutrient for plants, as it has multiple contributing roles. Potassium helps control how much water the plant takes in and its distribution, which lessens the effects of dryness. In addition, it helps plant cells become sturdy, making them less likely to break or fall over. It also serves in chemical and biochemical processes that help plants grow by creating organic matter and moving sugars and nutrients from production areas (leaves) to regions where plants need them (Rani *et al*., 2021).

Amino acids are critical to plants because they help start carbon digestion. This process works better because it makes more chlorophyll. They are also necessary to absorb nutrients in plants, remove heavy metals, and make plants less poisonous (Baqir *et al*., 2019). In plants, amino acids also have a beneficial effect that makes cell divisions last longer. This extensive cell division then leads to faster vegetative growth. Amino acids can directly affect a plant's bodily processes by helping to make enzymes that aid in carbon metabolism (Babik and Elkner, 2000). Plants can get more nutrients when they use amino acids, which are suitable for many parts of plant growth. Plants may have more chlorophyll if they have amino acids (Kałużewicz *et al*., 2017) producing more new leaves (Kawade *et al*., 2023) and ably take in nutrients from the soil to start growing (Tarasevičienė *et al*., 2009).

Adding amino acids to growth factors made them work better in the leaf area, amount of leaves, stems, dry weight, and chlorophyll level of the plant (Shehata *et al*., 2011; Al-Azzawi and Saleh, 2018). Putting amino acids on plant leaves is beneficial to help plants grow and produce more speedily. This plan worked well to lower nitrate intake, making them less effective at increasing antioxidants and metabolic processes. In turn, it increases the amount of enzymes in plant cells, as reported by Al-Mohammad and Al-Taey (2019). The production of carbohydrates and proteins, helping photosynthesis by adding to chlorophyll, controlling enzymes that help plants adapt to harsh environments, and promoting biological chemicals and physiological functions are all valuable biological processes. The presented study sought to investigate the impact of NPK and amino acid foliar application on the broccoli's (*B. oleracea* var. Italica) growth and yield-related traits.

MATERIALS AND METHODS

Experiment site and research factors

The field experiment on broccoli (*Brassica oleracea* L.) commenced in 2022 at the University of Kerbala, Iraq. Before starting field practices, soil samples taken at a depth of 30 cm incurred assessment for their chemical and physical properties (Table 1). The soil analysis ensued at the Central Laboratory, Department of Soil Sciences, College of Agriculture, University of Kerbala, Kerbala, Iraq. The study utilized a randomized complete block design (RCBD) with three replications, each replicate containing four experimental units and each experimental unit containing 15 plants.

The first factor had three concentrations of NPK (0, 1.5, and 2.5 g L^{-1}), with labels as A0, A1, and A2. Meanwhile, the second factor included three concentrations of amino acids (0, 1, and 2 ml L^{-1}), tagged as B0, B1, and B2. On January 29, 2023, applying drops of alzahi served as an adhesive and diffuser. First spraying of plants transpired 30 days after planting. The second spraying occurred two weeks after the initial application.

Preparing seedlings and planting

On November 12, 2022, seedlings contained within cork dishes came from a privately owned nursery. The soil within the field underwent preparation, involving three instances of plowing, followed by exposure to sunlight. Additionally, its polishing and leveling proceeded. The area gained partitioning into three rows, with a spacing of 75 cm between each row and 40 cm between each plant. Subsequent seedling transplanting continued into the designated field, with the resulting crop harvested on February 27, 2023.

Table 1. Chemical and physical characteristics of the experimental field soil before broccoli planting.

