



EFFECT OF FOLIAR-APPLIED GIBBERELIC ACID (GA₃) ON PHYSIOLOGICAL TRAITS AND YIELD OF TWO SORGHUM (*SORGHUM BICOLOR* (L.) MOENCH) CULTIVARS

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Abstract. A field experiment was conducted at the Research Station of the Department of Field Crops, College of Agriculture, Tikrit University, during the 2025 growing season to investigate the effect of foliar application of gibberellic acid (GA₃) on some physiological traits and yield of two sorghum cultivars (*Sorghum bicolor* (L.) Moench). The experiment was conducted using a randomized complete block design (RCBD) with three replications and included two factors. The first factor was two sorghum cultivars (Abu Sabaa and Ridan) and the second factor was four concentrations of gibberellic acid (GA₃) (0, 20, 40 and 60 mg L⁻¹). The traits studied were shoot dry matter weight at 45 and 75 days after emergence, absolute growth rate, leaf chlorophyll concentration, total grain and biological yields. The results showed that the Ridan cultivar significantly outperformed Abu Sabaa in shoot dry matter weight at 45 and 75 days after emergence, absolute growth rate, chlorophyll concentration, and biological yield, whereas no significant differences were observed between the two cultivars in total grain yield. Foliar application of gibberellic acid also resulted in a significant and progressive increase in most of the studied traits with increasing concentration. The highest means were obtained at 60 mg L⁻¹ with 50.88 and 97.27 g plant⁻¹ for shoot dry matter weight at 45 and 75 days, respectively, 1.547 g plant⁻¹ day⁻¹ for absolute growth rate, 52.69 SPAD for chlorophyll concentration, 5619 kg ha⁻¹ for total grain yield and 16080 kg ha⁻¹ for biological yield. The interaction treatments also showed clear differential responses of the two cultivars to the various GA₃ concentrations, with the Ridan × 60 mg L⁻¹ treatment recording the highest values for most of the studied traits.

Keywords: Sorghum, gibberellic acid, GA₃, plant growth regulators, physiological traits.

1. Introduction

Sorghum is one of the most important cereal crops worldwide because of its nutritional, feed, and industrial value. Its grain is used mainly in human and

animal nutrition and in the production of starch, oils, and many food products. The crop is also characterized by a short life cycle and can be grown in two seasons, spring and autumn, which enhances its economic and productive importance [1].

Sorghum cultivars differ markedly in their physiological and productive traits owing to genetic differences among them and to the interaction of their genotypes with the prevailing environmental conditions. This variation is evident in a number of physiological, yield, and growth traits, among others. These differences are an important basis for determining a cultivar's ability to exploit available resources and to achieve different levels of growth and yield. Evaluating cultivar performance and selecting suitable cultivars are therefore key factors for improving Sorghum productivity in diverse agricultural environments [2].

Despite its importance, Sorghum production in many regions remains below demand owing to several factors, particularly environmental stresses, water shortage, and the limited use of modern agricultural technologies. Recent studies have therefore turned to plant growth regulators as a technology that can help improve growth and productivity by regulating the physiological processes of the plant [3].

Gibberellic acid (GA_3) is one of the most important natural plant hormones of the gibberellin group. It plays a vital role in controlling growth and development by stimulating cell division and elongation, promoting stem elongation and leaf growth, enhancing photosynthetic efficiency and promoting dry matter accumulation. In addition, GA_3 treatment may improve the grain-filling rate, delay leaf senescence and increase yield components such as grain weight through its effect on plant growth and on partitioning of assimilates to reproductive organs [4].

The response of Sorghum to foliar application of GA_3 depends on concentration, time of application and cultivar and hence it is necessary to determine the correct concentrations and time of application for each growing environment.

Accordingly, this study aimed to evaluate the effect of foliar application of GA_3 on some physiological and productive traits of Sorghum.

2. Materials and Methods

2.1 Study Factors and Field Operations

A field experiment was carried out at the Research Station of the Department of Field Crops, College of Agriculture, Tikrit University, during the 2025 growing season, using a randomized complete block design (RCBD) with three replicates and eight experimental units per replicate. Each experimental unit measured 9 m², giving a total of 24 experimental units. The experiment included two factors: the first was two Sorghum cultivars, Abu Sabaa and Ridan; the second was four concentrations of gibberellic acid (GA_3): the control (no application), 20, 40, and 60 mg L⁻¹. The experiment thus comprised eight treatments × three replicates.

