


## Effect of Chitosan Seed Priming on Phenological and Vegetative Growth Traits of Sorghum (*Sorghum bicolor* L. Moench) Varieties under Field Conditions

Dania Salman Qahraman 

Department of Field Crops Sciences, College of Agriculture, University of Diyala, Iraq

E-mail: [daniasalman@uodiyala.edu.iq](mailto:daniasalman@uodiyala.edu.iq)

### Abstract

A field experiment was conducted at the Research Station, Department of Field Crops, College of Agriculture, University of Diyala, during the 2025 autumn season to evaluate the effect of chitosan seed soaking on vegetative growth and phenological traits of seven sorghum (*Sorghum bicolor* L. Moench) varieties. The experiment included two factors: chitosan concentrations (0 and 200 mg L<sup>-1</sup>) and seven varieties (LILO, J, Buhooth, Giza, Rabih, Khair and Inqadh), arranged in a factorial experiment using a randomized complete block design (RCBD) with three replications. Data were analyzed using SAS software, and treatment means were compared using Duncan's multiple range test.

Results showed that chitosan significantly improved both vegetative and phenological traits compared to the control. Seed soaking reduced the number of days from planting to 50% flowering and from flowering to physiological maturity by 3.7% and 6.05%, respectively. It also increased plant height, number of leaves, and leaf area by 10–20%, 8–15%, and 12–25%, respectively. Significant differences were observed among varieties. The Lilo variety recorded the lowest days to flowering (68.77 days) and maturity (30.61 days), while Giza and Lilo produced the highest plant height and leaf number. Significant interaction effects indicated variable varietal responses to chitosan. These findings confirm the effectiveness of chitosan as a seed priming agent to enhance sorghum growth under field conditions.

**Keywords:** Chitosan, Sorghum, Seed Priming

### I. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is considered one of the most important cereal crops worldwide, ranking fifth after wheat, rice, maize, and barley (Zheng et al. 2023). Its significance lies in its contribution to global food security, especially in regions affected by water scarcity and climate variability (Pate et al., 2025). The crop is widely used for human consumption, animal feed, and bioenergy production, which further increases its economic and agricultural importance.

One of the main reasons for the importance of sorghum is its ability to adapt to difficult environmental conditions. It has developed morphological and physiological mechanisms that allow it to tolerate drought, high temperatures, and poor soil fertility. Because of this, sorghum is widely cultivated in arid and semi-arid regions, where it serves as a reliable source of food and feed under unstable climatic conditions (Nkuna, 2022).

Recently, attention has increased toward the use of biostimulants as a sustainable approach to improve crop growth under stress conditions. Among these substances, chitosan has gained considerable interest. It is a natural polysaccharide derived from chitin and is known for its non-toxic and biodegradable nature. Previous studies have shown that chitosan can enhance plant growth by improving photosynthetic activity, nutrient uptake, and activating plant defense mechanisms against environmental stress (Tian et al., 2021).

However, despite the positive effects reported, the response of different sorghum varieties to chitosan application under field conditions is still not fully understood. Most studies have focused on general plant



responses, while limited information is available regarding cultivar-specific reactions, particularly under local environmental conditions. This represents an important research gap that needs further investigation.

In addition, genetic variation among sorghum varieties plays a crucial role in determining growth performance and adaptability. Varieties often differ in their response to environmental factors and agronomic practices, making it necessary to evaluate their performance under specific growing conditions to identify the most suitable ones (Nisreen and Sherzad, 2024).

Therefore, studying the interaction between sorghum varieties and biostimulants such as chitosan may provide valuable insights for improving crop productivity. It is expected that varieties will respond differently to chitosan application, which makes identifying the most responsive genotype essential for maximizing vegetative growth.

Accordingly, this study aims to: Evaluate the performance of selected sorghum varieties under local field conditions, investigate the effect of chitosan seed soaking on vegetative growth traits and determine the interaction between varieties and chitosan to identify the best-performing combinations.