Type of analysis	Value	Unit	Type of analysis	Value	Unit
EC	2.3	ds m^{-1}	Ca^{+2}	340	mg l^{-1}
pH	7.6		Mg^{+2}	135	
Available Nitrogen	44.3	mg kg^{-1}	Na^{+}	359	
Available Phosphorus	9.8		SO_4^{-2}	325	
Available Potassium	233.6		Cl^{-}	275	
Sand	331	g kg^{-1}	HCO^{3}	323	
Silt	297		Organic matter	11.3	
Clay	372		Soil texture	Mixture	

Parameters studied

A random assessment of plant height (cm) proceeded on six plants inside the experimental unit. A metric measuring tape helped determine the vertical distance between the soil surface and the apex of plant development. The plant's total number of leaves consisted of counting the large and medium-sized leaves. Measuring stem diameter (mm) in each experimental unit used a Vernier caliper at a standardized height of 5 cm above the area where the plant and earth make contact. Subsequently, computing the average stem diameter surfaced for marked plants. The weight of the flower disc (g) had five samples extracted from each experimental unit for transferring into paper bags for drying. The drying process employed an electric oven, with a constant temperature of 70 °C, until the weight of the samples reached a state of equilibrium. The mass of the pink disk detection utilized a precision balance (Al-Sahhaf, 1989). Measuring the diameter of the flower disc (mm) used a Vernier caliper on five flower heads from each experimental unit and then averaged.

Statistical analysis

All analyses of the recorded data engaged the analysis of variance (ANOVA) as per RCBD, according to the arrangement of factorial experiments (Steel and Torrie, 1980). The least significant difference ($LSD_{0.05}$) test aided the comparison and separation of the mean differences for all parameters, with the statistics software GenStat12 used for the analysis.

RESULTS AND DISCUSSION

Plant height

The results revealed NPK concentrations had significant disparity for plant height of broccoli (Table 2). Specifically, the third concentration of NPK (2.5 g L^{-1}) demonstrated superior performance by showing the tallest plants (63.78 cm). Conversely, the comparative treatment showed the lowest plant height (54.44 cm). The observed increase in plant height might be due to the action of nitrogen in the NPK component, as nitrogen is crucial in facilitating cell division and elongation processes (Lawlor, 2002; Ahmed *et al*., 2023; Al-Chalabi and Ibraheem, 2024).

The amino acid treatment at 2ml L^{-1} had the maximum average plant height, measuring 62.50 cm, whereas the control treatment displayed the minimum average (56.33 cm). It could be because amino acids aid the absorption of ions and nutrients from the soil solution, enhancing photosynthesis and promoting vegetative growth and development (Baqir *et al.,* 2019). The interaction between the two factors also had a notable impact on the plant height, with the interaction of treatments NPK (2.5 g L^{-1}) and amino acid (2 ml L^{-1}) yielded the highest average plant height (69.67 cm), and the control treatments (A0B0) had the lowest average for the said trait (33.00 cm).

Leaf number

For leaves per plant in broccoli, the NPK concentrations demonstrated significant differences (Table 3). The third concentration of NPK (2.5 g L^{-1}) showed the best performance, with the highest average of 18.076 leaf $plant^{-1}$. Conversely, the control treatment gave the lowest results (16.276 leaf $plant^{-1}$). Nitrogen promotes the manufacture of enzymes and chlorophyll molecules, which may explain the increase in the number of leaves, proteins, hormones, and amino acids involved in cellular division and elongation (Ethbeab *et al.,* 2022). Additionally, potassium, vital in enhancing the process of photosynthesis, facilitates the synthesis of carbohydrates and proteins required for various metabolic functions in plants, promoting the efficient transport of metabolic substances from leaves to plant roots and other plant parts (Kaur and Sharma, 2018).

Both amino acid treatments (1 and 2 ml L^{-1}) had the highest mean values of leaves for the said trait (17.477 leaf $plant^{-1}$), whereas the control treatment had the lowest (17.206 leaf $plant^{-1}$). The observed enhancement in the

Table 2. Effect of NPK, amino acids, and their interaction on the plant height of broccoli.

