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## The role of tyrosine in improving growth, yield, and yield components in sorghum Genotypes under drought conditions

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### ABSTRACT

Spring sorghum cultivation in Iraq faces significant challenges due to persistently high temperatures, particularly during flowering and fertilization. This leads to reduced flower fertility, poor grain set, and negatively impacts crop yield. Therefore, this study aimed to evaluate the efficacy of the amino acid Tyrosine in improving the growth, physiological characteristics, yield, and yield components of four sorghum (*Sorghum bicolor* L. Moench) genotypes: Inqath, Li, Giza, and Wed Ahmad. The experiment was conducted during the spring season of 2025 using a randomized complete block design (RCBD) with a split-plot arrangement and three replications. Genotypes were distributed in the subplots, and Tyrosine concentrations (0, 50, 100, and 150 mg L<sup>-1</sup>) were applied in the main plots. The results showed that spraying with 150 mg L<sup>-1</sup> significantly improved plant height, leaf area index, number of grains per head, 500-grain weight, and grain yield, while reducing proline content compared to the control treatment. Genotypes also responded differently to the amino acid, with the 'Salvation' variety achieving the highest grain yield. These results indicate that the use of Tyrosine contributed to improving plant physiology and mitigating the negative effects of heat stress prevalent during spring planting, leading to improved fertilization, grain filling, and increased productivity. This makes it a promising option for enhancing the sustainability of sorghum production in hot and semi-arid environments in Iraq.

**Keywords:** *Sorghum*, Heat stress tolerance, Yield components, Amino acids

### Introduction

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most important cereal crop worldwide after wheat, rice, maize, and barley. It is a strategic crop for food security in arid and semi-arid regions due to its high water-use efficiency and tolerance to harsh environmental conditions. *Sorghum* is cultivated in more than 110 countries, with Africa being the leading producer, followed by the Americas and Asia. Global production exceeds 60 million tons annually, and its importance is increasing due to its diverse uses in human food, animal feed, silage, starch, sugar syrup, bioethanol, and food industries (FAO, 2024; FAOSTAT, 2024; Kumara Charyulu *et al.*, 2024) [1, 2].

Climate change has become a major challenge for agricultural production due to increasing temperatures, heat waves, irregular rainfall, and prolonged drought periods. The Middle East and North Africa are among the regions most vulnerable to these changes, threatening agricultural sustainability and food security (IPCC, 2023) [3]. Iraq is particularly affected by rising spring temperatures, especially during flowering and fertilization stages, causing reduced pollen viability, poor fertilization, increased sterility, and decreased grain number and size. Heat stress also increases reactive oxygen species (ROS), causing damage to cell membranes, proteins, and chlorophyll, reducing photosynthetic efficiency and plant productivity (Taiz *et al.*, 2018; Hasanuzzaman *et al.*, 2020) [4].

Although sorghum is considered one of the most heat- and drought-tolerant cereal crops, prolonged heat stress during critical growth stages reduces physiological efficiency, disrupts source-sink relationships, and decreases grain number and weight through impaired translocation of photosynthetic products to grains (Ciampitti and Vyn, 2013; Prasad *et al.*, 2021) [5]. Therefore, improving stress tolerance through suitable Genotypes and sustainable management practices has become a priority in modern crop production. Genotypes differ genetically in their ability to maintain photosynthetic activity, water balance, pollen viability, fertilization efficiency, and yield components under unfavorable conditions; thus, evaluating varietal responses is essential for identifying adapted Genotypes under Iraqi conditions (Ayalew *et al.*, 2018) [6].

