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RESEARCH ARTICLE

Response of growth and yield of several sorghum varieties to plant density

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Abstract

The research was conducted in a farmer's field in Ramadi city, Anbar Governorate, during the spring and fall seasons of 2024 using a Randomized Complete Block Design (RCBD) with four replications and a split-plot arrangement, four genotypes of sorghum were used: “Rabeh,” “Kafer,” “Giza 113,” and “Inqath,” under three plant densities: 57.14 thousand plants ha^{-1}, 71.43 thousand plants ha^{-1} and 95.24 thousand plants ha^{-1}. Yield characteristics and components of sorghum were studied in terms of performance and variations. The results showed significant differences between varieties and plant densities, as the “Rescue” genotype was superior in grain yield, as the yield reached 6.37 Mgh^{-1} in the spring season and 7.67 Mgh^{-1} in the fall season. The “Inqath” variety also excelled in the number of grains per head, as it gave 2552 grains in the spring season and 2801.3 grains in the autumn season. Plant density had a significant effect on most traits in both the spring and fall seasons, while the interaction between plant density and genetic composition was significant in most of the traits studied. We conclude from this that most of the yield components in sorghum are more influenced by genetic factors. Therefore, the number of grains per head and grain weight can be relied upon as the main criteria in evaluating the grain yield of this crop. These characteristics accurately reflect the response of different varieties to environmental conditions and the interactions between them and plant density.

Keywords: anatomical structure; ascorbic acid; *Glycine max*; irrigation interval

Introduction

Sorghum (*Sorghum bicolor* L.) occupies an advanced position among agricultural crops globally, coming in fifth place in terms of productivity and area after wheat, rice, maize and barley. Sorghum is mainly used in the feed industry and is characterized by a high percentage of protein in its grains, which reaches about 12 %. In addition, sorghum is a crop that tolerates salinity and high temperatures, making it able to grow in harsh environments without significantly affecting its productivity. Despite this importance, the average productivity of sorghum in Iraq is still low compared to global production. According to available data for 2022, the average grain production of sorghum in Iraq does not exceed 0.33 Mgh^{-1}, while global production reached 1.30 Mgh^{-1}. This decline in production is due to several factors, most notably the lack of high-yielding genetic compositions, in addition to other problems related to soil service methods and crop management in general. (1, 2). Plant density is considered one of the most important agricultural processes that greatly affects grain yield, as increasing plant density, if appropriate environmental conditions for growth are available, leading to an increase in grain yield. Reaching the optimum density that gives the highest mean productivity of grain yield is one of the basic goals in improving productivity (3).

The mean yield of this crop can be increased by achieving an appropriate match between the genetic makeup of the crop, the surrounding environmental conditions and the appropriate plant density. Increasing grain yield per unit area depends on the interaction of several factors and plant and physiological characteristics, which together contribute to improving production. This includes the interaction between different physiological processes and the extent to which they affect plant growth and development during its life cycle (4, 5)

Understanding the interrelationship between grain yield, its components and related physiological processes is vital in improving agricultural productivity. The research aimed to study the response of four varieties of sorghum to plant density variables, with the aim of determining the most responsive variety and the best plant density that achieves the highest productivity per unit area. Through this study, the effect of plant density on crop growth and grain yield is evaluated, with the aim of reaching the optimal combination between variety and plant density that enhances productivity, which contributes to improving the sustainability and increasing the production of sorghum in agricultural areas.

Materials and Methods

A field experiment was carried out in the spring and fall seasons of 2024 in a farmer's field in Ramadi city, Anbar Governorate, using a three-block RCBD and a split-plate arrangement. The secondary panels were occupied by four varieties of sorghum: (Rabeh, Kafer, Giza 113 and Inqath), While the main panels were allocated to three plant densities: 57.14 thousand plants ha^{-1}, 71.43 thousand plants ha^{-1} and 95.24 thousand plants ha^{-1}, at a distance of 70 cm between the lines and with distances of 25 cm, 20 cm and 15 cm between plants.

