RESEARCH | Egyptian Journal of Agricultural Research | Sugar Crops

Yield and quality of some sweet sorghum varieties to nitrogen fertilization and irrigation regime

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Received: 18-02-2025**; Accepted:** 28-04-2025**; Published:** 09-04-2025 **DOI:** 10.21608/EJAR.2025.361448.1645

ABSTRACT

Sorghum [*Sorghum bicolor* var *Saccharatum, Moench* (L.)] has become a crucial global food crop. This study aimed to assess the performance of five sweet sorghum varieties under varying nitrogen fertilizer levels and irrigation frequencies, focusing on growth traits, yields, and technological characteristics. Field experiments were conducted in clay loam soil under a flood irrigation system at El-Sabahia Agricultural Research Station, Alexandria Governorate, Egypt, during the summer seasons of 2021 and 2022. A randomized complete block design (RCBD) with a split-split plot arrangement with three replicates was used. The main plots were designated for irrigation treatments: full irrigation with seven waterings (control), six waterings (skipping the 6^{th}), and five waterings (skipping the 6^{th} and 7^{th}). Subplots were assigned three nitrogen fertilizer levels (60, 90, and 120 kg N/fed), and sub-sub plots were used to randomly distribute five sweet sorghum varieties (Ahron, G.R Coba, Sugar Drip, Tracy, and MN 4490).The results showed that irrigation frequency, nitrogen levels, and sorghum variety significantly interacted with stalk dimensions, leaf area, yield, and quality traits during both seasons. The AMMI and GGE biplot analyses indicated that the Ahron variety was the highest-performing genotype for strip stalk yield when fertilized with 90 kg N/fed and irrigated six times (IR2).These findings highlight the importance of optimizing irrigation and nitrogen management alongside variety selection to enhance sweet sorghum productivity and quality.

Keywords: *Sweet sorghum, Varieties, Nitrogen fertilization, Irrigation, Stalk yield.*

INTRODUCTION

Sweet sorghum [*Sorghum bicolor* var *Saccharatum, Moench* (L.)] is an important C4 crop that is mainly utilized for human food, forage, and syrup, but it is also an important source of fiber and feedstock for biofuel production (Bollam *et al*., 2021). Sweet sorghum is a crop that is capable of high sugar, grain, and lignocellulosic biomass yields, but a synthesis of published nutrient response curves reveals gaps in our knowledge. Sweet sorghum grown worldwide and distributed across different continents including North America, Africa, Asia, and Australia (Morris *et al*., 2013; Kimber, 2000)**.** Sorghum is a staple food for the majority of the population in semi-arid tropical regions of Africa and Asia (Buffo *et al*., 1998; Dicko *et al*., 2006). Sweet sorghum thus can be considered as a cash crop (Umakanth *et al*., 2019). Sweet sorghum accumulates fermentable sugars (10 - 20 %) in the stalk and thus has an advantage in producing grain for food and bioethanol from stalk juice without compromising food security (Reddy *et al*., 2005). The cultivation of sweet sorghum is gradually increasing due to efficient water use (Staggenborg *et al*., 2008)**,** low fertilizer requirement, advantages in erosion and weed control. Despite its importance, sorghum yield remains low with less than one ton per hectare at a national scale (Trouche *et al*., 2001). Sweet sorghum productivity and quality are greatly affected by many factors. Variety selection is one of the most important decisions in the production of sweet sorghum syrup or sugars. There is a great variation among sorghum varieties in stalk height, diameter, number of internodes, total sugar production and yield and its components. Miller and Creelman, (1982); Mohamed *et al*., (2006) reported that stripped stalk yield, was the effective parameter of yield of juice and ethanol, in addition to the chemical characteristics which in turn affect the syrup quality of sweet sorghum varieties. Abd El-Lattief, (2011) indicated that the effect of cultivars on the measurements were significant except for apparent purity in the first and second seasons. Cv Honey had the highest stalk height, stalk diameter, stalk yield and forage (leaves) yield in two seasons, respectively. The importance of sorghum varieties and nitrogen element effect on sorghum quantity and quality traits (Almodares *et al*., 2010; Djanaguiraman and Ramesh 2013; Djodda *et al*., 2013; Abou-Amer and Kewan, 2014). Nitrogen application had a significant effect on plant height, number of leaves plant, sugar content, green stalk yield, juice yield, brix percent and potential ethanol yield (Sawargaonkar *et al*., 2013). The effect of nitrogen levels on the stem dimension of sweet sorghum were significant at 1%, as well as producing the maximum values of stem fresh weight and percentage of brix, total sugar, sucrose, purity and ethanol yield (Almodares and Hoseini, 2016).

Irrigation management stands as a pivotal environmental factor influencing sorghum growth, development and yield. The photosynthesis and dry matter accumulation in crops, directly reflected in plant height, stem diameter and yield, hinge upon adequate soil water supply. Bonfim *et al*., (2011) reported that yield and SPAD value of sorghum were maximized at 60% field capacity. Wang *et al*., (2012), also reported that plant height and stem diameter yield of sorghum in 90% water surface evaporation were significantly higher than the rain-fed treatment. In addition, moderate nitrogen rate increased crop chlorophyll content, promoted photosynthesis and improved light energy utilization efficiency, (El–Hawary, *et al*., 2012; Li *et al*., 2023**)** indicated that the interaction effect between irrigation intervals and nitrogen fertilizer rates was significant in all studied characters in both seasons. At all irrigation periods, increasing the nitrogen fertilizer rate from zero to 90 kg N/fed gradually increased all studied traits, except sucrose percentage which decreased in both seasons. Irrigation management and nitrogen rate interaction had a significant effect on sorghum growth (plant height and stem diameter), yield, aboveground biomass and zero~60 cm soil nitrogen accumulation ($p < 0.05$). In addition, sorghum is the best crop adapted to arid ecologies having irregular seasonal rainfall distribution and high temperatures during the summer period (Zelin *et al*., 2024). Increasing nitrogen rate increased soil nitrate nitrogen accumulation, while increasing irrigation-decreased soil nitrate nitrogen accumulation. Yield and quality make sorghum a source of an alternative summery forage crops (Yan *et al*., 2019). Therefore, determining the quality characteristics is very important in sorghum and sorghum-Sudan grass hybrid cultivation besides the selection of appropriate and efficient cultivars in the regions.

The objective of this research was to evaluate the performance of some sweet sorghum varieties grown under different nitrogen fertilizer levels and number of irrigations, and their effects on plant growth traits, yields, and technological characteristics.

MATERIALS AND METHODES

A. Study area attributes experimental design and treatments:

The present study was carried out in clay loam soil under a flood irrigation system at El-Sabahia Agricultural Research Station (31° 12′ N and 29° 58 ′ E), Alexandria Governorate, Egypt during the two summer seasons of 2020 and 2021 to evaluate the performance of some sweet sorghum varieties grown under different nitrogen fertilizer levels and a number of irrigations, and their effects on plant growth traits, yields, and technological characteristics. A randomized complete block design (RCBD) in a split-split plot arrangement was used with three replicates. The main plots were allocated with the number of irrigations [seven irrigations (full irrigation as a control), six irrigations (skipping the 6^{th} irrigation), and 5 irrigations (skipping the 6^{th} and 7^{th} irrigations)]. The sub-plots were occupied with three nitrogen fertilizer levels (60, 90, and 120 kg N/fed), whereas five sweet sorghum varieties (Ahron, G.R Coba, Sugar Drip, Tracy and MN 4490) were distributed randomly in the sub-sub plots. The origins of the studied sorghum varieties are shown in (Table 1). The experimental unit area was 15 m^2, including 5 ridges 0.6 m apart and 5 m long. Physical and chemical analyses of the experimental soil were done and defined according to (Champan and Pratt, 1978), as shown in (Table 2).

Table 1. Origins of studied Sorghum varieties.

Variety	Origins
(V1) Ahron	Texas
(V2) G.R Coba	Coba
(V3) Sugar Drip	Oklahoma
(V4) Tracy	Texas
(V5) MN 4490	Mississippi

Table 2. Soil physical and chemical characteristics of the experimental sites in 2021 and 2022 seasons.

Soil properties	Seasons	
	2021	**2022**
Sand %	16.20	13.46
Silt %	23.05	24.01
Clay %	60.75	62.53
Soil texture	Clay loam	Clay loam
pH (1:2.2)	8.40	8.31
EC (dS/m)	3.55	3.37
OM (%)	1.82	1.80
Soluble cations (meq/l)		
K^+	0.40	0.29
Ca^{++}	2.40	2.10
Mg^{++}	2.80	2.60
Na^+	6.70	6.65
Soluble anions (meq/l)		
$HCO3^-$	6.40	6.10
Cl^-	5.67	5.35
$SO4^{--}$	0.23	0.19
Available NPK (mg/kg soil)		
Available N	36.30	38.95
Available P	6.55	6.30
Available K	272.00	265.90

Nitrogen fertilizer was applied as urea "46% N" in two equal doses; the 1st dose was added after 35 days from sowing (DFS) and the 2nd one was applied one month later. Phosphor fertilizer of 30 kg P_2O_5/fed was added in the form of calcium superphosphate (15% P_2O_5) during seedbed preparation. Potassium fertilizer was applied with the 2nd nitrogen dose at rate of 25 kg K_2O/fed as potassium sulfate "48 % K_2O". The sweet sorghum varieties were sown on 16th and 24th of May, in the 1st and 2nd seasons, respectively, while harvesting was done at the age of 105 days (dough to ripe stage), in both seasons. The preceding winter crop was Egyptian clover. Other field practices were done as recommended by Sugar Crops Research Institute, Agricultural Research Center, Egypt.