## II. Materials and Methods

### 1-2- Experiment Site

The field experiment was conducted during the autumn season of 2025–2026 at the Field Crop Science Station, Department of Field Crops, College of Agriculture, University of Diyala / Iraq. The study aimed to investigate the effect of chitosan seed soaking on the phenological and vegetative growth characteristics of sorghum varieties under the framework of sustainable agriculture.

2- 2-Experimental Factors: the experiment consisted of two factors:

First factor: Chitosan

Two seed soaking treatments were used:

Control treatment (C0): soaking in distilled water

Chitosan treatment (C1): seed soaking with chitosan solution at a concentration of [200] mg L<sup>-1</sup> for [12] hours at room temperature. After soaking, the seeds were air-dried for two hours before sowing to ensure uniform moisture content.

Second factor: Varieties

Seven certified sorghum varieties were used: LILO, J, Buhooth, Giza, Rabih, Khair and Inqadh.

### 3-2Experimental Design

A factorial experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. The total number of experimental units was 42 (2 × 7 × 3).

### 4-2Soil Analysis

Soil samples were collected randomly from a depth of 0–30 cm from different locations within each replication. The samples were air-dried, ground, and sieved through a 2-mm mesh. A representative sample was analyzed in the laboratory of the College of Agriculture, University of Diyala, to determine physical and chemical soil properties (Table 1).

Table 1. Physical and chemical properties of the experimental soil

Property		The Value
Soil separates g kg <sup>-1</sup>	Sand g.kg <sup>-1</sup>	794
	Silt g.kg <sup>-1</sup>	134
	Clay g.kg <sup>-1</sup>	72
	texture	Sandy loam
Cation exchange capacity cmol kg <sup>-1</sup>		14.70
Electrical conduction (EC) ds.m <sup>-1</sup>		2.12
Soil pH		7.9
Organic matter %		0.45
Gypsum (CaSO <sub>4</sub> . 2H <sub>2</sub> O) g kg <sup>-1</sup>		0.130
Nitrogen mg kg-1		26.2
Phosphors mg kg-1		29.1
Potassium mg kg-1		129

## 5-2Agricultural Practices

The field was prepared by plowing twice in perpendicular directions using a moldboard plow, followed by harrowing and leveling. The field was then divided according to the experimental design into plots of 2 m<sup>2</sup>. Plant spacing was 20 cm, the distance between rows was 60 cm, with 25 cm between plots and 75 cm between replicates.

Sorghum seeds were sown on 13<sup>th</sup> July 2025 at a depth of 2–3 cm, using 3–4 seeds per hole to ensure germination, no chemical fertilizers were applied during the experiment to evaluate the potential of chitosan in enhancing plant growth and nutrient uptake from the soil's natural reserves.. Irrigation was applied immediately after sowing. Thinning was carried out two weeks after emergence to maintain one plant per hill. Harvesting was performed at physiological maturity.

## 6-2Studied Traits

### Number of days from planting to 50% flowering (day)

Recorded as the number of days from sowing until 50% of plants reached flowering, based on field observations.

### Number of days from 50% flowering to physiological maturity (day)

Calculated as the number of days from 50% flowering onset to physiological maturity was determined by the appearance of a black layer at the base of the grains and the loss of green color from the glumes.



**Plant height (cm)**

Plant height was measured by selecting 5 plants at random from each experimental plot, from the base of the plant at soil level to the tip of the terminal flower bud at the top of the plant, once the flowering stage was complete; the average was then calculated

**Number of leaves (leaf plant<sup>-1</sup>)**

**Stem diameter (mm)**

Measured using a Vernier caliper at three points on the stem after 50% flowering, and the average was recorded.

**Leaf area (cm<sup>2</sup>)**

Leaf area was calculated using the following equation (mananze et al., 2018):

$$\text{Leaf area} = \text{Leaf length} \times \text{Maximum leaf width} \times 0.75$$

. Data were analyzed using SAS software, and treatment means were compared using Duncan's multiple range test.