The field was divided into experimental units with an area of 9 m^2 (3×3 m) each. The planting date was 4/1/2024 for the spring season and 7/20/2024 for the fall season. The experiment was applied in a silty clay mixture soil in the fields of a farmer in the city of Ramadi. A random soil sample was taken from the experimental site before planting to determine some of its chemical and physical properties (Table 1). The land plowed and smoothed, then dab fertilizer (48 % P) was spread at an average of 200 kg ha^{-1} and urea fertilizer (46 % N) at an average of 240 kg ha^{-1}in two batches. Weeding and irrigation were carried out as needed. (6). A study of the desired traits was conducted by selecting random samples of ten plants from the two midlines in each experimental unit.

Characters of the study

1-Number of days from planting to 50 % flowering.

2-Plant height (cm) was measured after flowering was complete and was measured from the soil surface to the base of the head node.

3-The number of grains per head.

4-Weight of 1000 grains (gm)

5-Grain yield (Mg ha^{-1}). The calculation was made for the total heads of ten plants, then the average individual plant yield was calculated, then the yield was calculated according to the plant density for each experimental unit and from the two middle lines.

Table 1. Some chemical and physical properties of the experimental soil before planting

Soil properties	Unit	Value
(O.M)	%	0.75
$CaSO_4$	%	1.21
$CaCO_3$	%	21.88
(N)		109
(P)	μg. . kg^{-1}	7.97
(K)		137
Sand		536
Clay	g . kg^{-1} .soil	304
Silt		160
Texture		**Sandy clay**

The data were analyzed statistically for the traits studied by analysis of variance. The means were compared using the Least Significant Difference (LSD) at the 5 % probability level (7).

Results and Discussion

Number of days from planting to 50 % flowering

The study indicates that the duration of days required to reach 50 % flowering varies depending on the genetic makeup and plant density. According to the results of Table 2, the "Giza 113" genotype outperformed the rest of the genotypes in achieving the lowest mean number of days to flower, as it took 60.27 days in the spring season and 57.83 days in the fall season. As for plant density, the low density (57.14 thousand plants ha^{-1}) showed fewer mean days for flowering, as it took 66.55 days in the spring season and 60.90 days in the fall season.

On the other hand, high density (95.24 thousand plants ha^{-1}) was associated with the highest mean number of days to flowering for both seasons, which indicates that flowering is significantly affected by plant density. The interaction between genotypes and plant density showed a significant effect, as an increase in the number of days to flowering was observed as plant density increased, with different behavior between genotypes. Despite the increase in plant density, the "Giza 113" variety remained the fastest in flowering, as it took 59.40 days in the spring season and 56.60 days in the fall season when the density was low. This suggests that flowering is influenced by several factors such as genotype and plant density, as well as the interplay of light and temperature, which play a major role in controlling the timing of flowering. The delay in flowering with increasing plant density aligns with previous findings (8-10), which emphasized that limited light availability in dense stands affects hormonal balance and delays floral initiation. The genotype "Giza 113" maintained early flowering under low density, confirming the strong role of genetic control over flowering timing. These results validate the interaction of plant density and genotype in controlling phenological traits.

The interaction between genotype and plant density had a significant effect on the number of days it took the plant to reach 50 % flowering, in both the spring and fall seasons. The results showed that the "Giza 113" genotype was superior in achieving the lowest number of days to flower when planted at a low plant density, as it took 59.40 days in the spring season and 56.60 days in the fall season. This shows that 'Giza 113' was more induced to flower quickly compared to the other genotypes and that this interaction

Table 2. Response of varieties to the effect of plant densities on the number of days from planting to 50 % flowering of sorghum in the spring and fall seasons of 2024