B. The recorded data:

1. Growth characteristics:

At harvest, the following characters were determined in a sample of 20 represented plants from each sub plot:

1. Plant height (m) was measured from soil surface to the base of panicle.
2. Plant diameter (cm) was measured on the fifth basal internode on the stalks.
3. Stalk fresh weight/plant (g).
4. Leaf area (cm^2). Leaf area was calculated by using the following formula:

Leaf area (cm^2) = maximum leaf width (cm) × maximum leaf length (cm) × 0.75 (Gardner *et al*., 1985).

2- Quality parameters:

1. Total soluble solids percentage (TSS %) was determined using a Refractometer at 20°C.
2. Sucrose percentage in 100 cm^3 of juice was determined using "Sacharemeter" according to (A.O.A.C., 1995).
3. Juice extraction percentage (JEP) was calculated according to the equation:

JEP% = (Juice weight x 100 /stripped stalks weight).

4. Purity percentage was computed using the following equation according to (Singh and Singh, 1998):

$$\text{Purity \%} = \frac{\text{Sucrose \%}}{\text{TSS\%}} \text{x} 100$$

2. Yield and its components:

At harvest, plants of four guarded rows were harvested, stripped and topped to determine:

1. Stalk weight / plant
2. Stripped stalk yield /fed (ton).
3. Syrup yield/fed (ton) resulting from heating the juice and evaporated the moisture in an open stainless pan until it reaches the boiling point and at 75% TSS was weighted

Statistical analysis:

Analysis of variance (ANOVA) was performed using the SPSS Statistics 18.0. Statistical computations were carried out using Gen-stat software version 15.1 (VSN International limited, 2012) for AMMI (Additive Main-effects and Multiplicative Interaction) and GGE (Genotype main effect (G) plus Genotype by Environment Interaction (GE)) biplot analysis. The graphic representation of genotypes and environments by AMMI analysis results from a model of main additive effects and multiplicative interaction (Gebremedhin *et al.,* 2014). AMMI analysis was used to determine the stability of genotypes across environments using principal component axis (PCA) scores. Similarly, IPCA2 scores close to zero revealed more stable genotypes, while large values indicated more responsive and less stable genotypes. GGE biplot analysis was used to visualize the relationship between testers and entries and to determine the "which-won-where" portion. GGE biplot also reveals the stability of genotypes; genotypes located near the biplot origin are considered as widely adapted genotypes while genotypes located faraway are considered as being specifically adapted.

RESULTS

1. Growth characteristics:

1.1. Stalk height and diameter:

Data in (Table 3) showed that the differences among the number of irrigations were significant in their effect on stalk height and diameter in both seasons. A positive statistical response in stalk height and diameter was observed when the number of irrigations was decreased from IR1 (seven irrigations) to IR2 (six irrigations) and/or IR3 (five irrigations), in both seasons. The plants subjected to IR2 resulted in the highest values of stalk diameter, recording a significant increase of 0.27 cm (12.4%) and 0.22 cm (10.1%) compared to IR1 (control), in the 1st and 2nd seasons, respectively. The examined sweet sorghum varieties significantly differed in stalk height and diameter in both seasons. Varieties V2 and V5 produced the tallest stalks, recording 2.30 and 2.62 m in the 1st and 2nd seasons, respectively. The highest values of stalk thickness were recorded by variety V1 in both seasons. In contrast, V3 recorded the lowest averages of stalk diameter in both seasons and the lowest stalk height in the 2nd season.

Feeding sorghum plants with different nitrogen fertilizer levels significantly affected stalk height and diameter in both seasons. Raising N levels to 120 kg N/fed resulted in a significant and gradual increase in stalk height in the 1st season. The maximum stalk diameter was observed at 90 kg N/fed and 120 kg N/fed in the 1st and 2nd seasons, respectively.

The interaction between irrigation number and nitrogen levels significantly influenced stalk diameter in both seasons (Table 4). Plants subjected to IR3 and 120 kg N/fed in the 1st season, as well as IR1 and 60 kg N/fed in the 2nd season, produced the greatest stalk height. The maximum stalk diameter was recorded with the interaction of IR3 and 90 kg N/fed in the 1st season, and IR2 with 60 kg N/fed in the 2nd season. Stalk diameter was also significantly affected by the interaction between irrigation number and variety in both seasons. The highest stalk height was recorded by V2 under IR3 in the 1st season and by V5 under IR1 in the 2nd season. Meanwhile, the greatest stalk diameter was observed in V1 under IR2 in both seasons. The interaction between variety and nitrogen level significantly influenced stalk dimensions in both seasons, except for stalk height in the 1st season. V5 combined with 90 kg N/fed in the 2nd season produced the greatest stalk height. The maximum stalk diameter was recorded by V5 with 60 kg N/fed in the 1st season and by V1 with 60 kg N/fed in the 2nd season.

The three-way interaction among irrigation, variety, and nitrogen level also showed a significant effect on stalk dimensions. In the 1st season, the combination of IR2, V5, and 120 kg N/fed gave the greatest stalk height, while in the 2nd season, it was IR1, V1, and 60 kg N/fed. Regarding stalk diameter, the best performance was recorded by IR3, V5, and 60 kg N/fed in the 1st season, and IR2, V5, and 60 kg N/fed in the 2nd season.

1.2. Leaf area /plant

Data presented in (Table 3) show that the number of irrigations had a significant effect on leaf area in both seasons. The highest leaf area values were recorded under IR2 (six irrigations), reaching 4846.4 and 4591.2 cm² in the 1st and 2nd seasons, respectively. These values reflect a significant increase of 19.1% and 14.5% compared to the control treatment IR1 (seven irrigations), in the respective seasons. Sweet sorghum varieties showed significant differences in leaf area across both seasons. Variety V2 had the highest leaf area in the 1st season (4750.3 cm²), while V5 excelled in the 2nd season (4527.6 cm²). On the other hand, variety V3 consistently recorded the lowest leaf area values in both seasons. Regarding nitrogen fertilizer levels, increasing the rate to 120 kg N/fed significantly enhanced the leaf area of sweet sorghum plants, with maximum values obtained at this rate in both seasons. Specifically, 120 kg N/fed resulted in leaf area increases of 21.7 and 18.9% compared to the lowest nitrogen level (30 kg N/fed) in the 1st and 2nd seasons, respectively.

Table 3. Effect of number of irrigations, and nitrogen fertilizer levels on stalk height, dimeter and leaf area of some sweet sorghum varieties, in 2021 and 2022 seasons.

Treatments	Stalk height (m)		Stalk Dimeter (cm)		Leaf area (cm²)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
A) Number of irrigations (IR)						
Irrigation 1	2.03	2.16	1.91	1.96	139.71	116.85
Irrigation 2	1.99	2.17	2.11	1.99	124.13	100.61
Irrigation 3	1.95	2.15	2.18	2.17	130.39	115.28
LSD 0.05	**0.05**	**0.01**	**0.10**	**0.05**	**2.75**	**1.35**
B) Nitrogen fertilizer levels (F)						
60 Kg/fed	1.94	2.14	1.92	1.92	135.80	116.08
90 Kg/fed	2.14	2.16	2.12	2.10	118.69	99.08
120 Kg/fed	2.16	2.19	2.16	2.12	139.75	117.59
LSD 0.05	**0.02**	**0.03**	**0.06**	**0.05**	**2.79**	**1.96**
C) Variety (V)						
Ahrone (V1)	1.59	2.23	2.26	2.25	127.45	114.60
G.R. coba (V2)	2.30	2.03	1.93	1.99	127.60	111.78
Sugar drip (V3)	1.81	1.83	1.89	1.91	152.81	131.03
Tracy (V4)	2.10	2.09	1.99	2.01	116.02	88.67
MN 4490 (V5)	2.16	2.61	2.20	2.07	133.17	108.50
LSD 0.05	**0.05**	**0.07**	**0.09**	**0.05**	**10.20**	**10.90**

The interaction between irrigation number and nitrogen level significantly affected leaf area in both seasons (Table 4). The highest values were observed when plants were irrigated with IR2 and fertilized with 120 kg N/fed, achieving 4956.3 cm² and 4715.8 cm² in the 1st and 2nd seasons, respectively. The interaction between irrigation regime and variety also had a significant effect on leaf area. The highest means were recorded by variety V2 under IR2 in the 1st season and by V5 under IR2 in the 2nd season. Similarly, the interaction between variety and nitrogen fertilizer level was significant in both seasons. The best performance was observed in variety V2 with 120 kg N/fed in the 1st season and in variety V5 with 90 kg N/fed in the 2nd season. Moreover, the three-way interaction among irrigation number, variety, and nitrogen level had a significant influence on leaf area in both seasons. The highest recorded values were from the combination of IR2, V2, and 120 kg N/fed in the 1st season (5053.4 cm²), and IR2, V5, and 90 kg N/fed in the 2nd season (4781.6 cm²).