The experimental field was prepared by ploughing and smoothing. Seeds were sown on 20 July 2025 in rows 75 cm apart, with 20 cm between plants within the row, at a depth of 4–5 cm and with three seeds per hill. The seedlings were thinned to one plant per hill 15 days after emergence. Urea (46% N) was used as the nitrogen source and was applied at a constant rate of 320 kg N ha⁻¹ to all treatments, split into two doses: the first at sowing and the second 40 days after emergence. Phosphorus was applied as triple superphosphate (TSP) in a single

dose, banded along the rows at sowing. Potassium sulfate (41.5% K) was used as the potassium source at a rate of 200 kg K ha⁻¹ [5], split into three doses: the first at sowing, the second 20 days after emergence, and the third 40 days after emergence. The plots were irrigated by sprinkler irrigation according to crop requirements until the end of the experiment.

Before sowing, five random soil samples were collected from the field, air-dried, ground, and passed through a sieve with 2 mm openings, then mixed to obtain a representative sample. The sample was sent to the Soil Science Laboratory, Department of Soil Science, Tikrit University, for the determination of its chemical and physical properties (Table 1).

Table 1. Some physical and chemical properties of the soil at the study site (0–0.3 m depth).

Property	Value	Unit
Sand	471	g kg ⁻¹
Silt	299	
Clay	240	
Soil texture	–	Sandy loam
Bulk density	1.39	Mg m ⁻³
Electrical conductivity (EC)	3.11	dS m ⁻¹
pH	7.42	–
Organic matter (OM)	0.84	g kg ⁻¹
Calcium sulfate	59.14	
Carbonate minerals	200.11	
Cation exchange capacity (CEC)	15.00	cmol _c kg ⁻¹

2.2 Traits studied

- **Shoot dry weight (g plant⁻¹):** Shoot (stem and leaf) dry weight was determined at two stages, 45 and 75 days after emergence. Five plants were randomly taken from each experimental unit and oven-dried at 70 °C for 72 h until constant weight.
- **Absolute growth rate (AGR, g plant⁻¹ day⁻¹):** AGR was calculated according to the following equation [6]:

$$AGR = (W_2 - W_1) \div (T_2 - T_1)$$

- where W_1 and W_2 are the shoot dry weights at the first and second stages, respectively, and T_1 and T_2 are the times (in days) of the two samplings.
- **Leaf Chlorophyll Content (SPAD):** Leaf chlorophyll content was measured using a portable chlorophyll meter (SPAD Meter). The third fully expanded leaf from the top of five plants in each experimental unit was measured and the mean value calculated.
- **Total Grain Yield (kg ha⁻¹):** The panicles were harvested from the plants in the two central rows of each experimental unit. The grains were then threshed, gathered and weighed.
- Total grain yield was calculated based on the total grain weight and the harvested area, and the yield was expressed as kg ha⁻¹.

- **Biological yield (kg ha⁻¹):** Five plants were randomly taken from the middle rows of each experimental unit, air-dried, and weighed, and the mean single-plant yield was calculated. The biological yield was then obtained using the following equation:
- Biological yield = single-plant yield × plant density

2.3 Statistical analysis: The data were analyzed statistically according to the randomized complete block design using SAS software, and the treatment means were compared using Duncan's multiple range test at the 0.05 probability level, following [7].

3. Results and Discussion

3.1 Shoot dry weight at 45 days after emergence (g plant⁻¹)

The results in Table 2 showed significant differences among the Sorghum cultivars in shoot dry weight. Ridan was significantly superior, recording the highest mean (45.34 g plant⁻¹), whereas Abu Sabaa recorded a mean of 42.11 g plant⁻¹.

Regarding the effect of GA₃ concentrations alone, the results showed significant differences among the concentrations used. The 60 mg L⁻¹ concentration gave the highest mean shoot dry weight (50.88 g plant⁻¹), followed by 40 mg L⁻¹ (46.55 g plant⁻¹) and then 20 mg L⁻¹ (41.67 g plant⁻¹), whereas the control (0 mg L⁻¹) gave the lowest mean (35.80 g plant⁻¹).