**III. Results**

**1-3-Number of days from sowing to 50% flowering (day)**

The results of the statistical analysis revealed significant differences among treatments for the number of days from sowing to 50% flowering, whereas the interaction between them was not significant , (Table 2).

The chitosan seed soaking treatment (C1) significantly reduced the number of days required to reach 50% flowering compared with the control (C0). The control treatment recorded the highest mean value of 75.40 days, whereas the chitosan treatment recorded the lowest mean value of 72.60 days, resulting in an average reduction of approximately 2.8 days. This reduction may be attributed to the role of chitosan in enhancing early seedling vigor, stimulating physiological and metabolic activities, improving hormonal balance, and increasing photosynthetic efficiency, which together accelerate plant development and hasten the transition from vegetative to reproductive growth stages. This result is consistent with (Chakraborty et al.,2020)

Regarding varieties, the results showed clear significant variation among genotypes. The Buhooth cultivar recorded the longest period to reach 50% flowering (79.72 days), and it did not differ significantly from Inqadh and Rabih varieties, which also showed relatively late flowering behavior. In contrast, the Lilo cultivar exhibited the earliest flowering and required a significantly shorter period, with no significant difference observed compared to the Khair cultivar. These differences reflect the genetic variability among sorghum varieties, which plays a key role in determining phenological development. The present findings are consistent with those reported by Hamad and Adagash (2017), who also emphasized the influence of genetic factors on flowering time in sorghum.

**Table (2) Effect of chitosan on the number of days from planting to 50% flowering in sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	68.44	69.11	d 68.77
J	71.77	70.00	cd 70.88
Buhooth	81.11	78.33	a 79.72
Giza	75.44	72.44	bc 73.94
Rabih	79.89	76.67	ab 78.28
Khair	70.89	68.00	d 69.44
Inqadh	79.00	78.89	ab 78.94
Average	a 75.40	b 72.60	74 G.M.=



### 2.3. Number of days from 50% flowering to physiological maturity (days)

The results of the statistical analysis revealed that chitosan treatment, varieties, and their interaction had a significant effect on the number of days from 50% flowering to physiological maturity in sorghum (Table 3).

Chitosan seed soaking (C1) significantly reduced the duration of this stage compared with the control treatment (C0). The shortest mean value was recorded under chitosan treatment (35.36 days), whereas the control recorded the highest mean value (37.64 days). This reduction may be attributed to the role of chitosan in enhancing physiological activity and improving the efficiency of assimilate utilization, which accelerates grain filling and consequently shortens the period required to reach physiological maturity. (Bakhoum et al., 2022)

With respect to varieties, significant variation was observed among genotypes. The Lilo cultivar recorded the shortest duration (30.61 days), indicating faster completion of the post-flowering stage. In contrast, the Giza cultivar recorded the longest duration (40.17 days), followed closely by the Buhooth cultivar (40.11 days), with no significant differences between them. These variations are likely due to genetic differences among varieties and their differential responses to environmental conditions during the reproductive phase. Similar findings were reported by Fadeyi et al. (2025), who emphasized the influence of genotype on maturity-related traits.

Regarding the interaction between chitosan and varieties, a significant interaction effect was observed. The combination of chitosan treatment with the Lilo cultivar resulted in the shortest duration (30.22 days), which was not significantly different from the control × Lilo combination (31.00 days). In contrast, the longest duration was recorded in the control × Buhooth combination (41.67 days), followed closely by control × Giza (41.22 days), with no significant difference between them. This interaction indicates that varieties differ in their responsiveness to chitosan application in terms of accelerating physiological maturity.