Tyrosine is a biosynthetic precursor of tocopherols, plastoquinone and ubiquinone that are essential to plant itself. Furthermore, tyrosine is used as a substrate to synthesize numerous specialized metabolites in different groups of plants, such as rosmarinic acid (RA) and its derivatives in the families of Lamiaceae and

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Boraginaceae (Kilgore *et al.*, 2016) [7]. The core cyclic structure of tocopherol, plastoquinone and ubiquinone is supplied by the amino acid tyrosine and these compounds are synthesized in all plants. In addition to its antioxidant activity, tocopherol, and its isoprenoid derivatives, the tocotrienols, have several other physiologic functions in plants (Falk *et al.*, 2010) [8]. The term tocochromanols is synonymous with vitamin E and is part of our nutrition. The tocotrienols differ from tocopherols in that they have three double bonds in the isoprenoid side chain, and are not as widely distributed as tocopherols (Xu *et al.*, 2020) [9]. Plastoquinone is found in all green lineages, ranging from cyanobacteria and algae to land plants, and acts as electron transporter in photophosphorylation, thus is indispensable to plant growth.

Considering the economic importance of sorghum and the increasing effects of heat stress on production in Iraq, this study aimed to evaluate the response of four sorghum Genotypes to different concentrations of Tyrosine. The study aimed to identify the most efficient variety under heat stress conditions and determine the role of Tyrosine in improving growth characteristics, physiological indicators, yield components, and grain yield, contributing to the development of sustainable management practices for sorghum production in hot and semi-arid environments.

## Materials and methods

The field experiment was conducted during the spring season of 2025 at the experimental in one of the agricultural fields in the Al-Nil sub-district, located in Babil Governorate, (central Iraq). The aim was to study the effect of foliar spraying with the amino acid stimulant Tyrosine on improving the drought tolerance of four sorghum genotypes. The experiment was carried out using a completely randomized block design with a split-plot arrangement and three replications.

The study factors included:

Factor 1: *Sorghum* genotypes: (Li, Wed Ahmad, Giza and Inqath)

Factor 2: Foliar spray concentrations of the amino acid Tyrosine (0 mg L<sup>-1</sup> (control treatment), 50 mg L<sup>-1</sup>, 100 mg L<sup>-1</sup> and 150 mg L<sup>-1</sup>)

The main plots included spraying sorghum plants with four concentrations of the amino acid as mentioned above, while the subplots included sorghum Genotypes. Field operations were carried out on the soil by plowing it twice perpendicularly, followed by smoothing and leveling. The experimental plot was then divided into experimental units according to the design used. Each replicate was divided into 12 experimental units with dimensions of (2.5 x 3 m), and the row length was 3 m. Prior to planting the soil received phosphate fertilizer at 100 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> as triple superphosphate (45% P<sub>2</sub>O<sub>5</sub>) and mixed into the soil during tillage. The amount of nitrogen fertilizer (46% N) applied was 100 kg N ha<sup>-1</sup>, applied in three equal doses: after emergence, 40 cm and flowering stage (Ministry of Agriculture, 2006) [10]. Planting was done in rows with a spacing of 50 cm between rows and 25 cm between hills. *Sorghum* seeds were sown on April 10th at a rate of 3 seeds per hill. The plants were then thinned to one plant per hill three weeks after planting. The experiment was irrigated immediately after planting, and subsequent irrigations were carried out as needed. Weeding was done as required. The corn stem borer was controlled with diazinon granular herbicide (10% active ingredient) twice, the first time at stages 4–5. The first treatment was applied to the leaves two weeks after the first (Ministry of Agriculture, 2015) [11]. The aqueous solution of the amino acid Tyrosine was applied twice during the season (the control treatment was sprayed with distilled water only). The first application was 40 days after emergence using a 15-liter knapsack sprayer. The treatment plants were sprayed until thoroughly wet, and a spreading agent was used at a rate of 15 cm<sup>2</sup> per 100 liters of water to ensure complete wetting of the leaves. The second application of the amino acid was 20 days after the first. The plants were harvested at full maturity. The following characteristics were studied: plant height, leaf area index, plant proline content, number of grains per head, grain weight, and grain yield.