Genotypes	Spring season: Plant density, thousand plants h^{-1}				Fall season: Plant density, thousand plants h^{-1}			
	57.14	71.43	95.24	Means	57.14	71.43	95.24	Means
Rabeh	67.50	69.10	70.20	68.93	60.50	62.10	62.40	61.67
Kafer	69.10	69.40	70.70	69.73	62.20	63.30	65.20	63.57
Giza 113	59.40	60.50	60.90	60.27	56.60	57.70	59.20	57.83
Inqath	70.20	70.13	71.40	70.58	64.30	65.80	67.20	65.77
Means	66.55	67.28	68.30		60.90	62.23	63.50	
LSD 5%	G	P.D.	G × P.D.		G	P.D.	G × P.D.	
	1.11	0.58	1.17		1.81	1.53	3.04	

between the genotype (Giza 113) and the (low) plant density led to a reduction in the number of days needed to reach flowering. These results are also consistent with what was mentioned in the referenced source, which means that this phenomenon has been confirmed in previous studies (11).

Plant height

The availability of solar radiation affects plant growth, especially in crops with limited growth such as sorghum. According to the study, plant height in crops such as sorghum is determined by the appearance of the head, which is influenced by genetic makeup and available growth factors. According to the results mentioned in Table 3, the highest mean plant height was recorded in the Rabeh cultivar, which reached 1167.20 cm in the spring season and 185.47 cm in the fall season. The data also indicates that increasing plant density from 57.14 to 95.24 thousand plants ha^{-1} led to an increase in plant height by 8.5 % in the spring season and 2.39 % in the fall season. The reason for this increase is due to the distortion resulting from the high density, which leads to the elongation of the internodes in the plant. This phenomenon supports what was mentioned by the source (10), where he explained that increasing plant density leads to an increase in plant height until the density reaches 100 thousand plants ha^{-1}, but after this point, growth stops due to a decrease in photosynthesis because of a lack of light reaching the plants. The increase in dry matter is due to the plant's ability to efficiently absorb light, which is vital for dry matter production. If the plant leaves can receive enough solar radiation, it enhances the overall growth of the plant (12, 13) Increased plant density: leads to plants competing for light. Initially, this can stimulate more growth (as in the case of high density), But upon reaching certain density (100 thousand plants ha^{-1}), fogging can have a negative effect on growth, limiting the increase in height due to lack of light. The effect of the interaction between genotypes and plant density on plant height.

The results showed that the "Giza 113" genotype was superior in giving the highest height when planted at a high density of 95.24 thousand plants. ha^{-1}in both seasons (spring and fall). The average plant height reached 138.5 cm in the spring season and 174.3 cm in the fall season. This relationship is because of high plant density on the light reaching the plant. At higher density, the plant experiences greater shade, reducing the amount of light reaching its leaves. As a result of this misleading, there is an increase in the level of auxin in the stems, which is a growth hormone that helps in elongating cells and thus increasing the height of the plant. Auxin: It is a plant hormone that stimulates the elongation of cells in the stems and high levels in the stems directly affect the increase in height. High plant density When plant density is high, the amount of light reaching the plants decreases, which stimulates increased auxin levels in the stems to stimulate vertical growth (increase in height) to compensate for the lack of light. The increase in height in the "Giza 113" genotype at high density reflects the genetic response to growth in a way that is strongly influenced by plant density. An increase in auxin because of reduced light also causes stems to elongate, which explains why plant height increases in conditions of high density, although high density may also reduce plant growth in other respects due to lack of light. Overall, these results demonstrate the importance of the interaction between genotype and plant density in determining plant height and illustrate how density affects the vegetative growth of plants through modification of auxin levels in stems .(24 ,23 ,18 ,14)

Number of grains per head

The results of Table 4 indicate the response of the "Inqath" variety in giving the highest mean number of grains per head, which reached 2552 and 2801.3 grains in the spring and fall seasons, respectively. The results show an increase of 11.6 % in the spring season and 2.9 % and 2.1 % compared to the varieties "Rabeh", "Kafer" and "Giza 113", respectively. In the fall season, the increase was 12.2 %, 2.9 % and 5.7 % compared to the same varieties. We also notice from the table that there was a significant increase in the number of grains per head with increasing plant density, as the high plant density gave the highest mean of 2662.3 and 2835 grains in the spring and fall seasons, respectively, compared to the low density which gave the lowest mean of 2242.3 and 2498.5 grains per year. Same two seasons. As for the interaction of