NPK \ Amino acids	B0	B1	B2	Means (cm)
A0	33.00	56.00	55.00	54.44
A1	59.00	60.33	63.00	60.78
A2	57.67	64.00	69.67	63.78
Means (cm)	56.33	60.11	62.50	
$LSD_{0.05}$ NPK = 0.754, Amino acids = 0.754, Interaction = 1.306				

Table 3. Effect of NPK, amino acids, and their interaction on the leaves per plant of broccoli.

NPK \ Amino acids	B0	B1	B2	Means (leaves plant^{-1})
A0	16.113	16.293	16.423	16.276
A1	17.616	17.620	17.796	17.675
A2	17.896	18.120	18.213	18.076
Means (leaves plant^{-1})	17.206	17.344	17.477	
$LSD_{0.05}$ NPK = 0.068, Amino acids = 0.068, Interaction = 0.125				

Table 4. Effect of NPK, amino acids, and their interaction on the stem diameter of broccoli.

NPK \ Amino acids	B0	B1	B2	Means (mm)
A0	2.170	2.970	3.047	2.729
A1	3.127	3.297	3.253	3.226
A2	3.243	3.310	3.423	3.326
Means (mm)	2.847	3.192	3.241	
$LSD_{0.05}$ NPK = 0.120, Amino acids = 0.120, Interaction = 0.210				

said trait can refer to the involvement of amino acids in various metabolic processes, such as carbohydrate synthesis, protein formation, facilitation of photosynthesis by contributing to chlorophyll production, promotion of enzymatic activity, and stimulation of biological compounds and physiological mechanisms. Consequently, these amino acids contribute to the overall enhancement of plant growth and development (Khan *et al.,* 2019). The interaction effects between the two factors (Table 3) were also significant for the leaves per plant. Specifically, the interaction of NPK (2.5 g L^{-1}) and amino acid (2 ml L^{-1}) exhibited the utmost mean value (18.213 leaf plant^{-1}), surpassing the control treatment, which displayed the lowest mean value (16.113 leaf plant^{-1}).

Stem diameter

Table 4 details findings demonstrating a strong relationship between the NPK concentrations—concentration 2.5 g L^{-1} performed best, producing the broadest mean stem diameter value (3.326 mm). In contrast, the stem diameter average for the control treatment was the smallest (2.729 mm). The rationale for this phenomenon can be due to the function of phosphorus inside the NPK compound, as it serves as a crucial constituent of several enzymes, proteins, and nucleic acids (DNA and RNA). Moreover, phosphorus plays a vital role in facilitating and retaining energy within the metabolic processes of crop plants. The phosphorus is also essential for developing diverse organic molecules, including nucleic acids and sugars. These chemical compounds are crucial in enhancing the earlier-mentioned features in crop plants (Tarasevičienė *et al.,* 2009).

The results from the same table also provided a significant effect between the amino acid parameters, as the third concentration (2 ml L^{-1}) gave the highest average of 3.241 mm. It did not differ significantly from the second concentration (1 ml L^{-1}), which averaged 3.192 mm, whereas the control condition showed the lowest average for stem diameter (2.847 mm). The potential cause is the amino acids, essential in enhancing growth traits by promoting enzymatic reactions, facilitating vitamin synthesis within the plant, and augmenting cell membrane permeability. These findings also align with past findings in broccoli plants (*B. oleracea* var. *Italica*) (Halshoy *et al.*, 2023). The significance of the interaction effects between the second dose of NPK and the amino acid was also evident in the results. The interaction of NPK (2.5 g L^{-1}) and amino acid (2 ml L^{-1}) exhibited the maximum average for stem diameter in broccoli plants (3.423 mm), and the control had the lowest value for the said trait (2.170 mm).

Flower disc weight

The outcomes in Table 5 showed a significant effect between the concentrations of NPK, as the third concentration (2.5 g L^{-1}) gave the highest average (510.84 g $plant^{-1}$) compared with the control treatment with the minimum average weight for the said trait (411.80 g $plant^{-1}$). The observed rise in the said trait might be due to the notable involvement of nitrogen in the synthesis of chlorophyll molecules and the formation of enzymes, proteins, hormones, and amino acids. Consequently, these processes contribute to an overall increase in the pink disc weight in broccoli (Salman and Razzaq, 2022).