## Statistical analysis

Statistical analysis was performed using a randomized complete block design with a split-pane arrangement. Analysis of Variance (ANOVA) was conducted to test the significance of the studied factors and their interactions at a 5% significance level. Means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05. All statistical analyses were performed using the GenStat statistical software.

## Results and discussion

### Plant height (cm)

The results in Table (1) show significant differences in the average height of sorghum plants depending on the variety, the concentration of the Tyrosine, and the interaction of these factors. The Giza variety significantly outperformed others in average plant height, reaching an average of (258.47 cm), while the Inqath, Li, and Wad Ahmad Genotypes recorded averages of (151.80, 145.42, and 151.75 cm), respectively. This superiority is attributed to the genetic differences between the Genotypes, as different genetic makeups possess varying capacities for nutrient absorption and utilization, in addition to differences in photosynthetic efficiency, cell division rate, and cell elongation. These differences directly impact vegetative growth and plant height. These results are consistent with those of Taiz *et al.* (2018) [4], who indicated that genetic traits are the primary factor determining growth efficiency and plant response to environmental and management conditions. Marschner (2012) [12] also demonstrated that nutrient uptake and utilization efficiency varies according to the crop's genetic makeup.

The results also showed a significant effect of the concentration of the amino acid Tyrosine. Increasing the concentration from 0 to 150 mg/L<sup>-1</sup> led to an increase in average plant height from 160.11 cm to 195.23 cm, indicating that the use of the amino acid gradually improved vegetative growth with increasing concentration. This can be explained by the fact that humic acid preparations and amino acid improve soil properties and increase nutrient availability, in addition to stimulating root growth, increasing cell membrane permeability, and stimulating enzyme activity associated with biosynthesis. This, in turn, increases the efficiency of water and nutrient uptake, leading to an increased rate of cell division and elongation, and consequently, increased plant height. Canellas *et al.* (2014) [13] demonstrated that humic acids play a role similar to plant growth regulators, stimulating root growth and improving nutrient uptake. Du Jardin (2015) also indicated that plant amino acid enhance physiological processes, increase nutrient utilization efficiency, and boost plant stress tolerance. The interaction between variety and amino acid concentration showed significant differences. The Giza variety achieved the highest plant height (288.47 cm) at a concentration of 150 mg L<sup>-1</sup>, while the Li variety recorded the lowest height (133.60 cm) in the control treatment (0 mg L<sup>-1</sup>). These results suggest that the response of Genotypes to amino acid varies according to their genetic susceptibility, as each variety possesses a different capacity to utilize amino acid and convert them into increased vegetative growth. This is attributed to variations in root system efficiency, nutrient uptake rate, and plant physiological activity, which explains the difference in plant height increase among different Genotypes when Tyrosine concentration is increased.

### Leaf area index

The results in Table (2) indicate that the concentrations of the amino acid spray (Tyrosine) significantly affected the leaf area index of sorghum, while no significant differences were shown between the Genotypes. The Genotypes did not register significant differences in the average leaf area index, although the Giza variety had the highest average (3.88), followed by the Wad Ahmad genotyp (3.73), then the Inqath genotyp (3.40), while the Li variety recorded the lowest average (3.31). The lack of significance among the Genotypes can be explained by the fact that the leaf area index is a trait highly influenced by environmental conditions and agricultural management, in addi

tion to the similarity in the genetic makeup of the studied Genotypes in their ability to form leaf surface, which led to a reduction in the statistical differences between them. Taiz *et al.* (2018) [4] explained that the expression of vegetative growth traits results from the interaction between genetic makeup and environmental factors, and genetic differences may not be clearly apparent when growing conditions are similar.