Table 3. Response of varieties to the effect of plant densities on plant height of sorghum in the spring and fall seasons of 2024

Genotypes	Spring season Plant density, thousand plants h^{-1}				Fall season Plant density, thousand plants h^{-1}			
	57.14	71.43	95.24	Means	57.14	71.43	95.24	Means
Rabeh	161.3	167.9	172.4	167.20	183.9	185.7	186.8	185.47
Kafer	111.7	114.3	117.7	114.57	142.5	143.8	145.4	143.90
Giza 113	129.5	134.4	138.5	134.13	168.7	172.9	174.3	171.97
Inqath	120.9	122.5	126.4	123.27	165.5	167.3	169.4	167.40
Means	130.85	134.78	138.75		165.15	167.43	168.98	
LSD 5%	G	P.D.	G × P.D.		G	P.D.	G × P.D.	
	5.11	7.41	14.33		5.30	3.6	7.21	

Table 4. Response of varieties to the effect of plant densities on the number of grains per head of sorghum in the spring and fall seasons of 2024

Genotypes	Spring season Plant density, thousand plants h^{-1}				Fall season Plant density, thousand plants h^{-1}			
	57.14	71.43	95.24	Means	57.14	71.43	95.24	Means
Rabeh	2081	2299	2491	2290.3	2286	2567	2642	2498.3
Kafer	2325	2486	2645	2485.3	2571	2725	2892	2729.3
Giza 113	2233	2532	2738	2501.0	2503	2619	2840	2654.0
Inqath	2330	2551	2775	2552.0	2634	2804	2966	2801.3
Means	2242.3	2467.0	2662.3		2498.5	2678.7	2835.0	
LSD 5%	G	P.D.	G × P.D.		G	P.D.	G × P.D.	
	162.05	101.11	N. S		150.9	99.21	198.64	

genotypes with plant densities, the results were not significant in the spring season, which indicates that the behavior of the genotypes was in the same direction with increasing plant density, that is, the greater the plant density, the greater the mean number of grains per head for all varieties, which This means that the two factors (genetic structure and plant density) were independent in their response to the trait. The "Inqath" variety recorded the highest number of grains per head in both seasons, align with the overall findings of the study indicating that grain yield components are predominantly influenced by genetic factors. Despite the observed effect of increasing plant density on grain number, the non-significant interaction between genotype and plant density in the spring season supports the conclusion that genotype and density act independently in influencing this trait. This reinforces the study's conclusion that grain number per head can serve as a reliable selection criterion in yield evaluation, especially since the genetic contribution remains consistent across varying densities.

Weight 1000 Grain

Grain weight is one of the main components that affect crop yield, as grain formation and filling begin quickly after fertilization and approximately three- quarters of the dry weight of the grain accumulates at the end of the dough phase (19). The results of Table 5 indicate the response of the varieties to the weight of 1000 grains, where the variety "Kaffir" excelled in giving the highest mean for the weight of 1000 grains, which reached 24.60 g in the spring season. While the variety "Rabeh" obtained the lowest mean for the trait, reaching 22 g in the same season, 60 g in the spring season. While the variety "Rabeh" obtained the lowest mean for the trait, reaching 22 g in the same season. As for the fall season, the superiority of the "Kaffir" variety continued to give it the highest mean amounting to 28.64 g, with no significant difference between it and the "Giza 113" variety. While the "Rabeh" variety recorded the lowest mean amounting to 25.29 g. (19-22). It is also noted from the table that there was a significant increase in the weight of 1000 grains with increasing plant density, as low plant density gave the highest mean grain weight, reaching 20.04 and 28.16 grams in the spring and fall seasons, respectively. Compared to high density, which gave a lower mean of 22.40 and 27.09 g in the same two seasons. This is because increasing plant density leads to a decrease in grain weight due to competition for raw materials, which leads to a decrease in the number of endosperm cells and their starchy granules. While the number of cells increases with photosynthesis, which enhances the production of manufactured materials and thus positively affects the weight of the grain (23-25), The results indicate that there is a significant difference between the genotypes and plant densities, as the "Kaffir" genotype showed an optimal response with the plant density of 54.14 thousand plants ha-^{1}, which gave the highest 1000 grain weight of 25.20 and 29.30 g in the spring and fall seasons, respectively. While the "Rabeh" variety with plant density of 95.24 thousand plants ha^{-1} gave the lowest mean for grain weight, reaching 21.40 and 25.15 g in the spring and fall seasons, respectively.