2. Quality parameters:

2.1. Total soluble solids (TSS %) and Sucrose %

Data in (Table 5) showed that the number of irrigations had a significant effect on total soluble solids (TSS %) and sucrose percentage in both seasons. A positive statistical response in TSS % and sucrose% was observed when the number of irrigations was decreased from IR1 (seven irrigations) to IR2 (six irrigations) in both seasons, except for TSS % in the 2nd season. The plants subjected to IR2 resulted in the highest TSS percentage and sucrose percentage, recording an increase of 0.3 and 0.13% for TSS percentage and 7.4% and 1.9% for sucrose percentage, as compared to IR1 as a control treatment, in the 1st and 2nd seasons, respectively. The examined sweet sorghum varieties significantly differed in TSS percentage and sucrose percentage in both seasons. The V5 variety recorded the highest TSS percentage, reaching 17.02 and 16.83% in the 1st and 2nd seasons, respectively. However, the highest sucrose percentage values were obtained from the V1 variety in the 1st season and from the V5 variety in the 2nd season. The V2 variety recorded the lowest average values of TSS percentage in both seasons and sucrose percentage in the 1st season.

Nitrogen fertilization had a significant impact on TSS percentage and sucrose % in both seasons. Decreasing nitrogen levels up to 120 kg N/fed, as the recommended rate, resulted in a significant and gradual increase in TSS percentage and sucrose percentage in both seasons. The highest TSS percentage and sucrose percentage values were recorded with the addition of 90 kg N/fed in both seasons.

Table 4. The interactions of irrigations and nitrogen fertilizer levels on stalk height, diameter and leaf area of some sweet sorghum varieties, in 2021 and 2022 seasons

IR	V	F	Stalk height (m)		Stalk diameter (cm)		Leaf area (cm^2)	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
7	**V1**	**60**	1.87	1.45	2.11	2.18	146.76	126.55
		90	2.28	2.25	1.39	1.50	154.33	124.96
		120	1.17	1.24	1.70	1.67	86.01	74.35
	V2	**60**	2.55	2.38	2.20	2.45	196.53	178.41
		90	1.85	2.14	2.05	2.13	84.21	55.88
		120	1.23	1.27	1.82	1.96	167.35	142.39
	V3	**60**	2.14	2.12	1.85	1.73	144.62	127.29
		90	1.95	1.87	1.66	1.84	212.70	181.50
		120	1.85	1.42	2.06	1.85	166.73	148.09
	V4	**60**	2.95	3.02	2.83	1.63	127.97	106.58
		90	1.73	1.70	1.91	1.80	96.74	66.10
		120	2.45	2.41	2.22	2.33	115.01	86.81
	V5	**60**	2.05	2.10	2.08	2.10	137.24	128.57
		90	2.52	2.15	1.55	1.62	123.58	93.12
		120	1.90	1.60	1.25	1.35	135.91	112.10
6	**V1**	**60**	1.55	1.45	2.73	2.75	151.44	130.97
		90	2.45	2.40	2.21	2.25	105.54	94.88
		120	2.63	2.17	1.68	1.58	175.06	164.81
	V2	**60**	1.42	1.55	1.81	2.28	72.73	62.81
		90	2.18	2.22	2.98	2.93	101.01	77.04
		120	1.68	1.73	2.31	2.33	84.01	69.43
	V3	**60**	2.00	1.93	2.21	2.20	175.57	142.42
		90	1.50	1.53	1.63	1.81	103.54	88.09
		120	2.60	2.42	2.40	1.65	126.69	97.23
	V4	**60**	1.97	1.52	2.13	1.52	164.27	113.37
		90	1.35	1.41	2.22	2.37	84.10	59.11
		120	2.12	2.12	2.15	2.23	122.58	88.60
	V5	**60**	1.75	1.87	2.41	2.32	107.86	103.52
		90	1.70	1.48	2.51	2.17	100.80	72.11
		120	3.02	3.17	1.30	1.70	186.69	144.83
5	**V1**	**60**	1.65	1.77	2.33	2.35	93.74	90.91
		90	2.02	2.09	1.93	1.98	111.74	118.03
		120	1.73	1.82	1.96	1.95	122.47	105.90
	V2	**60**	2.40	2.38	1.65	1.97	148.53	125.66
		90	1.30	1.63	3.05	1.53	127.67	150.59
		120	1.72	1.67	2.56	2.34	166.36	143.82
	V3	**60**	2.33	2.40	1.83	1.92	134.77	128.43
		90	2.28	2.28	2.12	2.10	133.13	109.80
		120	1.60	1.65	2.25	1.68	177.51	156.45
	V4	**60**	1.73	2.43	2.80	2.28	92.48	75.21
		90	1.55	1.63	2.31	2.23	96.28	72.60
		120	2.88	2.84	1.55	1.87	144.75	129.66
	V5	**60**	1.22	1.53	1.78	1.73	142.44	100.51
		90	2.25	2.60	1.55	2.40	144.96	122.36
		120	2.56	2.38	1.95	1.65	119.08	99.34
LSD at 0.05								
IR x F			0.32	0.09	0.18	0.56	5.79	5.39
IR x V			0.08	0.13	0.15	0.33	9.42	6.20
F x V			NS	0.13	0.15	0.33	7.48	6.96
IR x F x V			0.14	0.22	0.26	0.58	12.95	12.05
P – levels			**	**	**	**	**	**

The interaction between the number of irrigations and nitrogen fertilizer levels significantly influenced TSS percentage and sucrose percentage in both seasons (Table 6). Sorghum plants subjected to IR1 (seven irrigations) and fed with 120 kg N/fed produced the greatest TSS percentage in both seasons. Meanwhile, plants irrigated under IR3 achieved the maximum sucrose percentage values when fertilized with 90 kg N/fed in both seasons. TSS percentage and sucrose percentage were also significantly affected by the interaction between the number of irrigations and varieties in both seasons. The highest TSS percentage values were recorded in the V4 variety subjected to IR2 in both seasons. On the other hand, the V1 variety irrigated with IR3 in the 1st season and the V5 variety irrigated with IR2 in the 2nd season produced the highest sucrose percentage. The interaction between variety and nitrogen fertilizer levels showed a significant influence on TSS percentage and sucrose percentage in both seasons (Table 6). Sorghum plants of the V5 variety fed with 120 kg N/fed in both seasons produced the greatest TSS percentage. Meanwhile, the V1 variety achieved the maximum sucrose percentage values when fertilized with 60 kg N/fed in the 1st season, while the highest values resulted from the interaction between the V5 variety and 90 kg N/fed in the 2nd season. The three-way interaction among the number of irrigations, variety, and nitrogen fertilizer levels significantly influenced TSS percentage and sucrose percentage in both seasons. The highest TSS percentage was recorded in sorghum plants subjected to IR2 (six irrigations), V4, and fertilized with 90 kg N/fed in both seasons. The highest sucrose percentage was obtained from IR3 (five irrigations), V1, and 90 kg N/fed in the 1st season, whereas the highest means resulted from the interaction between IR3 (five irrigations), V1, and 60 kg N/fed in the 2nd season.

Table 5. Effect of number of irrigations, and nitrogen fertilizer levels on TSS percentage, sucrose percentage and purity percentage of some sweet sorghum varieties, in 2021 and 2022 seasons.