Regarding the effect of varying concentrations of the Tyrosine, spraying with the stimulant significantly increased the leaf area index. The average rose from 2.94 in the control treatment to 3.50 at a concentration of 50 mg/L, then to 4.10 at 100 ml/L, and reached its highest value of 4.37 at 5 ml/L. This is attributed to the fact that the amino acid contains active compounds, including humic acids, micronutrients, and growth promoters, which improve root growth, increase water and nutrient absorption, activate cell division and elongation, increase chlorophyll production, and enhance photosynthetic efficiency. This, in turn, led to increased leaf growth and a higher leaf area index. Canellas *et al.* (2014) [13] indicated that humic acids play a significant role in improving vegetative growth by promoting root development and increasing nutrient uptake. Similarly, du Jardin (2015) demon-

strated that amino acid enhance the efficiency of plant physiological processes and increase nutrient utilization, resulting in increased leaf area.

The interaction between Genotypes and Tyrosine concentrations showed significant differences. The Inkath variety achieved the highest leaf area index (4.96) at a concentration of 150 mg L<sup>-1</sup>, while the Giza 113 variety recorded the lowest value (2.56) in the control treatment (0 mg L<sup>-1</sup>). This reflects the varying responsiveness of Genotypes to Tyrosine. Some Genotypes possess a higher efficiency in utilizing bioactive compounds and converting them into vegetative growth, leading to an increased number and size of leaves, and consequently, a higher leaf area index. Furthermore, increased leaf area leads to improved solar radiation interception and higher photosynthetic efficiency, which positively impacts dry matter accumulation and plant productivity. These findings are consistent with those of Calvo *et al.* (2014), who demonstrated that plant responses to amino acid vary depending on the plant's genetic makeup, the type of stimulant, and its concentration, and that the interaction of these factors determines the degree of improvement in growth characteristics.

**Table 1.** Effect of variety, concentrations (Tyrosine), and their interaction on the average plant height (cm) of sorghum in 2025.

| Genotypes              | Amino acid (Tyrosine) concentrations mg L <sup>-1</sup> |        |        |        | Average Genotypes    |
|------------------------|---------------------------------------------------------|--------|--------|--------|----------------------|
|                        | 0                                                       | 50     | 100    | 150    |                      |
| Inkath                 | 137.85                                                  | 147.22 | 150.03 | 172.11 | 151.80               |
| Li                     | 133.60                                                  | 142.55 | 148.80 | 156.73 | 145.42               |
| Geza                   | 228.00                                                  | 244.13 | 273.27 | 288.47 | 258.47               |
| Wed Ahmad              | 141.00                                                  | 146.67 | 155.72 | 163.60 | 151.75               |
| L.S.D 0.05 interaction |                                                         |        | 8.71   |        | L.S.D 0.05 Genotypes |
| Average Amino acid     | 160.11                                                  | 170.14 | 181.96 | 195.23 | 4.67                 |
| L.S.D 0.05 Amino acid  |                                                         |        | 6.12   |        |                      |

**Table 2.** The effect of variety and concentrations of spraying the Tyrosine and their interaction on the average leaf area index of sorghum for the year 2025.

| Genotypes              | (Tyrosine) concentrations mg L <sup>-1</sup> |      |      |      | Average Genotypes    |
|------------------------|----------------------------------------------|------|------|------|----------------------|
|                        | 0                                            | 50   | 100  | 150  |                      |
| Inkath                 | 3.42                                         | 4.09 | 4.76 | 4.96 | 3.40                 |
| Li                     | 2.77                                         | 3.14 | 3.77 | 3.91 | 3.31                 |
| Geza                   | 2.56                                         | 3.18 | 3.64 | 3.85 | 3.88                 |
| Wed Ahmad              | 2.99                                         | 3.54 | 4.22 | 4.75 | 3.73                 |
| L.S.D 0.05 interaction |                                              |      | 0.53 |      | L.S.D 0.05 Genotypes |
| Average Tyrosine       | 2.94                                         | 3.49 | 4.10 | 4.37 | n.s                  |
| L.S.D 0.05 Amino acid  |                                              |      | 0.41 |      |                      |