Grain yield (Mgh^{-1})

The effect of genetic composition and plant density on grain yield in crops and demonstrated the importance of these factors in improving agricultural productivity. The text explains how plant breeders seek to increase grain yield per unit area by selecting the best genotypes and following scientific agricultural processes, including controlling plant density. The "Save" genotype outperformed the grain yield in the spring season. The "Save" variety was "It is the highest in grain yield, it reached 6.37 Mgh^{-1} and was not significantly different from the "Giza 113" variety. As for "Rabeh," it was lower, as its grain yield reached 4.58 Mgh^{-1}. In the fall season, "Inqaz" achieved the highest grain yield of 7.68 Mgh^{-1}. This superiority is since it provided the highest mean grain per head, which reflects the effect of genetic composition on yield. As for "Rabeh," it provided the lowest yield in the fall season, 5.76 Mgh^{-1} (26-29). As for the effect of plant density on yield, increasing plant density from 57.14 thousand plants. ha^{-1} to 95.24 thousand plants. ha^{-1} led to a significant increase in yield. In the spring season, the increase in yield was 8.34 % compared to the density of 71.43 thousand plants. ha^{-1} and 17.97% compared to the density of 57.14 thousand plants. ha^{-1}. In the fall season, the increase in yield at high density was 6.9% compared to the density of 71.43 thousand plants. ha^{-1} and 18.5 % compared to the density of 57.14 thousand plants. ha^{-1}.

Difference in response between genotypes, it can be noted that the difference in response of genotypes results from the difference in their genetic makeup, which leads to variation in yield even in the same environmental conditions. For example, 'Inqth' clearly excels in yield due to its genetic makeup that helps it produce better grains. Effect of plant density, Plant density greatly affects grain yield, as increasing density leads to increased competition between plants for light and nutrients, which can stimulate faster and larger growth (30, 31). However, this effect also requires the availability of appropriate environmental conditions such as water and nutrients. These results are consistent with what was reported by previous studies that confirmed that increasing plant density leads to an increase in grain yield per unit area, especially if the environmental conditions are suitable for growth at high density, plants are closer

Table 5. Response of varieties to the effect of plant densities on the weight of 1000 grains (g) of sorghum in the spring and fall seasons of 2024

Genotypes	Spring season Plant density, thousand plants h^{-1}				Fall season Plant density, thousand plants h^{-1}			
	57.14	71.43	95.24	Means	57.14	71.43	95.24	Means
Rabeh	22.60	22.01	21.40	22.00	25.37	25.36	25.15	25.29
Kafer	25.20	24.91	23.70	24.60	29.30	28.41	28.22	28.64
Giza 113	23.70	23.43	21.77	22.97	29.10	28.51	27.92	28.51
Inqath	24.67	24.15	22.71	23.84	28.85	27.81	27.09	27.92
Means	24.04	23.62	22.40		28.16	27.52	27.09	
LSD 5%	G 1.28	P.D. 1.11	G × P.D. 2.25		G 2.04	P.D. 1.02	G × P.D. 2.06	

together, increasing competition for resources, but if other factors such as water and light are sufficient, this competition may lead to increased production (32-36). The interaction between genotypes and plant density had a significant effect on yield in both seasons (spring and fall). It appears that the "Inqath" variety was superior in yield when using high plant density, compared to the "Rabeh" variety when using low density. In the spring season, the "Inqath" variety at high density (95.24 thousand plants. ha^{-1}) achieved the highest yield of 6.91 $Mgha^{-1}$.