**Table (3) Effect of chitosan on the number of days from 50% flowering to physiological maturity in sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	g 31.00	g 30.22	e 30.61
J	abc 39.89	bcd 38.67	ab 39.28
Buhooth	a 41.67	bcd 38.55	a 40.11
Giza	a 41.22	abc 39.11	a 40.17
Rabih	efg 34.11	fg 33.67	d 34.89
Khair	bcd 38.78	cd 38.22	b 38.83
Inqadh	ef 35.56	fg 32.78	d 34.17
Average	a 37.64	b 35.36	36.5 G.M.=

### 3.3. Plant Height (cm)

The analysis of variance indicated significant differences among chitosan treatments, varieties, and their interaction for plant height (Table 4)

Chitosan seed soaking (C1) significantly increased plant height compared with the control treatment (C0). The highest mean plant height was recorded in the chitosan treatment (122.57 cm), whereas the control recorded the lowest value (110.55 cm). This improvement may be attributed to the role of chitosan in enhancing nutrient uptake efficiency, stimulating enzymatic activities related to growth, and improving plant tolerance to environmental stresses, which collectively promote better vegetative development. Tian et al. (2021).



Significant variation was also observed among varieties. The Lilo cultivar recorded the tallest plants (128.98 cm), with no significant difference compared to the Giza cultivar (128.19 cm), while the J cultivar showed the shortest plants (101.31 cm). These differences reflect the genetic variability among sorghum varieties, which influences growth potential and adaptability. Similar findings were reported by (Al-Taher et al. 2012 ; Hasoni, 2021), who emphasized the genetic control of plant height in sorghum.

Regarding the interaction effect, significant differences were observed among treatment combinations. The highest plant height (135.67 cm) was recorded in the Giza cultivar under chitosan treatment, whereas the lowest value (98.41 cm) was observed in the J cultivar under the control treatment. This variation indicates that varieties differ in their response to chitosan application, highlighting the importance of genotype × treatment interaction in determining plant growth performance.

**Table (4) Effect of chitosan on plant height in sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	c 123.52	a 134.44	a 128.98
J	h 98.41	gh 104.21	d 101.31
Buhooth	fg 108	efg 109.55	c 108.78
Giza	c 120.72	a 135.67	a 128.19
Rabih	111.7 def	c 122.30	b 116.99
Khair	gh 103.74	b 127.16	b 115.45
Inqadh	fg 107.78	bc 124.67	b 116.22
Average	b 110.55	a 122.57	116.56 G.M.=

#### Number of leaves (leaf plant<sup>-1</sup>)4.3

The analysis of variance revealed significant differences among chitosan treatments, varieties, and their interaction for the number of leaves per plant (Table 5)

Chitosan seed soaking (C1) significantly increased the number of leaves compared with the control treatment (C0). The highest mean value was recorded under chitosan treatment (15.59 leaves plant<sup>-1</sup>), whereas the control treatment recorded the lowest value (14.40 leaves plant<sup>-1</sup>). This increase may be attributed to the role of chitosan in stimulating enzymatic activities involved in metabolic processes, enhancing cell division, and promoting leaf development, which ultimately leads to an increase in leaf number (Chibu et al., 2000 ; Ávila et al., 2023)

Significant variation was also observed among varieties. The Lilo cultivar recorded the highest mean number of leaves (16.39 leaves plant<sup>-1</sup>), closely followed by the Giza cultivar (16.55 leaves plant<sup>-1</sup>), with no significant differences between them. In contrast, the Rabih cultivar recorded the lowest value (13.78 leaves plant<sup>-1</sup>). Other varieties, including J, Buhooth, and Khair, showed intermediate values ranging from 13.87 to 14.55 leaves plant<sup>-1</sup>. These differences reflect genetic variability among varieties, which influences vegetative growth potential.

Regarding the interaction effect, a significant difference was observed among treatment combinations. The highest number of leaves (18.00 leaves plant<sup>-1</sup>) was recorded in the Lilo cultivar under chitosan treatment, whereas the lowest value (13.40 leaves plant<sup>-1</sup>) was observed in the Khair cultivar under the control treatment. These results indicate that varieties differ in their responsiveness to chitosan application, highlighting the importance of genotype × treatment interaction in determining vegetative growth performance.