### Leaf proline content (mg L<sup>-1</sup>)

As shown in the results in Table (3), the variety, concentration of the amino acid spray (Tyrosine) and the interaction between the variety and the spray concentration significantly affected the leaf proline content of sorghum. The results showed significant differences between the Genotypes in leaf proline content, with the Li variety recording the highest average (2.76 mg L<sup>-1</sup>), followed by the Wed Ahmad variety with an average of (2.16 mg L<sup>-1</sup>), then the Giza variety with an average of (1.91 mg L<sup>-1</sup>), while the Inkath variety recorded the lowest average (1.64 mg L<sup>-1</sup>). This variation indicates genetic differences among the Genotypes in their ability to form and accumulate proline, as this trait is associated with the plant's ability to adapt to different environmental conditions and stresses. The variation in proline content between Genotypes may be due to differences in the activity of enzymes responsible for proline synthesis, particularly P5CS, or differences in the efficiency of its breakdown by the enzyme ProDH. These differences reflect the variety's ability to regulate osmotic balance and

protect cell membranes. Taiz *et al.* (2018) [4] indicated that proline accumulation is an important physiological mechanism used by plants to maintain turgor pressure and protect proteins and membranes under stress conditions. Regarding the effect of the amino acid concentration (Tyrosine), the results showed a significant decrease in proline content with increasing concentration. The average decreased from 3.13 mg L<sup>-1</sup> in the control treatment to 2.46 mg L<sup>-1</sup> at a concentration of 50 ml/L, then to 1.76 mg L<sup>-1</sup> at a concentration of 100 ml/L, reaching its lowest value at a concentration of 150 ml/L with an average of 1.13 mg L<sup>-1</sup>. This decrease can be explained by the fact that adding the amino acid improved the plant's physiological state and alleviated stress-causing conditions, thus reducing the plant's need to accumulate proline as a defense mechanism. A decrease in proline content when nutritional and water conditions improve often indicates a reduction in the plant's internal stress level, not necessarily a weakening of its defense capacity, as this results from improved growth and increased efficiency of vital processes.

The effectiveness of Tyrosine in reducing proline accumulation is attributed to its content of active organic compounds, including humic acids, which contribute to improved root growth and increased nutrient absorption, as well as improved plant hydration and activation of metabolic processes. Hammad, and Ali (2014) [14], Canellas *et al.* (2014) [13] demonstrated that humic substances act as physiological stimulants that influence plant growth, regulate nutrient absorption, and improve the efficiency of vital processes. The Li variety, under the control treatment (0 ml/L - 1), recorded the highest proline content (3.64 mg L<sup>-1</sup>), while the Inqaz variety, under the concentration (150 mg/L<sup>-1</sup>), recorded the lowest value (0.85 mg L<sup>-1</sup>). This indicates that different Genotypes respond differently to the amino acid. Some Genotypes have a higher propensity for proline accumulation under unfavorable conditions, while improving physiological conditions with the amino acid reduces this accumulation. Furthermore, the decrease in proline in the Tyrosine treatments was accompanied by increases in other growth indicators, such as plant height, leaf area index, and chlorophyll content, demonstrating an improvement in the plant's physiological state.

### Number of grains per head (grains head<sup>-1</sup>)

The results in Table (4) showed a significant effect of variety, Tyrosine concentration, and their interaction on the number of grains per head in sorghum during 2025. Significant varietal differences were observed, with the Li variety recording the highest average (3237.25 grains head<sup>-1</sup>), followed by Inqath (3029.75 grains head<sup>-1</sup>), Wed Ahmad (2515.50 grains head<sup>-1</sup>), while Giza recorded the lowest average (1870.00 grains head<sup>-1</sup>). These differences are attributed to genetic variation among Genotypes in yield-related traits, including the number of fertile florets, pollination and fertilization efficiency, grain