The percentage increase in yield for "Inqath" was more than for "Rabeh" at low density (57.14 thousand plants ha^{-1}) by 57.4 %. As for the fall season, the variety "Inqath" at high density achieved the highest yield of 8.29 Mgh^{-1} and the percentage increase in yield at "Inqath" compared to "Rabeh" at low density was 57.6 % The effect of the interaction between genetic structure and plant density: The results in Table 6 showed that the "Inqath" was more responsive to high density in both seasons compared to "Rabeh." Whereas increasing plant density in the case of "rescue" led to a significant increase in grain yield, while "Rabeh" was less responsive to this interference, the reason for the increase in yield, when plant density increases, competition between plants for light and nutrients increases. In the case of 'rescue', the genetic makeup of this variety may be better adapted to the conditions created by high density, allowing it to achieve a significant increase in yield. While the 'Rahab' variety may not be able to benefit as much from this increase in density. High density may lead to an increase in plant height due to shading, which may help improve the use of available resources (such as light and nutrients), especially in genotypes that are well adapted to these conditions. The interaction between genotype and plant density has a significant effect on increasing yield. The success of this increase depends on genetic ability for plants to respond to changes in plant density, "Salvation" showed outstanding performance with high density in both seasons, while "Rabeh" was less responsive. The significant yield increase of "Inqath" under high plant density compared to "Rabeh" at low density (by 57.4 % and 57.6 % in spring and fall, respectively) confirms the strong genotype × plant density interaction. These findings support the conclusion drawn in the current study that genetic background plays a key role in sorghum's ability to exploit denser planting conditions. The superior performance of "Inqath" can be attributed to its genetic ability to maintain higher grain number and better resource utilization under competition, which aligns with earlier results e.g., (26,27,29) showing that optimal genotypes can benefit significantly from increased density when environmental factors are favorable. In contrast, "Rabeh" displayed limited adaptability under such stress, indicating that genotypic selection for high-density tolerance is essential for maximizing yield in sorghum.

Conclusion

Genetic composition plays a major role in determining yield, as varieties such as "Salvage" can excel in grain production thanks to their good genetic composition. Plant density positively affects grain yield per unit area, especially when environmental conditions are appropriate. However, there is a limit to the effect of intensity, as too much intensity can reduce the amount of light available to plants Which limits their benefit from the photosynthesis process. In general, the importance of choosing appropriate genetic compositions and determining the optimal plant density emerges as decisive factors in increasing grain yield and achieving high productivity in agriculture. The interaction between genetic composition and plant density has a significant effect on increasing yield, The success of this increase depends on the genetic ability of plants to respond to changes in plant density. "Rescue" showed outstanding.

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Authors' contributions

BMA, ZAA, ASAR wrote the article and designed it.

Compliance with ethical standards

Conflict of interest: None

Ethical issues: None

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Table 6. Response of varieties to the effect of plant densities on Grain yield ($Mg.h^{-1}$) of sorghum in the spring and fall seasons of 2024

Genotypes	Spring season: Plant density, thousand plants h^{-1}				Fall season: Plant density, thousand plants h^{-1}			
	57.14	71.43	95.24	Means	57.14	71.43	95.24	Means
Rabeh	4.38	4.54	4.83	4.58	5.25	5.87	6.14	5.76
Kafer	5.52	5.71	6.43	5.89	6.55	7.33	7.81	7.23
Giza 113	5.48	6.41	6.83	6.24	6.48	7.31	7.82	7.20
Inqath	5.79	6.41	6.91	6.37	7.10	7.63	8.29	7.68
Means	5.29	5.77	6.25		6.35	7.04	7.51	
LSD 5%	G	P.D.	G × P.D.		G	P.D.	G × P.D.	
	0.46	0.39	0.81		1.74	1.02	2.06	

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