Treatments	**TSS%**		**Sucrose %**		**Purity %**	
	1st season	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**
A) Number of irrigations (IR)						
Irrigation 1	15.99	15.84	8.01	7.48	50.20	47.28
Irrigation 2	16.04	15.86	8.6	7.62	54.15	48.32
Irrigation 3	15.84	15.81	8.24	7.55	52.15	47.77
LSD 0.05	**0.04**	**0.12**	**0.1**	**0.16**	**1.11**	**0.67**
B) Nitrogen fertilizer levels (F)						
60 Kg/fed	15.65	15.66	8.21	7.25	52.51	48.72
90 Kg/fed	16.14	16.03	8.39	7.78	52.33	48.63
120 Kg/fed	16.07	15.82	8.24	7.82	51.64	46.02
LSD 0.05	**0.14**	**0.12**	**0.15**	**0.16**	**0.80**	**0.95**
C) Variety (V)						
Ahrone (V1)	15.98	15.3	9.29	7.29	58.58	47.7
G.R. coba (V2)	15.01	15.2	7.63	7.32	51.44	48.33
Sugar drip (V3)	15.75	15.98	8.23	7.75	52.34	48.68
Tracy (V4)	16	15.88	7.92	7.4	49.49	46.63
MN 4490 (V5)	17.01	16.83	8.34	7.99	48.99	47.6
LSD 0.05	**0.17**	**0.19**	**0.20**	**0.13**	**1.23**	**0.95**

2.2. Purity percent

The data in (Table 5) demonstrated that the number of irrigations had a significant effect on purity % in both seasons. A positive statistical response was observed when the number of irrigations was reduced from IR1 (seven irrigations) to IR2 (six irrigations) and/or IR3 (five irrigations) in the first season. The highest purity percent values were recorded in plants subjected to IR3, with a significant increase of 4% (8.3%) in the 1st season. In the 2nd season, IR2 recorded an increase of 3.1% (6.7%) compared to IR1 as a control treatment. Sweet sorghum varieties exhibited significant differences in purity percent across both seasons. The V1 and V3 varieties recorded the highest purity percent values, reaching 57.64% and 48.68% in the 1st and 2nd seasons, respectively. Meanwhile, the lowest purity percent values were recorded for V5 and V4 in the 1st and 2nd seasons, respectively. Nitrogen fertilizer levels significantly affected purity percent in both seasons. A decrease in nitrogen levels up to 120 kg N/fed resulted in a significant and gradual increase in purity percent. The highest purity percent values were recorded with the addition of 60 kg N/fed in both seasons. The interaction between the number of irrigations and nitrogen fertilizer levels significantly influenced purity % in both seasons (Table 6). Sorghum plants subjected to IR3 (five irrigations) and fertilized with 90 kg N/fed in both seasons recorded the highest purity % values. Similarly, the interaction between the number of irrigations and varieties had a significant effect on purity % in both seasons.

Table 6. The interactions of irrigations and nitrogen fertilizer levels on TSS, sucrose and purity percentages of some sweet sorghum varieties, in 2021 and 2022 seasons

IR	V	F	TSS%		Sucrose %		Purity%	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
			2021	2022	2021	2022	2021	2022
7	V1	60	16.82	14.83	7.42	7.13	52.05	48.11
		90	15.35	16.35	7.38	7.95	48.16	48.68
		120	12.38	13.53	6.71	6.73	54.33	49.87
	V2	60	13.53	14.55	7.3	6.82	53.98	49.92
		90	18.51	17.52	8.79	8.35	47.49	47.67
		120	16.38	14.83	7.54	7.47	45.63	50.58
	V3	60	17.33	16.38	8.21	8.57	48.01	52.33
		90	16.42	15.82	8.68	7.69	52.74	48.61
		120	13.4	14.44	5.85	6.38	43.78	44.31
	V4	60	17.62	17.44	8.25	7.93	45.43	45.61
		90	15.43	14.65	6.93	6.75	47.15	46.14
		120	17.47	17.67	7.7	7.77	44.04	44.09
	V5	60	15.35	16.13	7.82	7.73	51.93	47.94
		90	18.44	17.40	8.29	7.62	48.86	43.76
		120	15.35	16.35	7.45	7.30	48.46	44.52
6	V1	60	15.42	14.38	6.63	6.55	53.62	45.54
		90	14.43	15.35	7.73	6.98	53.66	45.59
		120	15.5	15.17	8.00	8.22	53.84	54.18
	V2	60	17.48	16.43	8.11	8.20	51.17	49.88
		90	17.65	16.68	8.80	8.52	49.84	50.99
		120	13.45	14.62	7.47	7.67	60.91	52.61
	V3	60	15.40	15.00	6.53	6.85	42.37	45.70
		90	15.47	16.3	8.1	6.85	51.87	42.06
		120	19.4	19.16	8.55	8.93	45.79	46.71
	V4	60	15.47	16.42	8.27	8.88	53.38	54.04
		90	17.12	16.1	7.38	6.82	55.32	42.35
		120	11.73	12.87	7.53	7.01	64.18	54.48
	V5	60	16.32	15.30	8.28	8.07	50.45	52.86
		90	17.33	16.35	8.58	7.47	53.12	45.75
		120	18.43	17.45	8.30	7.32	47.46	42.01
5	V1	60	18.32	17.25	9.42	9.11	52.20	52.88
		90	13.60	14.53	7.13	7.45	52.57	51.35
		120	16.72	17.63	8.22	7.55	53.19	42.81
	V2	60	13.45	14.42	6.16	6.72	54.8	46.63
		90	15.57	16.25	7.54	8.08	45.94	49.71
		120	14.38	15.55	8.43	7.78	69.88	50.14
	V3	60	15.33	14.25	8.08	6.67	52.08	46.81
		90	15.47	17.65	8.63	8.83	50.03	50.12
		120	17.37	16.50	8.18	8.02	47.15	48.68
	V4	60	16.37	16.08	8.42	8.23	52.29	51.09
		90	16.5	15.50	7.53	6.35	47.57	40.97
		120	14.47	14.40	7.27	6.61	54.91	45.95
	V5	60	15.28	16.30	7.12	8.10	46.65	47.02
		90	13.65	13.63	6.59	6.43	52.97	49.64
		120	18.18	17.23	8.26	7.38	45.06	42.74
LSD at 0.05								
IR x F			0.07	0.21	0.16	0.28	5.16	1.93
IR x V			0.29	0.34	0.28	0.71	2.44	1.65
F x V			0.29	0.34	0.28	0.71	2.44	1.65
IR x F x V			0.52	0.58	0.49	1.23	4.22	2.85
P- Levels			**	**	**	**	**	**

The highest purity percentage values were observed in V1 subjected to IR3 in the 1st season and V3 irrigated with IR2 in the 2nd season. The interaction between variety and nitrogen fertilizer levels also showed a significant impact on purity % in both seasons, particularly in sorghum plants subjected to V1 and fertilized with 90 kg N/fed. Furthermore, the interaction among the number of irrigations, variety, and nitrogen fertilizer levels significantly influenced purity percent in both seasons. The highest purity percent values were observed in sorghum plants subjected to IR3 (five irrigations), V1, and fertilized with 90 kg N/fed in the 1st season. Similarly, in the 2nd season, the highest purity percent was recorded in plants irrigated with IR2 (six irrigations), V2, and fertilized with 90 kg N/fed.

3. Yield and its components:

3.1. Stalk weight / plant:

The data in (Table 7) revealed significant differences in stalk weight across the number of irrigations in both seasons. A positive statistical response in stalk weight was observed when the number of irrigations decreased from IR1 (seven irrigations) to IR2 (six irrigations) and/or IR3 (five irrigations) in both seasons. Specifically, plants subjected to IR2 resulted in the highest stalk weight, with a significant increase of 17.77 g (3.7%) in the 1st season and 41.5 g (8.67%) in the 2nd season compared to IR1 (control treatment). Sweet sorghum varieties showed significant differences in stalk weight in both seasons. V1 and V3 varieties produced the highest stalk weight, recording 546.36 g and 489.0 g in the 1st season, and 547.07 g and 530.53 g in the 2nd season, respectively. Conversely, the V5 variety exhibited the lowest average stalk weight in both seasons. The application of different nitrogen fertilizer levels also significantly affected stalk weight in both seasons. The nitrogen level of 90 kg N/fed produced the highest stalk weight, with values of 508.53 g in the 1st season and 517.93 g in the 2nd season. The interaction between the number of irrigations and nitrogen fertilizer levels had a significant effect on stalk weight in both seasons (Table 8). Sorghum plants subjected to IR1 (seven irrigations) and fertilized with 90 kg N/fed in the 1st season, as well as those irrigated with IR2 (six irrigations) and fertilized with 60 kg N/fed in the 2nd season, produced the greatest stalk weight. The interaction between the number of irrigations and varieties significantly affected stalk weight in both seasons. The highest stalk weight per plant was recorded in the V1 variety subjected to IR2 (six irrigations) in both seasons. The interaction between the variety and nitrogen fertilizer levels also had a significant effect on stalk weight per plant in both seasons (Table 8). Sorghum plants subjected to V1 and fertilized with 90 kg N/fed in both seasons produced the highest stalk weight per plant.

Finally, the interaction between the number of irrigations, variety, and nitrogen fertilizer levels significantly influenced stalk weight per plant in both seasons. Sorghum plants subjected to IR2 (six irrigations), V1, and fed with 90 kg N/fed in the 1st season, and those irrigated with IR2 (six irrigations), V3, and fertilized with 60 kg N/fed in the 2nd season, produced the greatest stalk weight per plant.

Table 7. Effect of number of irrigations, and nitrogen fertilizer levels on stalk weight, stripped stalk yield percentage and syrup yield of some sweet sorghum varieties, in 2021 and 2022.