formation, and the ability to accumulate and allocate assimilates during grain filling. Morris *et al.* (2020) reported that genetic variation among sorghum Genotypes is a major determinant of grain number and grain weight through differences in dry matter partitioning and source-sink efficiency. Tyrosine concentration significantly increased the number of grains per head, with the average rising from 2403.00 grains head<sup>-1</sup> in the control to 2613.75, 2778.25, and 2857.50 grains head<sup>-1</sup> at 50, 100, and 150 mg L<sup>-1</sup>, respectively. This improvement is attributed to enhanced nutrient uptake, greater root activity, improved photosynthetic efficiency, and increased assimilate production and translocation resulting from the humic substances and organic compounds in the amino acid. The associated increases in chlorophyll content and leaf area also promoted grain formation and filling. These findings agree with Rouphael and Colla (2020), who reported that plant amino acid improve nutrient use efficiency, physiological performance, and crop productivity. The interaction between Genotypes and Tyrosine concentrations was also significant. The Li variety produced the highest grain number (3439 grains head<sup>-1</sup>) at 100 mg L<sup>-1</sup>, followed by 3417 grains head<sup>-1</sup> at 150 mg L<sup>-1</sup>, whereas the Giza variety recorded the lowest value (1651 grains head<sup>-1</sup>) in the control treatment. These results indicate that varietal response to Tyrosine depends on genetic potential for utilizing the amino acid, as the increase in concentration did not produce the same response across all Genotypes. The superior performance of Li is likely related to its greater efficiency in inflorescence development, retention of fertilized florets, and utilization of improved nutritional status, whereas Giza exhibited a comparatively weaker response. Similar conclusions were reported by Schenck *et al.* (2018) [15], who emphasized that crop response to amino acid depends on the interaction between the amino acid type, plant genotype, and environmental conditions.

**Table 3.** Effect of variety and concentrations of spray (Tyrosine) and their interaction on the leaf content of proline (mg L<sup>-1</sup>) of sorghum for the year 2025.

| Genotypes              | (Tyrosine) concentrations mg L <sup>-1</sup> |      |      |      | Average Genotypes    |
|------------------------|----------------------------------------------|------|------|------|----------------------|
|                        | 0                                            | 50   | 100  | 150  |                      |
| Inkath                 | 2.50                                         | 1.89 | 1.33 | 0.85 | 1.64                 |
| Li                     | 3.64                                         | 3.12 | 2.49 | 1.78 | 2.76                 |
| Geza                   | 2.96                                         | 2.25 | 1.54 | 0.89 | 1.91                 |
| Wed Ahmad              | 3.41                                         | 2.56 | 1.69 | 0.99 | 2.16                 |
| L.S.D 0.05 interaction |                                              |      | 0.71 |      | L.S.D 0.05 Genotypes |
| Amino acid             | 3.13                                         | 2.46 | 1.76 | 1.13 | 0.13                 |
| L.S.D 0.05 Amino acid  |                                              |      | 0.28 |      |                      |

**Table 4.** Effect of variety and concentrations of spray Tyrosine and their interaction on the average number of grains per head of sorghum for the year 2025

| Genotypes              | Amino acid (Tyrosine) concentrations mg L <sup>-1</sup> |         |         |         | Average Genotypes    |
|------------------------|---------------------------------------------------------|---------|---------|---------|----------------------|
|                        | 0                                                       | 50      | 100     | 150     |                      |
| Inkath                 | 2736                                                    | 3057    | 3111    | 3215    | 3029.75              |
| Li                     | 2970                                                    | 3123    | 3439    | 3417    | 3237.25              |
| Geza                   | 1651                                                    | 1866    | 1914    | 2049    | 1870.00              |
| Wed Ahmad              | 2255                                                    | 2409    | 2649    | 2749    | 2515.50              |
| L.S.D 0.05 interaction |                                                         |         | 155.76  |         | L.S.D 0.05 Genotypes |
| Average amino acid     | 2403.00                                                 | 2613.75 | 2778.25 | 2857.50 | 112.55               |
| L.S.D 0.05 amino acid  |                                                         |         | 130.6   |         |                      |

### Weight of 500 grains (g)

The results in Table (5) indicate a significant effect of both the variety and the concentration of the amino acid spray (Tyrosine) on the average weight of 500 grains of sorghum in 2025.