Amino acid treatment (2 ml L^{-1}) had the maximum average flower disc weight (485.49 g $plant^{-1}$), while the lowest average for the said trait was apparently in the control treatment (464.60 g $plant^{-1}$). The process of spraying amino acids increased the weight of the disc in the broccoli plant since these acids stimulate cell growth and enhance metabolic processes, thus activating the growth processes to form more tissues, raising the final weight of the disc in broccoli (Hamza and Al-Taey*,* 2020).

Results from the same table also implied a significant interaction between the factors, as the highest interaction appeared between the third concentration of NPK (2.5 g L^{-1}) and the amino acid (2 ml L^{-1}), with an average of 523.23 g $plant^{-1}$. Meanwhile, less interference occurred in the control treatment for both factors, which gave an average of 404.80 g $plant^{-1}$.

Flower disc diameter

The outcomes shown in Table 6 provide a significant effect between the concentrations of NPK, as the third concentration (2.5 g L^{-1}) gave the maximum average of 18.671 mm, compared with the control treatment, which exhibited the minimum average (15.309 mm). NPK combinations are crucial in improving and increasing plant growth, as nitrogen enhances the growth of leaves and stems, contributes to the formation of proteins, and enhances vegetative growth. Phosphorus also contributes to developing roots and flowers while helping tolerate different environmental conditions, contributing to plant strength. These positive effects manifested in increasing the disc diameter of the broccoli plant. Therefore, improving the balance between these three elements supports ideal growth, as reflected in raising the diameter of the disc (Al-Jubouri and Al-Hamdany, 2021).

The results from Table 6 detailed a remarkable effect between spraying with amino acid concentrations, as the concentration of 2 ml L^{-1} provided the highest average of 17.560 mm. However, it did not differ significantly from the concentration of 1 ml L^{-1}, which gave an average of 17.206 mm, compared with the control treatment, reaching an average of 15.972 mm. Amino acids are vital in increasing the diameter of the disc through their participation in forming proteins, which is one of the chief elements in plant structure. Providing sufficient amino acids also works to enhance the growth and development of

Table 5. Effect of NPK, amino acids, and their interaction on the flower disc weight of broccoli.

NPK \ Amino acids	B0	B1	B2	Means Ig)
A0	404.80	412.93	417.67	411.80
A1	494.47	507.20	515.57	505.74
A2	494.53	514.77	523.23	510.84
Means (g)	464.60	478.30	485.49	
$LSD_{0.05}$ NPK = 0.892, Amino acids = 0.892, Interaction = 1.544				

Table 6. Effect of NPK, amino acids, and their interaction on the flower disc diameter of broccoli.

NPK \ Amino acids	B0	B1	B2	Means (mm)
A0	14.220	15.793	15.913	15.309
A1	15.897	17.060	17.317	16.758
A2	17.800	18.763	19.450	18.671
Means (mm)	15.972	17.206	17.560	
$LSD_{0.05}$ NPK = 0.4038, Amino acids = 0.4038, Interaction = N.S.				

tissues, which ultimately increases the size of the disc. The results agreed with Hussein and Allawi (2017).

These results aligned with their findings that applying amino acids promotes vegetative growth and development. The analysis also revealed a nonsignificant interaction effect between the two components for the flower disc diameter.

CONCLUSIONS

The latest study concluded that NPK concentrations effectively increased broccoli plants' growth and yield, especially the third concentration (2.5 g L^{-1}). It also noted that amino acids played an imperative role in improving and increasing productivity, especially the concentration of 2 ml L^{-1}, as its performance was better for growth and yield associated with broccoli. Likewise, a noticeable effect from the combination of both chemical compounds resulted in significantly enhancing plant height, the number of leaves, stem diameter, and flower disc weight.

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