For the interaction between cultivars and GA₃ concentrations, shoot dry weight differed among the interaction treatments. Ridan × 60 mg L⁻¹ gave the highest value (52.09 g plant⁻¹), whereas Abu Sabaa × 0 mg L⁻¹ gave the lowest (34.18 g plant⁻¹).

Table 2. Effect of Cultivars, Gibberellic Acid Concentrations, and Their Interaction on Dry Weight of Vegetative Growth at 45 Days After Germination (g plant⁻¹)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	34.18 ^d	39.76 ^c	44.83 ^b	49.67 ^a	42.11 B
Ridan	37.42 ^{cd}	43.58 ^{bc}	48.26 ^{ab}	52.09 ^a	45.34 A
Mean of GA₃	35.80 D	41.67 C	46.55 B	50.88 A	

3.2 Shoot dry weight at 75 days after emergence (g plant⁻¹)

The results in Table 3 showed that the Sorghum cultivars differed significantly in shoot dry weight at 75 days after emergence. Ridan recorded the highest mean (87.48 g plant⁻¹), while the mean for Abu Sabaa was 82.35 g plant⁻¹.

With respect to the effect of GA₃ concentrations alone, the results showed significant differences among the concentrations, and shoot dry weight increased progressively with increasing GA₃ concentration. The mean was 71.54 g plant⁻¹ in the control (0 mg L⁻¹), rising to 80.79 g plant⁻¹ at 20 mg L⁻¹ and 90.06 g plant⁻¹ at 40 mg L⁻¹, while 60 mg L⁻¹ gave the highest mean (97.27 g plant⁻¹).

For the interaction between cultivars and GA₃ concentrations, shoot dry weight ranged from 68.72 to 99.36 g plant⁻¹. Ridan × 60 mg L⁻¹ gave the highest value (99.36 g plant⁻¹), followed by Abu Sabaa × 60 mg L⁻¹ (95.18 g plant⁻¹), whereas Abu Sabaa × 0 mg L⁻¹ gave the lowest value (68.72 g plant⁻¹).

Table 3. Effect of Cultivars, Gibberellic Acid Concentrations, and Their Interaction on Dry Weight of Vegetative Growth at 75 Days After Germination (g plant⁻¹)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	68.72 ^d	77.85 ^c	87.64 ^b	95.18 ^a	82.35 B
Ridan	74.36 ^c	83.72 ^b	92.48 ^a	99.36 ^a	87.48 A
Mean of GA₃	71.54 D	80.79 C	90.06 B	97.27 A	

3.3 Absolute growth rate (g plant⁻¹ day⁻¹)

The results in Table 4 showed that Ridan was significantly superior in mean AGR (1.405 g plant⁻¹ day⁻¹) compared with Abu Sabaa (1.341 g plant⁻¹ day⁻¹), an increase of about 4.8%.

As for the effect of GA₃ concentration, AGR increased from 1.191 g plant⁻¹ day⁻¹ in the control (0 mg L⁻¹) to 1.304, 1.451, and 1.547 g plant⁻¹ day⁻¹ at 20, 40, and 60 mg L⁻¹, respectively. The 60 mg L⁻¹ concentration thus gave the highest AGR.

The interaction values show that the two cultivars responded in the same direction to increasing GA₃ concentration but differed in the magnitude of the response. In Abu Sabaa, AGR increased from 1.151 g plant⁻¹ day⁻¹ at 0 mg L⁻¹ to 1.270, 1.427, and 1.517 g plant⁻¹ day⁻¹ at 20, 40, and 60 mg L⁻¹, respectively, whereas in Ridan it increased from 1.231 to 1.338, 1.474, and 1.576 g plant⁻¹ day⁻¹ at the same concentrations. The highest value in the experiment was recorded by Ridan × 60 mg L⁻¹ (1.576 g plant⁻¹ day⁻¹), and the lowest by Abu Sabaa × 0 mg L⁻¹ (1.151 g plant⁻¹ day⁻¹).