Treatments	**Stalk weight/plant, g**		**Stripped stalk yield /fed (ton)**		**Syrup yield(ton/fad)**	
	1st season	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**
A) Number of irrigations (IR)						
Irrigation 1	515.51	478.51	14.28	14.16	1.20	1.32
Irrigation 2	528.36	521.01	14.72	14.88	1.36	1.39
Irrigation 3	525.95	455.75	13.64	13.73	1.28	1.34
LSD 0.05	4.65	3.03	0.15	0.34	0.02	0.02
B) Nitrogen fertilizer levels (F)						
60 Kg/fed	491.99	467.03	13.82	14.00	1.24	1.37
90 Kg/fed	568.69	517.93	13.98	13.87	1.26	1.32
120 Kg/fed	509.14	470.31	14.84	14.89	1.34	1.36
LSD 0.05	10.62	5.05	0.23	0.95	0.05	0.03
C) Variety (V)						
Ahrone (V1)	563.14	547.06	14.59	14.35	1.42	1.50
G.R. coba (V2)	509.62	452.58	14.64	14.73	1.20	1.26
Sugar drip (V3)	536.92	530.54	13.97	14.32	1.25	1.36
Tracy (V4)	551.71	455.97	14.24	14.14	1.24	1.24
MN 4490 (V5)	454.97	439.29	13.63	13.74	1.29	1.38
LSD 0.05	17.5	6.12	0.88	0.65	0.15	0.13

Table 8. The interactions of irrigations and nitrogen fertilizer levels on stalk weight, stripped stalk yield and syrup yield of some sweet sorghum varieties, in 2021 and 2022 seasons

IR	V	F	Stalk weight/plant (g)		Stripped stalk yield /fed (ton)		Syrup yield /fed (ton)	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
7	V1	60	448.50	442.33	13.52	13.40	1.20	0.96
		90	326.33	340.00	13.20	11.46	1.28	1.76
		120	371.80	366.68	12.07	11.97	1.14	1.65
	V2	60	403.65	412.08	12.67	12.83	1.09	0.89
		90	532.24	538.77	15.13	15.24	1.48	1.26
		120	673.72	679.23	17.80	17.90	1.44	1.18
	V3	60	581.77	581.25	16.05	17.04	1.04	1.21
		90	448.50	461.58	13.52	13.77	1.06	1.81
		120	528.08	522.92	15.03	14.94	0.91	1.09
	V4	60	467.32	471.68	13.88	13.96	1.16	1.33
		90	472.17	480.82	14.97	14.14	0.95	0.74
		120	492.14	477.83	14.35	14.08	1.45	1.45
	V5	60	568.75	558.38	15.81	15.61	1.31	2.10
		90	435.02	432.10	13.26	13.21	1.08	1.25
		120	415.42	412.10	12.90	12.83	1.37	1.14
6	V1	60	650.20	646.67	17.35	17.29	1.19	1.54
		90	459.38	468.33	13.73	13.90	1.34	1.52
		120	900.00	912.50	21.20	22.34	1.96	1.95
	V2	60	451.30	475.45	13.58	14.04	1.05	1.34
		90	286.05	272.12	11.43	10.17	0.96	1.29
		120	713.55	722.25	18.56	18.72	1.40	1.44
	V3	60	370.58	395.83	12.02	12.52	1.13	1.36
		90	540.12	574.17	15.26	15.91	1.78	1.58
		120	382.83	382.50	12.27	12.27	1.59	1.26
	V4	60	494.32	498.77	14.39	14.48	1.21	0.92
		90	481.67	479.50	14.15	14.45	1.28	1.54
		120	462.02	477.92	13.78	14.08	1.32	1.22
	V5	60	475.00	467.08	14.03	13.88	1.66	1.65
		90	616.77	621.25	16.72	16.80	1.37	1.14
		120	383.70	387.97	12.29	12.37	1.19	1.11
5	V1	60	392.12	391.42	13.45	12.44	1.43	1.59
		90	388.30	393.33	12.38	12.47	1.84	1.11
		120	482.25	465.42	14.37	13.84	1.37	1.45
	V2	60	336.38	335.42	11.39	12.37	1.13	1.55
		90	526.37	530.00	15.02	15.07	0.96	0.92
		120	588.47	592.92	16.18	16.27	1.31	1.43
	V3	60	428.83	426.25	13.15	13.10	1.55	1.28
		90	453.63	509.53	13.62	14.68	1.06	1.30
		120	514.02	509.17	14.77	14.67	1.11	1.38
	V4	60	422.15	440.83	13.40	13.38	1.07	1.09
		90	496.88	470.46	14.44	13.94	1.18	1.56
		120	503.50	512.50	14.83	14.74	1.56	1.34
	V5	60	410.98	459.42	12.61	13.73	1.36	1.77
		90	411.51	412.92	12.82	12.85	1.25	1.06
		120	380.22	386.58	12.22	12.35	1.04	1.24
LSD at 0.05								
IR x F			11.98	7.32	2.27	0.09	1.54	0.04
IR x V			14.59	11.74	1.59	0.13	0.05	0.05
F x V			14.59	11.74	1.59	0.13	0.05	0.05
IR x F x V			25.27	3.47	2.73	0.22	0.08	0.09
P- Levels			**	**	**	**	**	**

3.2. Stripped stalk yield and Syrup yield/fed (ton):

The data in (Table 7) revealed that the number of irrigations had a significant effect on stripped stalk yield and syrup yield (ton/fed) in both seasons. A positive statistical response was observed when irrigation was reduced from seven (IR1) to 6 (IR2) and 5 (IR3) irrigations in both seasons. The highest stripped stalk yield and syrup yield were recorded under IR2 treatment, showing significant increases of 0.44 ton (3.08%) and 0.72 ton (5.08%) in the 1st and 2nd seasons, respectively, compared to IR1. Similarly, syrup yield increased by 0.16 ton (13.33%) in the 1st season and 0.07 ton (5.3%) in the 2nd season under IR2 treatment. Sweet sorghum varieties significantly differed in stripped stalk and syrup yield in both seasons. The V1 and V2 varieties recorded the highest stripped stalk yield, reaching 14.59 and 14.64 tons in the 1st season, and 14.35 and 14.73 tons in the 2nd season, respectively. The highest syrup yield was obtained from the V1 variety in both seasons, while the lowest stripped stalk yield was observed in the V5 variety. Conversely, the lowest syrup yield was recorded in V2 and V4 varieties in the 1st and 2nd seasons, respectively. Nitrogen fertilizer levels had a significant impact on stripped stalk yield and syrup yield in both seasons. Increasing N levels up to 120 kg N/fed resulted in a significant and gradual rise in stripped stalk and syrup yields. The highest stripped stalk yield was recorded with 120 kg N/fed in both seasons, while the maximum syrup yield was observed with 120 kg N/fed in the 1st season and 60 kg N/fed in the 2nd season.

The interaction between the number of irrigations and nitrogen fertilizer levels significantly influenced stripped stalk yield and syrup yield (Table 8). The highest stripped stalk yield was achieved with IR2 (six irrigations) combined with 120 kg N/fed in both seasons. For syrup yield, the highest values were obtained with IR2 (six irrigations) combined with 120 kg N/fed in the 1st season and 90 kg N/fed in the 2nd season. The lowest stripped stalk yield was recorded with IR3 (five irrigations) combined with 60 kg N/fed, whereas the lowest syrup yield was observed with IR1 (seven irrigations) and 60 kg N/fed in the 1st season, and IR3 (five irrigations) and 90 kg N/fed in the 2nd season. The interaction between irrigation levels and varieties significantly affected stripped stalk yield and syrup yield in both seasons. The highest stripped stalk yield was observed in V1 subjected to IR2 (six irrigations) in both seasons. The highest syrup yield was obtained from V1 under IR3 (five irrigations) in the 1st season and IR2 (six irrigations) in the 2nd season. The lowest stripped stalk yield was recorded in V1 irrigated with IR1, while the lowest syrup yield resulted from V3 and V2 under IR1 in the 1st and 2nd seasons, respectively. The interaction between variety and nitrogen fertilizer levels also showed a significant impact. The highest stripped stalk yield was observed in V2 fertilized with 120 kg N/fed in both seasons, while the highest syrup yield was recorded in V1 under 120 kg N/fed in both seasons. Lastly, the interaction among irrigation, variety, and nitrogen fertilizer levels significantly influenced stripped stalk and syrup yield. The highest stripped stalk yield was obtained from plants subjected to IR2 (six irrigations), V1, and 120 kg N/fed in both seasons. The highest syrup yield was recorded under IR2 (six irrigations), V1, and 120 kg N/fed in the 1st season, whereas in the 2nd season, the highest syrup yield was observed under IR1 (seven irrigations), V5, and 60 kg N/fed.

4. AMMI and GGE biplot analysis:

In the AMMI model, Principal Component 1 (PC1) explained 55.92% of the total variation in stripped stalk yield (ton/fed.). In comparison, the GGE biplot analysis showed that PC1 accounted for 58.92% of the variation. The total variation captured by PC1 and PC2 was 78.16% in AMMI and 78.48% in GGE analysis (Table 9).