The results showed significant differences between Genotypes in the average weight of 500 grains. The Giza variety significantly outper-

formed, recording the highest average weight of (20.09 g), followed by the Wed Ahmad variety with an average of (16.51 g), then the Inqath variety with an average of (14.92 g), while the Li variety recorded the lowest average weight of (12.32 g). This difference is at

tributed to the genetic variation between Genotypes in traits related to grain filling, including grain size, dry matter accumulation rate, and the efficiency of photosynthetic translocation from the leaves and stems to the grains during the filling stage. The Genotypes differ in sink strength and their ability to store carbohydrates and proteins within the grain, leading to variations in final grain weight. Maiti *et al.* (2021) demonstrated that genetic variation among sorghum Genotypes directly affects grain characteristics, including grain weight, due to differences in photosynthetic efficiency and dry matter distribution across plant parts.

Regarding the effect of the amino acid concentration (Tyrosine), the results showed a significant increase in the weight of 500 grains with increasing spray concentration. The average weight increased from 13.66 g in the control treatment to 14.35 g at a concentration of 50 mL/L, then to 17.66 g at a concentration of 100 mL/L, reaching its highest value at a concentration of 150 mL/L, with an average weight of 18.17 g. This increase can be explained by the positive role of the amino acid in improving plant physiological growth and increasing the efficiency of photosynthesis production and translocation to the grains during the filling stage. Humic acids and other active com-

pounds in amino acid increase root activity and improve nutrient uptake, particularly nitrogen and potassium, leading to increased protein and carbohydrate synthesis necessary for grain formation and weight gain.

Furthermore, the increased chlorophyll content and improved leaf area index resulting from the use of Tyrosine, as shown in Tables 2 and 3, contributed to increased plant light source efficiency, thus increasing the amount of substances synthesized and translocated to the grains. Xu *et al.* (2020) [9] confirm that amino acid play a significant role in improving nutrient utilization efficiency and activating physiological processes, which translates into increased dry matter accumulation and improved yield characteristics. Fak and munne (2010) [8] also indicated that amino acid stimulate growth and improve the plant's ability to utilize environmental resources, leading to improved production components. These results are consistent with those reported by Abood *et al.* (2019) [16] and Bakry *et al.* (2020) [17]. The effect of amino acid on crops is not limited to increasing vegetative growth only, but extends to improving the components of the yield by increasing the efficiency of metabolic processes and improving the distribution of dry matter within the plant.

**Table 5.** Effect of variety and concentrations of spray Tyrosine and their interaction on the average weight of 500 grains (g) of sorghum for the year 2025.

| Genotypes              | Amino acid (Tyrosine) concentrations mg L <sup>-1</sup> |       |       |       | Average Genotypes    |
|------------------------|---------------------------------------------------------|-------|-------|-------|----------------------|
|                        | 0                                                       | 50    | 100   | 150   |                      |
| Inkath                 | 12.36                                                   | 13.16 | 16.55 | 17.59 | 14.92                |
| Li                     | 10.51                                                   | 10.63 | 13.98 | 14.16 | 12.32                |
| Geza                   | 18.41                                                   | 18.38 | 21.67 | 21.88 | 20.09                |
| Wed Ahmad              | 13.34                                                   | 15.22 | 18.44 | 19.05 | 16.51                |
| L.S.D 0.05 interaction |                                                         |       | n.s   |       | L.S.D 0.05 Genotypes |
| average amino acid     | 13.66                                                   | 14.35 | 17.66 | 18.17 | 0.62                 |
| L.S.D 0.05 amino acid  |                                                         | 0.53  |       |       |                      |