Table 4. Effect of Cultivars, Gibberellic Acid Concentrations, and Their Interaction on Absolute Growth Rate (g plant⁻¹ day⁻¹)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	1.151 ^d	1.270 ^c	1.427 ^b	1.517 ^a	1.341 B
Ridan	1.231 ^{cd}	1.338 ^{bc}	1.474 ^{ab}	1.576 ^a	1.405 A
Mean of GA₃	1.191 D	1.304 C	1.451 B	1.547 A	

The results in Tables 2, 3, and 4 showed significant differences among the Sorghum cultivars, the GA₃ concentrations, and their interaction in shoot dry weight and AGR, with Ridan significantly superior to Abu Sabaa in all the traits studied. This superiority may be attributed to genetic differences between the two cultivars in vegetative growth efficiency, leaf canopy formation, and the use of available resources, in addition to differences in the ability to produce and accumulate photosynthesis and convert them into dry matter, which was reflected in the continued superiority of Ridan across the different growth stages [8].

The results also showed that increasing the GA₃ concentration led to a clear and regular increase in shoot dry weight and AGR. This increase can be explained by the physiological role of GA₃ in regulating cell division and stem elongation and in stimulating shoot and root growth [9], which may improve the plant's ability to absorb water and nutrients and increase leaf formation and effective leaf area. This in turn enhances light interception and photosynthetic activity, and thus increases dry matter production and accumulation as growth progresses. The continuous increase in shoot dry weight from 45 to 75 days also shows the continuing activity of the shoot in synthesizing and accumulating dry matter in this period. These results agree with those reported in [10].

3.4 Leaf Chlorophyll Concentration (SPAD)

The results presented in Table (5) showed significant differences among sorghum cultivars, gibberellic acid (GA₃) concentrations, and their interaction in leaf chlorophyll concentration, indicating that the two cultivars differed in their responses to the applied GA₃ concentrations. The Ridan cultivar was significantly better than Abu Sabaa for the mean chlorophyll concentration (47.70 SPAD versus 46.51 SPAD for Abu Sabaa). This difference may be due to the genetic difference between the two cultivars in the efficiency of formation of chlorophyll pigment and their response to gibberellic acid treatment. These results are in agreement with those reported by [11].

The result also showed that the increase in concentration of GA₃ resulted in significant and progressive increase in leaf chlorophyll concentration in sorghum. The mean value was 40.39 SPAD under the control treatment (0 mg L⁻¹) and increased to 45.55, 49.80 and 52.69 SPAD in the GA₃ concentrations of 20, 40 and 60 mg L⁻¹, respectively. This trend indicates that GA₃ application contributed to promoting vegetative growth and improving the physiological status of the leaves, which may have enhanced chlorophyll formation or maintenance and improved the efficiency of leaves in carrying out photosynthesis. These results are consistent with those reported by [12].

Regarding the interaction between cultivars and GA₃ concentrations, the Ridan cultivar recorded the highest value of 53.00 SPAD at 60 mg L⁻¹, whereas Abu Sabaa recorded 52.37 SPAD at the same concentration. The lowest value was 39.69 SPAD for Abu Sabaa under the control treatment, followed by 41.08 SPAD for Ridan under the same treatment. It was observed that chlorophyll concentration increased progressively with each increase in GA₃ concentration in both cultivars. In Abu Sabaa, chlorophyll concentration increased from 39.69 to 44.83 and 49.16, reaching 52.37 SPAD, whereas in Ridan, it increased from 41.08 to 46.27 and 50.43, reaching 53.00 SPAD.

Table 5. Effect of Cultivars, Auxin Concentrations, and Their Interaction on Leaf Chlorophyll Concentration (SPAD)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	39.69 d	44.83 c	49.16 b	52.37 a	46.51 B
Ridan	41.08 d	46.27 c	50.43 b	53.00 a	47.70 A
Mean of GA₃	40.39 D	45.55 C	49.80 B	52.69 A	

3.5 Total Grain Yield (kg ha⁻¹)

The results presented in Table (6) showed that there were no significant differences among the cultivars in total grain yield.

The results also showed that foliar application of GA₃ at different concentrations resulted in a significant and progressive increase in total grain yield. The mean yield increased from 2904 kg ha⁻¹ under the control treatment (0 mg L⁻¹) to 3701, 4679, and 5619 kg ha⁻¹ at GA₃ concentrations of 20, 40, and 60 mg L⁻¹, respectively. The increase at 60 mg L⁻¹ reached approximately 93.49% compared with the control treatment. This response could be due to the physiological role of gibberellic acid (GA₃) in stimulating cell division and elongation and promoting growth of both the shoot and root systems, which may improve the efficiency of water and nutrient uptake, increase leaf formation and leaf area and enhance photosynthetic activity. This may consequently increase the production and accumulation of dry matter and photosynthetic assimilates with more translocation of these assimilates to the grains, thus contributing positively to the total grain yield.