Table 9. Trait-wise principal component 1 and 2 variance (PC1 and PC2) of total GGE variation in sweet sorghum varieties evaluated over two seasons and nine environments

Source	Stripped stalk yield	
	AMMI	GGE
IPCA 1	55.92	58.92
IPCA 2	22.24	19.56
Total	78.16	78.48

The AMMI analysis of variance for stripped stalk and juice yield of five sorghum varieties showed that environments (E), genotypes (G), and genotype × environment interaction (GEI) significantly affected variation.

In the AMMI biplot (Fig. 1), varieties G.R Coba, Tracy, and MN 4490 displayed higher yield performance as they were positioned on the right-hand side of the midpoint on the IPCA1 axis, indicating yields above the grand mean. All environments except E3, E4, and E5 also showed high yield potential and were similarly positioned on the right-hand side.

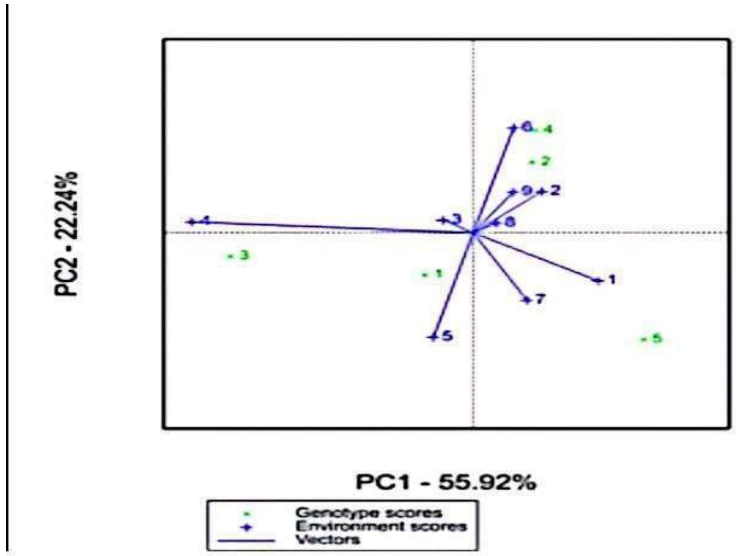

Fig. 1. The AMMI biplot relationship between five varieties and nine environments

In the GGE biplot analysis (Fig. 2), the biplot was divided into four sectors. Each genotype falling in the same sector as an environment is considered adapted to that environment. The combined analysis of both seasons revealed:

- Ahron was best adapted to environments **E2, E5, E7,** and **E8**
- Sugar-Drip and Tracy were more suited to **E3, E6,** and **E9**
- MN 4490 was most compatible with **E1**
- G.R Coba and Tracy had no specific adaptation in GGE for this trait

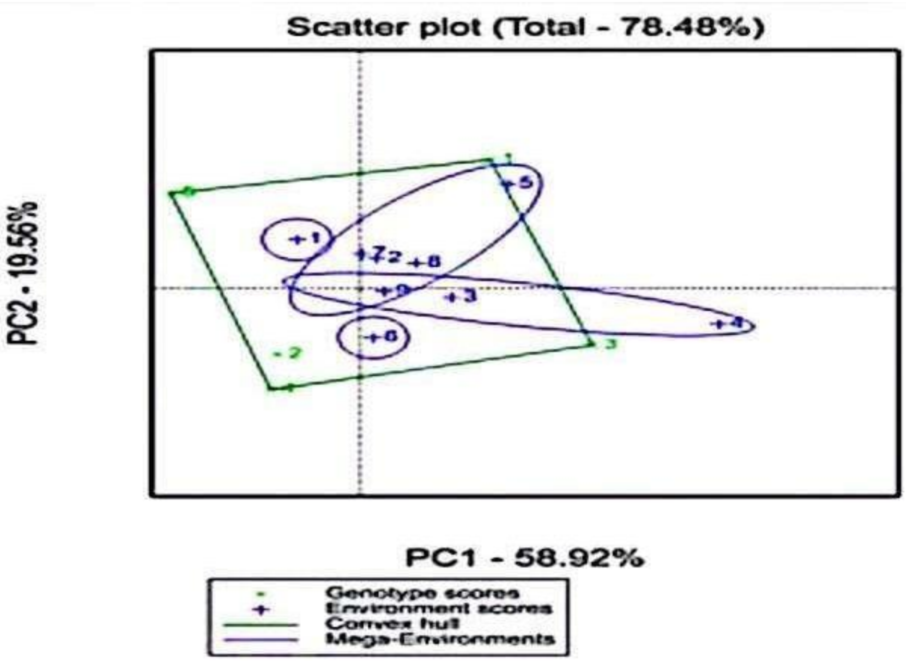

Fig. 2. The GGE biplot relationship between five varieties and nine environments.

DISCUSSION

1. Growth characteristics:

1.1. Stalk height and diameter:

The observed increase in stalk diameter when reducing irrigation frequency to six events (IR2) may be attributed to a reduction in soil moisture, which potentially induces more robust tissue development in response to mild water stress. This interpretation is in line with the findings of (Zelin *et al*., 2024). The variation in stalk height and diameter among the sweet sorghum varieties is likely due to genetic differences and their differential responses to environmental factors. Varieties V2 and V5 showed superior height performance, while V1 excelled in stalk thickness. These findings corroborate earlier results reported by (Galal *et al*., 2019). The observed improvements in growth characteristics with increasing nitrogen levels can be attributed to nitrogen's role in enhancing meristematic activity and promoting cell elongation. The significant gains in both stalk height and diameter at 120 kg N/fed emphasize the importance of adequate nitrogen availability, as previously discussed by (Besheit and Mekdad, 2016). Additionally, the significant interactions between irrigation, variety, and nitrogen levels highlight the complexity of optimizing sorghum growth. For example, V5 under optimal irrigation and nitrogen conditions produced exceptional stalk growth, while V1 displayed superior diameter under moderate input levels. These findings suggest that matching variety traits with suitable agronomic practices is essential to maximize sorghum performance.

1-2. Leaf area /plant:

The significant improvement in leaf area under moderate irrigation (IR2) suggests that this level provides a favorable balance between soil moisture and aeration, enhancing physiological activity and promoting leaf expansion. Excessive irrigation (IR1) may have caused oxygen deficiency in the root zone, thereby limiting leaf development. The observed variation in leaf area among the different varieties is likely due to genetic differences in canopy structure and leaf development potential. The superior performance of V2 and V5 supports findings by previous studies that reported these genotypes as high performers under varying environmental conditions. Nitrogen's role in stimulating vegetative growth, particularly leaf development, is well established. The increase in leaf area with higher nitrogen levels (especially 120 kg N/fed) may be attributed to improved chlorophyll synthesis and protein formation, which enhance overall plant vigor. These findings are in agreement with the reports of (Marawan and Sadiq, 2021). The significant interactions between irrigation, variety, and nitrogen level underscore the importance of integrated crop management. Matching irrigation and fertilization strategies with the optimal variety can lead to significant improvements in biomass accumulation, as indicated by the expanded leaf area observed in combinations such as IR2 × V2 × 120 kg N/fed and IR2 × V5 × 90 kg N/fed.

2.1. Total Soluble Solids (TSS %) and Sucrose %:

The increase in TSS percentage and sucrose percentage with reduced irrigation (IR2) suggests that moderate water stress enhances sugar accumulation in sorghum stalks. Excessive irrigation (IR1) likely leads to dilution effects, reducing sugar concentration, while severe water stress (IR3) might limit photosynthetic activity. These findings align with those of (Zelin *et al*., 2024), who reported similar trends in sorghum quality parameters under different irrigation regimes. The variations in TSS percentage and sucrose percentage among sweet sorghum varieties highlight genetic differences in sugar metabolism and accumulation. The superior performance of V5 in TSS percentage and sucrose percentage in the 2nd season suggests that this variety has a strong capacity for sugar synthesis and storage, making it more suitable for bioethanol production and other industrial uses.

The observed increase in TSS percentage and sucrose percentage with higher nitrogen application, particularly at 90 kg N/fed, may be attributed to nitrogen's role in stimulating enzymatic activity related to sugar metabolism. However, further increases in nitrogen levels (120 kg N/fed) did not always lead to higher sugar accumulation, indicating a possible threshold beyond which excess nitrogen promotes vegetative growth at the expense of sugar storage. These findings are in agreement with previous studies by (Yan *et al*., 2019). The significant interactions between irrigation, variety, and nitrogen fertilization emphasize the need for integrated management strategies to optimize sorghum quality. The highest TSS % and sucrose % resulted from IR2 × V4 × 90 kg N/fed and IR3 × V1 × 60-90 kg N/fed treatments, demonstrating that a balance between water supply, genetic selection, and fertilization is essential for maximizing sugar content in sorghum.