**Table (5) Effect of chitosan on the number of leaves in sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	14.78 bc	18.00 a	a 16.39
J	14.00 c	15.10 bc	b 14.55
Buhooth	13.67 c	14.07 c	b 13.87
Giza	16.43 ab	16.67 ab	a 16.55
Rabih	13.56 c	14.00 a	b 13.78
Khair	13.40 c	15.67 abc	b 14.53
Inqadh	14.98 bc	15.60 abc	ab 15.29
Average	b 14.40	a 15.59	14.99 G.M.=

### Stem diameter (mm)5.3

The analysis of variance indicated significant differences among chitosan treatments and varieties for stem diameter, whereas the interaction between them was not significant (Table 6).

Stem diameter plays an important role in plant growth by reflecting the development of vascular bundles and conductive tissues, which enhance the transport of water and nutrients absorbed by the roots. Therefore, it is considered a reliable indicator of vegetative growth and plant response to environmental and agronomic conditions.(Nkuna, 2022)

The results showed that chitosan seed soaking significantly increased stem diameter compared with the control treatment. The highest mean value was recorded in the chitosan treatment (13.39 mm), while the control treatment recorded the lowest value (12.69 mm). This improvement may be attributed to the role of chitosan in enhancing photosynthetic activity, which is reflected in improved vegetative growth traits such as plant height, leaf number, and stem thickness. In addition, chitosan may influence the activity of plant growth regulators such as gibberellic acid (GA<sub>3</sub>) and zeatin, thereby promoting cell division and stem development (Hidangmayum et al., 2019 ; Hasoni, 2021).

Significant variation was also observed among varieties. The Inqadh cultivar recorded the highest stem diameter (14.86 mm), outperforming the other varieties, whereas the Buhooth cultivar recorded the lowest value (12.29 mm), with no significant differences compared with J, Buhooth, Rabih, and Khair varieties. These differences can be attributed to genetic variability among varieties, particularly in their ability to form vascular tissues and cambial activity, as well as differences in photosynthetic efficiency and biomass accumulation, which ultimately influence stem thickness.

**Table (6) Effect of chitosan on stem diameter in sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	12.15	12.55	c 12.35
J	12.75	12.83	c 12.79
Buhooth	12.00	12.26	c 12.29
Giza	12.93	14.25	b 13.42
Rabih	12.37	13.00	c 12.68
Khair	12.51	12.72	c 12.61
Inqadh	13.78	15.93	a 14.86
Average	b 12.69	a 13.39	13.04 G.M.=



### 6.3. Leaf area (cm<sup>2</sup>)

The analysis of variance revealed significant differences among chitosan treatments, varieties, and their interaction for leaf area (Table 7)

Chitosan seed soaking (C1) significantly increased leaf area compared with the control treatment (C0). The highest mean value was recorded under chitosan treatment (4692.14 cm<sup>2</sup>), whereas the control recorded the lowest value (3556.28 cm<sup>2</sup>). This increase may be attributed to the role of chitosan in stimulating cell division and cell elongation, regulating hormonal balance, and improving photosynthetic efficiency. In addition, enhanced water and nutrient uptake under chitosan treatment contributes to improved vegetative growth and greater leaf expansion. These findings are in agreement with Rojas-Pirela et al. (2024), who reported that chitosan acts as a biostimulant that enhances leaf expansion through improved photosynthetic performance and hormonal regulation.

Significant variation was also observed among varieties. The Giza cultivar recorded the highest leaf area (5627.7 cm<sup>2</sup>), with no significant difference compared with the Buhooth cultivar (5469.8 cm<sup>2</sup>). In contrast, the J cultivar recorded the lowest value (2536.7 cm<sup>2</sup>), followed closely by the Khair cultivar (2650.6 cm<sup>2</sup>), with no significant differences between them. These differences may be attributed to the superiority of the Giza cultivar in plant height (Table 4) and number of leaves (Table 5), which directly contributed to a larger total leaf area. Similar results were reported by Al-Shammari (2019), who emphasized the relationship between vegetative growth traits and leaf area development.