The interaction results further indicated that the two cultivars did not respond similarly to increasing GA₃ concentrations. In the Abu Sabaa cultivar, grain yield increased from 3018 kg ha⁻¹ at 0 mg L⁻¹ to 3764, 4547, and 5316 kg ha⁻¹ at 20, 40, and 60 mg L⁻¹, respectively.

In contrast, the Ridan cultivar showed an increase in grain yield from 2789 kg ha⁻¹ under the control treatment to 3638, 4812, and 5921 kg ha⁻¹ at the same concentrations, respectively. It is noteworthy that the Ridan cultivar recorded the highest grain yield at the 60 mg L⁻¹ concentration, reaching 5921 kg ha⁻¹, whereas the Abu Sabaa cultivar recorded a grain yield of 5316 kg ha⁻¹ at the same concentration.

Table 6. Effect of Cultivars, Auxin Concentrations, and Their Interaction on Total Grain Yield (kg ha⁻¹)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	3018 ^f	3764 ^d	4547 ^c	5316 ^b	4161 ^a
Ridan	2789 ^g	3638 ^e	4812 ^c	5921 ^a	4290 ^a
Mean of GA ₃	2904 ^d	3701 ^c	4679 ^b	5619 ^a	

3.6 Biological yield (kg ha⁻¹)

Results in table 7 showed significant differences among the Sorghum cultivars, GA₃ concentrations and their interaction on biological yield which indicates the response of the different cultivars to gibberellic acid treatments and the ability of gibberellic acid to modify the overall plant growth. Ridan was significantly superior in mean biological yield (13,031 kg ha⁻¹) compared with 12,750 kg ha⁻¹ for Abu Sabaa. This superiority may be related to genetic differences between the two cultivars in vegetative growth efficiency, dry matter formation, and the partitioning

of photosynthates among plant organs, in addition to differences in water and nutrient use efficiency [14].

The results also showed a clear upward response of biological yield to increasing GA₃ concentration, with the mean rising from 9,928 kg ha⁻¹ in the control to 16,080 kg ha⁻¹ at 60 mg L⁻¹. This tendency suggests that the administration of GA₃ promoted growth related physiological processes, namely cell division and elongation and shoot development which enhanced dry matter accumulation and hence biological yield.. Improved root growth and a greater efficiency of roots in absorbing water and nutrients may also have contributed to enhanced vegetative growth and increased plant biomass. These results are consistent with those reported in [15].

As for the interaction between cultivar and GA₃ concentration, the highest biological yield was recorded by Ridan at 60 mg L⁻¹ (16,784 kg ha⁻¹), whereas the lowest value was also recorded by Ridan, in the control treatment (0 mg L⁻¹), at 9,672 kg ha⁻¹.

Table 7. Effect of Cultivars, Gibberellic Acid Concentrations, and Their Interaction on Biological Yield (kg ha⁻¹)

Cultivars	Gibberellic Acid (GA ₃) Concentration (mg L ⁻¹)				Mean Cultivars
	0	20	40	60	
Abu Sabaa	10184 ^e	11892 ^d	13547 ^c	15376 ^b	12750 B
Ridan	9672 ^f	11541 ^d	16126 ^c	16784 ^a	13031A
Mean of GA₃	9928 D	11717 C	13837 B	16080 A	

4. Conclusions

- The Ridan cultivar significantly outperformed the Abu Sabaa cultivar in shoot dry weight, absolute growth rate, leaf chlorophyll concentration, and biological yield, whereas the cultivars did not differ significantly in total grain yield.
- Foliar application of gibberellic acid (GA₃) resulted in a significant and progressive increase in most of the studied traits as the concentration increased from 0 to 60 mg L⁻¹.
- The 60 mg L⁻¹ concentration recorded the highest values for most of the studied traits, indicating its effectiveness in improving sorghum growth and productivity under the conditions of the experiment.
- The interaction treatments showed differences in the responses of the two cultivars to GA₃, with the Ridan × 60 mg L⁻¹ treatment recording the highest values for most of the studied traits.