2.2. Purity percentage:

The findings indicate that reducing the number of irrigations contributed to an increase in purity percentage, particularly when irrigation was reduced to IR3 in the 1st season and IR2 in the 2nd season. This suggests that water stress might enhance sugar concentration by limiting excessive water uptake and dilution effects. These results are consistent with those mentioned by (Finch, 2020). The differences among varieties in purity percentage highlight the role of genetic variation, as V1 and V3 consistently outperformed others. This could be attributed to their superior genetic makeup, which allows them to maintain higher sugar purity under varying environmental conditions. These results were in agreement with those reported by (Mohamed *et al*., 2006). The observed positive response to nitrogen fertilization suggests that reducing nitrogen levels within an optimal range can enhance purity percentage, likely due to its role in improving sugar metabolism and reducing excessive vegetative growth. These results are consistent with those mentioned by (Marawan and Sadiq 2021; Zelin, *et al*., 2024). The significant interactions between irrigation, nitrogen levels, and varieties emphasize the need for tailored agronomic management. Optimizing irrigation and fertilization based on variety-specific responses can help maximize purity percentage and improve overall sorghum quality.

3. Yield and Its Components:

3.1. Stalk Weight / Plant:

The results indicate that the number of irrigations significantly affects stalk weight, with fewer irrigations (IR2 and IR3) leading to higher stalk weight values. This could be due to the reduction in soil moisture, which may stimulate plant growth in the examined conditions, as seen in the increase in stalk weight under IR2. These findings are consistent with previous research, which suggests that moisture stress can enhance plant growth by promoting better root development and nutrient uptake (Yan *et al*., 2019). The differences among varieties in stalk weight highlight the role of genetic variation in sorghum performance. Varieties like V1 and V3 outperformed others, indicating that their genetic makeup allows them to produce higher biomass under the tested conditions. Nitrogen fertilization further influenced stalk weight, with 90 kg N/fed proving to be the most effective in stimulating stalk growth, likely due to its impact on plant metabolism and growth processes. These observations may be due to the role of the nitrogen element effect in stimulating the meristemic activity and cell elongation of plants. These results are consistent with (Ismail *et al*., 2007). The interactions observed between irrigation, nitrogen levels, and varieties suggest that optimizing both irrigation and fertilization practices can significantly improve stalk weight. These findings emphasize the importance of adjusting agricultural practices to suit the specific variety and environmental conditions for optimal growth.

3.2. Stripped stalk yield and syrup yield/fed (ton):

The results suggest that reducing the number of irrigations up to IR2 (six irrigations) positively influenced both stripped stalk yield and syrup yield, likely due to optimized water availability, which prevented excessive vegetative growth and improved sugar concentration. However, further reductions in irrigation (IR3) led to a decline in yield, possibly due to increased water stress. These results are consistent with those mentioned by (Yan *et al*., 2019). The observed differences among sorghum varieties indicate that genetic variation plays a crucial role in yield potential, with V1 and V2 showing superior performance in stripped stalk yield, while V1 exhibited the highest syrup yield across both seasons. These differences may be attributed to varying genetic responses to environmental conditions (Mohamed *et al*., 2006). The effect of nitrogen fertilizer on yield highlights its importance in stimulating plant growth and improving sugar accumulation. The results indicate that excessive nitrogen (beyond 120 kg N/fed) does not necessarily enhance syrup yield and may instead promote excessive vegetative growth at the expense of sugar accumulation. These observations may be due to the role of the nitrogen element effect in stimulating the meristemic activity and cell elongation of plants. These results are consistent with (Marawan and Sadiq, 2021). The significant interactions between irrigation, nitrogen levels, and varieties underline the importance of integrated agronomic management. Optimizing irrigation and fertilization strategies based on variety-specific responses can maximize both stripped stalk yield and syrup yield while ensuring efficient resource utilization.

4. AMMI and GGE biplot analysis:

The polygon views in both AMMI and GGE biplots provided insight into genotype performance across environments. In AMMI (Fig. 1), G.R Coba and Tracy exhibited high mean yields with specific adaptation to environments E2, E6, E8, and E9. Among them, Tracy had a higher yield overall, but G.R Coba showed stronger specific adaptability. Likewise, MN 4490 was well adapted to E1 and E7. AMMI Analysis. Genotypes or environments located on the right-hand side of the midpoint of the axis (IPCA1) have higher yields than those on the left-hand side (Ngeve and Bouwkamp, 1993). In the GGE biplot (Fig. 2), Ahron was identified as a winning genotype in multiple environments, particularly E2, E5, E7, and E8, with Sugar-Drip favoring E3, E6, and E9. Interestingly, MN 4490 remained specifically adapted to E1, while G.R Coba and Tracy showed poor adaptability across the studied environments in GGE analysis. Dynamic as opposed to static stability is preferred by breeders and agronomists to have genotypes that could produce more yields when optimal agronomic inputs and favorable environmental conditions are provided (Djurovi´c *et al*., 2014). The placement of genotypes on the vertex of the polygon suggests potential superiority or inferiority in certain environments (Hagos and Abay, 2013). These findings align with previous reports by (Reddy *et al*., 2014; Rao *et al*., 2011) on high-yielding and stable genotypes for stalk yield.

Furthermore, genotypes with large PC1 scores (indicating high mean yield) and small PC2 scores (indicating high stability) are considered ideal (Frashadfar *et al*., 2012). Based on this criterion, Ahron emerged as the most suitable variety for E8, characterized by 90 kg N/fed application under IR2 (six irrigations), suggesting its potential for high stripped stalk yield under such agronomic conditions.

CONCLUSION

Under the conditions of this study, it was noted that, the Sorghum Ahron variety that was subjected to IR2 (six irrigations), and fed with 120 kg N/fed, produced the greatest stripped stalk yield in both seasons. Whereas, the same variety when irrigated with IR2 (six irrigations), and fed with 120 kg N/fed fertilization in the 1st season, and MN 4490 variety when irrigated with IR1 (seven irrigations), and fed with 60 kg N/fed fertilization, in the 2nd season produced the greatest syrup yield. As same as, according to the AMMI and GGE biplot analysis, variety Ahron was the winning genotype for strip stalk yield when feed 90 kg N/fed and irrigated with IR2 (six irrigations).

REFERENCES

A.O.A.C. (1995). *Official methods of analysis* (16th ed.). Association of Official Analytical Chemists.

Abd El-Lattief, E. A. (2011). Nitrogen management on the production of two sweet sorghum cultivars under arid region conditions. *Asian Journal of Crop Science, 3*, 77–84.

Abou-Amer, A. I., & Kewan, K. Z. (2014). Effect of NP fertilization levels on sorghum (*Sorghum bicolor* L.) yield and fodder quality for animals. *Alexandria Journal of Agricultural Research, 59*(1), 51–59.

Almodares, A., & Hoseini, S. H. (2016). Effect of sowing dates and nitrogen levels for ethanol production from sweet sorghum stalks and grains. *African Journal of Agricultural Research, 11*(4), 266–275.

Almodares, A., Ranjbar, M., & Hadi, M. R. (2010). The effects of nitrogen treatments and harvesting stages on the aconitic acid, invert sugar, and fiber in sweet sorghum cultivars. *Journal of Environmental Biology, 31*(6), 1001–1005.

Besheit, R. S., & Mekdad, A. A. (2016). Effect of nitrogen fertilization on the productivity and sensitivity of two sweet sorghum varieties to pink stem borer (*Sesamia cretica* Led.) infestation. *Assiut Journal of Agricultural Sciences, 47*(6-1), 1–17.

Bollam, S., Romana, K. K., Rayaprolu, L., Vemula, A., Das, R. R., Rathore, A., ... & Gupta, R. (2021). Nitrogen use efficiency in Sorghum: exploring native variability for traits under variable N-Regimes. *Frontiers in Plant Science*, *12*, 643192.

Bonfim-Silva, E. M., Da Silva, T. J. A., Cabral, C. E. A., Kroth, B. E., & Rezende, D. (2011). Initial development of grasses under water stress. *Revista Caatinga, 24*(1), 180–186

Buffo, R. A., Weller, C. L., & Parkhurst, A. M. (1998). Relationships among grain sorghum quality factors. *Cereal Chemistry*, *75*(1), 100-104.

Champan, H. D., & Pratt, P. F. (1978). Methods of analysis for soil, plant and water. *University of California, Division of Agriculture*.

Dicko, M. H., Gruppen, H., Traoré, A. S., Voragen, A. G., & van Berkel, W. J. (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African journal of biotechnology*, *5*(5), 384-395.

Djanaguiraman, M., & Ramesh, D. (2013). Increasing mill able cane yield of sweet sorghum through altered nitrogen, population level and plant growth regulators spray. *Crop Production*, *2*(1), 08-18.

Djodda, J., Nukenine, E. N., Ngassam, P., & Yougouda, H. (2013). Degree of infestation of transplanted sorghum (*Sorghum bicolor* L. Moench) by Lepidoptera stem borers and their biodiversity in Diamaré (Maroua, Cameroon). *American Open Journal of Agricultural Research, 1*(1), 1–7.