Regarding the interaction effect, a significant difference was observed among treatment combinations. The highest leaf area (6195.7 cm<sup>2</sup>) was recorded in the Giza cultivar under chitosan treatment, followed by the Buhooth cultivar under chitosan treatment, with no significant difference between them. In contrast, the lowest value was recorded in the J cultivar under the control treatment (2033.7 cm<sup>2</sup>). These results indicate that chitosan application enhances leaf development across varieties, with variable responses depending on the genetic background.

**Table (7) Effect of chitosan on the leaf area of sorghum varieties**

Chitosan Varieties	Control C0	Chitosan Soaking C1	Average
Lilo	gh 2799.5	de 4215.8	d 3507.7
J	i 2033.7	fg 3039.6	e 2536.7
Buhooth	cd 4799.0	a 6140.5	5469.8 a
Giza	bc 5059.7	a 6195.7	a 5627.7
Rabih	e 4094.1	bc 4987.8	b 4540.9
Khair	hi 2379.3	gh 2922.0	e 2650.6
Inqadh	de 4174	b 5491.7	b 4832.8
Average	b 3556.28	a 4692.14	G.M.= 4124.21

## IV. Conclusion

The present study demonstrated that chitosan seed soaking had a positive and significant effect on the vegetative growth and phenological traits of sorghum varieties under field conditions. Chitosan application enhanced plant growth performance by improving physiological processes such as nutrient uptake, photosynthetic efficiency, and hormonal regulation, which resulted in increased plant height, leaf number, leaf area, stem diameter, , as well as a reduction in the duration of day growth stages.

Considerable genetic variation was observed among the studied varieties, indicating that sorghum genotypes differ in their growth potential and adaptability to environmental conditions. Moreover, the significant interaction between chitosan treatment and varieties in most traits highlights the importance of genotype-specific responses to biostimulant application.



It can be concluded that chitosan is an effective and environmentally friendly biostimulant for improving sorghum vegetative growth. However, the efficiency of its application largely depends on cultivar selection. Therefore, integrating suitable varieties with chitosan seed priming can be considered a promising strategy to enhance sorghum productivity under field conditions.

## V. References

**Al-Shammari, Ali Hussein Awad. 2019.** Growth and Yield Response of Sorghum bicolor L. (Moench) Varieties to Nano-Zinc and Copper Foliar Application. Master's Thesis. College of Agriculture – University of Basrah.

**Al-Taher, Faisal Mahbas, Shaima Ibrahim Al-Rifai, and Mahdi Saleh Al-Zarkani. 2012.** Response of (*Sorghum bicolor* L. Moench) genotypes to different growing locations and seasons. Thi Qar Scientific Journal of Agriculture: 8. 1-14.

**Bakhoum, G.; Sadak M.; and Tawfic M. 2022.** Chitosan and chitosan nanoparticle effect on growth, productivity and some biochemical aspects of *Lupinus termis* L. plant under drought conditions. Egypt Journal Chemistry 65(5): 537-49.

**Chibu, H.; Shibayama H.; Mitsutomi M. and Arima S. 2000.** Effects of chitosan application on growth and chitinase activity in several crops. Marine and Highland Bioscience Center Report, 12, 27-35.

**Hamad, M. A. and ADagash, Y. M. I. 2017.** Phenology, growth and yield of some sorghum (*Sorghum bicolor* (L.) Moench) genotypes under irrigated condition at sinnar. Journal of Agricultural and Veterinary Sciences. Vol. 18, no2.-2017.

**Hasoni, Ali Adnan. 2021.** Effect of irrigation intervals on the growth and yield of sorghum varieties (*Sorghum bicolor* (L.) Moench) and associated weeds. Master's thesis, College of Agriculture, University of Basra.