5. References

- [1] Zahid, M. K., Ahmad, D., Amin, R., & Bao, J. (2025). Sorghum starch: Composition, structure, functionality, and strategies for its improvement. *Comprehensive reviews in food science and food safety*, 24(1), e70101.
- [2] Welderufael, S., Abay, F., Ayana, A., & Amede, T. (2024). Genetic diversity, correlation and genotype× yield× trait (GYT) analysis of grain yield and

- nutritional quality traits in sorghum (*Sorghum bicolor* [L.] Moench) genotypes in Tigray, northern Ethiopia. *Discover Agriculture*, 2(1), 4.
- [3] Zheng, H., Dang, Y., Diao, X., & Sui, N. (2024). Molecular mechanisms of stress resistance in sorghum: Implications for crop improvement strategies. *Journal of Integrative Agriculture*, 23(3), 741-768.
 - [4] Ritonga, F. N., Zhou, D., Zhang, Y., Song, R., Li, C., Li, J., & Gao, J. (2023). The roles of gibberellins in regulating leaf development. *Plants*, 12(6), 1243.
 - [5] Rashad, M. Q. (2018). *Response of Sorghum (Zea mays L.) to potassium fertilizer type at different nitrogen levels in gypsum soil* [Master's thesis, University of Tikrit, College of Agriculture].
 - [6] Hunt, R. (1978). *Plant growth analysis* (Studies in Biology No. 96). Edward Arnold (Publishers) Ltd., London.
 - [7] Al-Rawi, K. M., & Khalaf-Allah, A. M. (1980). *Design and analysis of agricultural experiments* (in Arabic). Ministry of Higher Education and Scientific Research, University of Baghdad.
 - [8] Pabelo, J. S., Miguez, F. E., Schnable, P. S., & Salas-Fernandez, M. G. (2025). Crop growth model-enabled genetic mapping of biomass accumulation dynamics in photoperiod-sensitive sorghum. *The Plant Genome*, 18(3), e70111.
 - [9] Ali, A. Y. A., Ibrahim, M. E. H., Zhou, G., Nimir, N. E. A., Elsiddig, A. M. I., Jiao, X., ... & Elradi, S. B. M. (2021). Gibberellic acid and nitrogen efficiently protect early seedlings growth stage from salt stress damage in Sorghum. *Scientific Reports*, 11(1), 6672.
 - [10] Fadhil, A. H. (2025). Responses of Sorghum (*Sorghum bicolor* L.) Varieties to gibberellic acid (GA3). *Basrah Journal of Agricultural Sciences*, 38(Special Issue), 377-386.
 - [11] Ali, A. Y. A., Ibrahim, M. E. H., Zhou, G., Nimir, N. E. A., Elsiddig, A. M. I., Jiao, X., ... & Elradi, S. B. M. (2021). Gibberellic acid and nitrogen efficiently protect early seedlings growth stage from salt stress damage in Sorghum. *Scientific Reports*, 11(1), 6672.
 - [12] Liu, J., Wu, Y., Dong, G., Zhu, G., & Zhou, G. (2023). Progress of research on the physiology and molecular regulation of sorghum growth under salt stress by gibberellin. *International Journal of Molecular Sciences*, 24(7), 6777.
 - [13] Hernández Rodríguez, A., Díaz Pacheco, A., Martínez Tolibia, S. E., Melendez Xicohtencatl, Y., Granados Balbuena, S. Y., & Lopez y Lopez, V. E. (2024). Bioprocess of gibberellic acid by *Fusarium fujikuroi*: The challenge of regulation, raw materials, and product yields. *Journal of Fungi*, 10(6), 418.
 - [14] Narayanan, S., Aiken, R. M., Vara Prasad, P. V., Xin, Z., & Yu, J. (2013). Water and radiation use efficiencies in sorghum. *Agronomy Journal*, 105(3), 649-656.
 - [15] Ali, A. Y. A., Ibrahim, M. E. H., Zhou, G., Nimir, N. E. A., Elsiddig, A. M. I., Jiao, X., ... & Elradi, S. B. M. (2021). Gibberellic acid and nitrogen efficiently protect early seedlings growth stage from salt stress damage in Sorghum. *Scientific Reports*, 11(1), 6672.