### Grain yield (ton ha<sup>-1</sup>)

Data in Table (6) indicated that variety, Tyrosine concentration and interaction of these factors significantly affected the sorghum grain yield. Significant differences were observed among Genotypes, with Inqath recording the highest average yield (4.88 t ha<sup>-1</sup>), followed by Wed Ahmad (4.93 t ha<sup>-1</sup>), Li (4.38 t ha<sup>-1</sup>), while Giza recorded the lowest (4.53 t ha<sup>-1</sup>). These differences are attributed to genetic variation among Genotypes in resource utilization efficiency, photosynthate distribution, and yield components, including grain number, grain weight, and grain filling efficiency. Tyrosine application significantly increased grain yield, rising from 3.89 t ha<sup>-1</sup> in the control treatment to 4.43, 4.86, and 5.55 t ha<sup>-1</sup> at concentrations of 50, 100, and 150 mL<sup>-1</sup>, respectively. This increase is related to the positive effects of amino acid on nutrient uptake, root activity, chlorophyll content, photosynthetic efficiency, and carbohydrate production and translocation to reproductive organs. Rouphael and Colla (2020) reported that amino acid improve nutrient use efficiency and physiological processes, resulting in enhanced crop productivity. The increase in grain yield was associated with improvements in yield components.

Tyrosine increased the number of grains per head from 2403.00 in the control treatment to 2857.50 grains head<sup>-1</sup> at the highest concentration and increased 500-grain weight from 13.66 g to 18.17 g, indicating improved grain formation and filling efficiency through enhanced dry matter accumulation and translocation. The improvement in yield was also associated with enhanced physiological traits, including increased plant height, leaf area index, and chlorophyll content, along with reduced proline content, indicating improved plant performance and lower stress effects. These findings agree with Abood *et al.* (2019) [16], who indicated that amino acid enhance crop productivity through improving physiological processes and nutrient utilization efficiency. The interaction between Genotypes and Tyrosine concentrations was significant. The Inqath variety treated with 150 mL<sup>-1</sup> recorded the highest grain yield (6.10 t ha<sup>-1</sup>), whereas Li under the control treatment recorded the lowest (3.71 t ha<sup>-1</sup>). This demonstrates that Genotypes differ in their response to amino acid according to genetic potential. Although Giza 113 had the highest 500-grain weight and Li had the highest grain number per head, Inqath achieved the highest grain yield due to the combined contribution of yield components and efficient dry matter partitioning.

**Table 6.** Effect of variety and concentrations of the spray Tyrosine and their interaction on the average grain yield (ton ha<sup>-1</sup>) of sorghum for the year 2016.

| variety   | Amino acid (Tyrosine) concentrations mg L <sup>-1</sup> |      |      |      | average variety |
|-----------|---------------------------------------------------------|------|------|------|-----------------|
|           | 0                                                       | 50   | 100  | 150  |                 |
| Inkath    | 3.85                                                    | 4.49 | 5.09 | 6.10 | 4.88            |
| Li        | 3.71                                                    | 4.29 | 4.67 | 5.47 | 4.53            |
| Geza      | 3.78                                                    | 4.28 | 4.66 | 4.82 | 4.38            |
| Wed Ahmad | 4.22                                                    | 4.67 | 5.02 | 5.81 | 4.93            |

(continued on next page)

| variety                | Amino acid (Tyrosine) concentrations mg L <sup>-1</sup> |      |      |      | average variety    |
|------------------------|---------------------------------------------------------|------|------|------|--------------------|
|                        | 0                                                       | 50   | 100  | 150  |                    |
| L.S.D 0.05 interaction |                                                         |      | 1.53 |      | L.S.D 0.05 variety |
| average amino acid     | 3.89                                                    | 4.43 | 4.86 | 5.55 | 0.71               |
| L.S.D 0.05 amino acid  |                                                         |      | 0.93 |      |                    |

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