Djurovi´c, D. S., Madi´c, M. R., Bokan, N. R., Stevovi´c, V. I., Tomi´c, D. D., & Tanaskovi´c, S. T. (2014). Stability parameters for grain yield and its component traits in maize hybrids of different FAO maturity groups. *Journal of Central European Agriculture, 15*(4), 199–212.

El-Hawary, M. A., Hager, M. A., Abd-Elkader, A. M., & KHallf Alla, Y. Z. (2012). Effect of irrigation intervals and nitrogen fertilizer on growth and yield of two sweet sorghum varieties. *Journal of Plant Production, Mansoura University, 3*(5), 819–833.

Finch, T. (2020). Restoring farmlands for food and nature. *One Earth*, *3*(6), 665-668.

Frashadfar, E., Safari, H., & Jamshidi, B. (2012). GGE biplot analysis of adaptability in wheat substitution lines. *International Journal of Agriculture and Crop Sciences, 4*(13), 877–881.

Galal, A. O. M., Yousif, E. M. M., & Abo ELenen, F. M. F. (2019). Response of four sweet sorghum varieties to different levels of nitrogen fertilization. *Journal of Chemical and Environmental Sciences, 14*(4), 79–96.
Gebremedhin, W., Firew, M., & Tesfye, B. (2014). Stability analysis of food barley genotypes in Northern Ethiopia. *African Crop Science Journal, 22*, 145–154.
Gardner, F. P., Pearce, R. B., & Michell, R. L. (1985). *Physiology of crop plants*. Iowa State University Press.
Hagos, G. H., & Abay, F. (2013). AMMI and GGE biplot analysis of bread wheat genotypes in the northern part of Ethiopia. *Journal of Plant Breeding and Genetics, 1*(1), 12–18.
Ismail, A. M. A., Mohamed, S. A., Samia, Y. M., & Nahed Zohdy, O. (2007). Response of sweet sorghum to nitrogen and bio-fertilization treatments. *Egyptian Journal of Agricultural Research, 85*(2), 573–586.
Kimber, C. T. (2000). Origins of domesticated sorghum and its early diffusion to India and China. In C. W. Smith & R. A. Frederiksen (Eds.), *Sorghum: Origin, history, technology, and production* (pp. 3–98). John Wiley & Sons.
Li, D., Liu, H., Gao, S., Leghari, S. J., Hou, H., & Li, Y. (2023). Effect of post-drought rehydration on winter wheat fluorescence and photosynthetic indices under different levels of nitrogen application. *Water*, *15*(2), 305.
Marawan, N. R., & Sadiq, J. M. (2021). Evaluation of the response of sorghum to tillage systems and nitrogen fertilization. *International Journal of Agronomy, 2021*, 1–12.
Miller, R. W., & Creelman, S. D. (1982). Sorghum: A new fuel. In *35th Annals. Corn and Sorghum Research Conference* (pp. 219–232).
Mohamed, K. E., Ferweez, H., & Allam, S. M. (2006). Effect of K fertilization on yield and quality of sweet sorghum juice and syrup. *Bulletin of Faculty of Agriculture, Cairo University, 57*, 401–416.
Morris, G. P., Ramu, P., Deshpande, S. P., Hash, C. T., Shah, T., Upadhyaya, H. D., ... & Kresovich, S. (2013). Population genomic and genome-wide association studies of agroclimatic traits in sorghum. *Proceedings of the National Academy of Sciences*, *110*(2), 453-458.
Ngeve, J. M., & Bouwkamp, J. C. (1993). Comparison of statistical methods to assess yield stability in sweet potato. *Journal of American Society Horticultural Sciences, 118*, 304–310.
Rao, P. S., Reddy, P. S., Rathore, A., Reddy, B. V., & Panwar, S. (2011). Application of GGE biplot and AMMI model to evaluate sweet sorghum (*Sorghum bicolor*) hybrids for genotype × environment interaction and seasonal adaptation. *Indian Journal of Agricultural Sciences, 81*(5), 438–444.
Reddy, B., Ramesh, S., Reddy, S., Ramaiah, B., Salimath, P., & Kachapur, R. (2005). Sweet sorghum: A potential alternative raw material for bioethanol and bio-energy. *International Sorghum and Millets Newsletter, 46*, 79–86.
Sawargaonkar, G. L., Patil, M. D., Wani, S. P., Pavani, E., Reddy, B. V. S. R., & Marimuthu, S. (2013). Nitrogen response and water use efficiency of sweet sorghum cultivars. *Field Crops Research, 149*, 245–251.
Singh, R. K., & Singh, G. P. (1998). Effect of sampling time on efficacy of selection for quality traits in sugar cane. *Sugar Cane, 3*, 13–17.
Staggenborg, S. A., Dhuyvetter, K. C., & Gordon, W. B. (2008). Grain sorghum and corn comparisons: Yield, economic, and environmental responses. *Agronomy Journal, 100*(6), 1600–1604.
Trouche, G., Da, S., Pale, G., Sohoro, A., Ouedraogo, O., & Den Gosso, D. (2001). Évaluation participative de nouvelles variétés de sorgho au Burkina. In H. Henri & L. Jacques (Eds.), *La sélection participative: Impliquer Les Utilisateurs Dans L'amélioration Des Plantes* (36–55). CIRAD-MICAP.
Umakanth, A. V., Sai Krishna Nikhil, B., & Tonapi, V. A. (2019). Genetic diversity studies in sweet sorghum [*Sorghum bicolor* (L.) Moench], a candidate crop for biofuel production. *Forage Research, 45*(1), 28–32.
VSN International. (2012). *GenStat for Windows* (15^{th} ed.).
Wang, J. S., Guo, R., Dong, R. W., Ding, Y. C., Han, X., & Jiao, X. Y. (2012). Effects of different irrigation amounts on the growth, yield, and water use efficiency of sorghum. *Chinese Agricultural Science Bulletin, 28*, 156–160.
Wang, Z., Nie, T., Lu, D., Zhang, P., Li, J., Li, F., ... & Waller, P. M. (2024). Effects of Different Irrigation Management and Nitrogen Rate on Sorghum (*Sorghum bicolor* L.) Growth, Yield and Soil Nitrogen Accumulation with Drip Irrigation. *Agronomy*, *14*(1), 215.
Yan, F., Zhang, F., Fan, X., Fan, J., Wang, Y., Zou, H., ... & Li, G. (2021). Determining irrigation amount and fertilization rate to simultaneously optimize grain yield, grain nitrogen accumulation and economic benefit of drip-fertigated spring maize in northwest China. *Agricultural Water Management*, *243*, 106440.
Zelin, W., Nie, T., Lu, D., Zhang, P., Li, J., Li, F., Zhang, Z., … & Waller, P. M. (2024). Effects of different irrigation management and nitrogen rate on sorghum (*Sorghum bicolor* L.) growth, yield and soil nitrogen accumulation with drip irrigation. *Agronomy, 14*(1), 215. https://doi.org/10.3390/agronomy14010215

انتاجية وجودة بعض أصناف الذرة السكرية تحت تأثير التسميد النيتروجيني ونظام الري

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يُعدّ نبات الذرة السكرية من المحاصيل الغذائية الهامة على مستوى العالم. هدفت هذه الدراسة إلى تقييم أداء خمسة أصناف من الذرة السكرية تحت مستويات مختلفة من التسميد النيتروجيني ومعدلات الري، مع التركيز على صفات النمو، والإنتاجية، والخصائص التكنولوجية. أُجريت التجارب الحقلية في تربة طينية صفراء باستخدام نظام الري بالغمر في محطة بحوث المحاصيل السكرية بالصباحيه، محافظة الإسكندرية، مصر، خلال موسمي 2021 و2022. استُخدم تصميم القطاعات العشوائية الكاملة (RCBD) بنظام القطع المنشقة المتكررة بثلاث مكررات، حيث خُصصت القطع الرئيسية لمعدلات الري: ري كامل بسبع ريات (الكونترول)، ست ريات (مع حذف السابعة)، وخمس ريات (مع حذف السادسة والسابعة). أما القطع الثانوية فخُصصت لثلاثة مستويات من السماد النيتروجيني (60، 90، و120 كجم ن/فدان)، بينما وُزعت الأصناف الخمسة (Ahrone، G.R Coba، Sugar Drip، Tracy، وMN 4490) عشوائيًا في القطع الثانوية الفرعية. أظهرت النتائج وجود تأثير معنوي لمعدلات الري ومستويات النيتروجين والصنف على أبعاد الساق، مساحة الورقة، الإنتاجية، وصفات الجودة في كلا الموسمين. كما بين تحليل AMMI وGGE أن الصنف "Ahrone" كان الأفضل من حيث إنتاجية السيقان عند التسميد بـ90 كجم ن/فدان والري ست مرات (IR2). وتُبرز هذه النتائج أهمية تحسين إدارة الري والتسميد النيتروجيني إلى جانب اختيار الصنف المناسب لتعزيز إنتاجية وجودة الذرة السكرية.
الكلمات المفتاحية: الذرة السكرية، الأصناف، التسميد النيتروجيني، الري، إنتاج الساق.