**Hidangmayum, A.; P. Dwivedi; D. Katiyar and A. Hemantaranjan .2019.** Application of Chitosan on Plant Responses with Special Reference to Abiotic Stress. Physiology and Molecular Biology of Plants. 25(2): 313-326.

**Hongxiang Zheng, Yingying Dang and Na Sui. 2023.** Sorghum: A Multipurpose Crop. Review J Agric Food Chem. Nov 22;71(46):17570-17583.

**Kaviya Thennarasu, Ramah Kandasamy, Sakthivel Nalliappan, Sivasakthivelan Panneerselvam & Senthilvalavan Pitchamuthu. 2025.** Impact of biostimulants on crop growth and soil health - A review . Plant Science Today, ISSN 2348-1900 (online).

**Mastu Pate, Rubina Gill, Prasann Kumar, Ramandeep Singh and Umesh Kumar Singh.2025.** Impact of Various Nutrient Management Technique on Growth, Yield and Quality Attributes of Sweet Sorghum (*Sorghum bicolor* L.). Agricultural Science Digest - A Research Journal .DOI:10.18805/ag.D-6313.

**Maura Rojas-Pirela, Petronia Carillo, Cristo´ bal La´ rez-Vela´ squez and Gianfranco Romanazzi. 2024.** Effects of chitosan on plant growth under stress conditions: similarities with plant growth promoting bacteria. ront. Plant Sci., 08 November. REVIEW article.

**Moutoshi Chakraborty , Mirza Hasanuzzaman, Mahfuzur Rahman, Md. Arifur Rahman Khan, Pankaj Bhowmik, Nur Uddin Mahmud, Mohsin Tanveer and Tofazzal Islam .2020.** Mechanism of Plant Growth Promotion and Disease Suppression by Chitosan Biopolymer. Agriculture 2020, 10, 624.

**Nisreen, S., & Sherzad, N. 2024.** Comparative study of varieties and nutrient response in Sorghum bicolor under environmental conditions. University of Kirkuk Journal for Agricultural Sciences.

**Nkuna, M. 2022.** The effect of chitosan in the germination and growth of sorghum bicolor. MSc Thesis, University of the Western Cape (Updated data).



**Olasupo James Fadeyi, Thomas Oladeji Fabunmi, Victor Idowu, Olugbenga Olowe and Christopher Olu Adejuyigbe. 2025.** Agronomic responses of selected improved sorghum [*Sorghum bicolor* (L.) Moench] varieties to scheduled water stress. *Discover Agriculture*. 3:230.

**Roniel Geraldo Ávila, Paulo César Magalhães, Luciana Cristina Vitorino, Layara Alexandre Bessa, Kamila Rezende Dázio de Souza, Raphael Barros Queiroz, Adriano Jakelaitis and Marconi Batista Teixeira. 2023.** Chitosan Induces Sorghum Tolerance to Water Deficits by Positively Regulating Photosynthesis and the Production of Primary Metabolites, Osmoregulators, and Antioxidants. *Journal of Soil Science and Plant Nutrition* 23:1156–1172

**S. E. MANANZE, I. PÔÇAS and M. CUNHA. 2018.** Maize Leaf Area Estimation in Different Growth Stages Based on Allometric Descriptors. *African Journal of Agricultural Research* 13(4):202-209.

**Tian, Z.; Wang J. W.; Li J. and Han B. 2021.** Designing future crops: challenges and strategies for sustainable agriculture. *The Plant Journal*, 105(5), 1165-1178.

**Xia Wang, Maolin He, Xueli Wang, Song Liu, Lin Luo, Qin Zeng, Yangjin Wu, Yinan Zeng, Zhonglin Yang, Guoqiang Sheng, Ping Ren, Han Ouyang and Rong Jia. 2024.** Emerging Nanochitosan for Sustainable Agriculture. *Int. J. Mol. Sci*.

