Research Article

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Response of biomass, grain production, and sugar content of four sorghum plant varieties (*Sorghum bicolor* (L.) Moench) to different plant densities

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Abstract: Sorghum (*Sorghum bicolor* (L.) Moench) is a potential plant for food, livestock feed, biofuel, sugar, alcohol, and other bioindustry products. Sorghum could be adaptable to grow and expand in marginal areas of the world. Varieties of sorghum have their specific morpho-agronomic characters. It would be significant to compare the performance of multiple sorghum varieties to identify a suitable one for the intended use. The increase in biomass plant production could be caused by cultivation factors, such as an increased planting density. This study aims to determine the response of four different sorghum varieties to the treatment of the plant density on the biomass, grain production, and sugar content of stem juice. This research was conducted using two factors: sorghum variety ("Super 1," "Keler," "Lepeng," and "Rio") and the plant density (two, four, and six plants per hole or 106,667; 213,333; and 320,000 plants ha^{-1}, respectively). The results of the study showed that all four sorghum varieties tested could be used as biomass resources. The highest plant dry biomass was gained from six plants per hole with 44.0 t ha^{-1}, whereas the lowest one was two plants per hole with 30.4 t ha^{-1}. "Super 1" was a superior variety due to the significant highest sugar content of the stem juice (13.9°Brix) and grain production. "Lepeng" variety was the lowest in both sugar content (8°Brix) and grain production, whereas "Keler" and "Rio" varieties contained sugar in between 8.5 and 10.8°Brix of the stem juice.

Keywords: sorghum, variety, biomass, sugar content, density

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1 Introduction

Food and energy crises have become the main global challenges with the increase in population. Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most widely produced cereal crop in the world after corn, rice, wheat, and barley [1]. Sorghum is a multipurpose crop, which produces food, fodder, sugars, fibers, and other bioindustrial products [2–4]. Recently, the crop has also been getting attention as a source of bioenergy. Sweet sorghum plants accumulate sugars at high concentrations in their stems, which can be readily converted to liquid fuels by fermentation [5]. In addition, the crop is also promising as the source of biomass that can be converted into liquid fuels via the second-generation bioethanol production or biopellet for direct combustion. Pellet made from sorghum biomass has been estimated to have a potential for substituting fossil fuel in electricity generation [6]. Current technology of field-based phenotyping for sorghum biomass has also been developed [7].

Climate change induces the increases of abiotic stresses including drought, high and low temperatures, soil salinity, nutrient deficiencies, and toxic metals [8]. Sorghum is a tolerant crop to adverse environmental conditions, including low fertility, drought, salinity, and high temperature [9–11]. Due to its high adaptability to grow in marginal land areas, sorghum has been an emerging favorite multipurpose crop in recent years [9]. Crop production can be increased through agricultural expansion or input use [8,12]. Hence, the sorghum crop can also be an option to be expanded in marginal land of the world.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a major repository for world sorghum germplasm. It has recorded a total of 36,774 accessions from 91 countries [13]. The germplasm of sorghum in the world is also the source of traits to improve food and fodder quality, animal feed, and industrial products. Varieties or accessions of sorghum have their specific morpho-agronomic characters. The desirable characters can also be different according to the usage; for example, a higher yield of grain is important in the case of cultivation for food, whereas a higher accumulation of sugars in their stem is required for biofuel production [14–17]. Hence, it would be significant to compare the performance of multiple sorghum varieties to identify a suitable one for the intended use.

For most crops, including sorghum, plant density has a major influence on biomass, crop yield, and economic profitability. Therefore, optimizing plant density, which may be defined by both the number of plants per unit area and the arrangement of plants on the ground, is a prerequisite for obtaining higher productivity [18–25]. High plant density is one of the main agronomic practices required to achieve maximum yields in modern cropping systems [26–30]. Planting grain sorghum with a density from 2 to 16 plants m^{-2} provided dynamics of plant growth; however, it needs to be validated by testing for other cultivars to get the general framework for the growth modeling [31]. Understanding the growth and production response to the plant population density of varieties in sorghum is of great importance to determine the optimal sowing density.

In this study, we compared the performance of different sorghum varieties while examining the effects of the number of seeds sown per hole, intending to find suitable varieties and plant density to be used in sorghum cultivation in marginal lands. Examined parameters include growth, biomass, grain production, and sugar content of stem juice, assuming the use of sorghum not only for a food source but also for biomass and sugar content in support of energy production. The results of studies should provide useful information not only for the farmers and business stakeholders but also for policymakers or local governments.

The hypotheses for this study are as follows: (1) sorghum varieties possess morpho-agronomic characteristics and the varieties tested are suitable for the intended use; (2) sorghum plants will have the optimal population density to get maximum production; and (3) since the soil fertility and water are available, the optimal plant density will depend on the above-ground competition.

2 Materials and methods

In this study, we compared the performance of four sorghum varieties under the different densities of seed sowing to find the best practice to get higher yields in the cultivation of this crop in marginal lands. As a case study, the source of sorghum varieties/accessions tested was from Indonesia, and the study location was in Indonesia. The results of this study could be adopted and used as a reference to the other countries, especially with similar environmental conditions to those in Indonesia.

2.1 Research location

The research was conducted from August 2018 to January 2019 at Cibinong Science Center and Botanic Gardens of the National Research and Innovation Agency, Bogor Regency of West Java, Indonesia. The altitude of the field was 250 m above sea level. During the study period, monthly average minimum and maximum temperatures were 25.88°C and 26.59°C, respectively; average daily air humidity ranged between 74.55 and 84.13%; average daily wind speed ranged within 1.33 and 1.80 km h^{-1}; and the average daily rainfall ranged between 7.37 and 20.35 mm [32].

The chemical properties of the soil in the study field were analyzed in all plots before cultivation. Soil pH was rather acidic ranging between 5.2 and 6.2 (Appendix Table 1). The soil contained a low-to-high organic carbon (C) and a low-to-medium total nitrogen (N), giving a low-to-high C/N ratio. Cation exchange capacity was low to medium, and available phosphorus ranged from medium to high. The soil texture was clay (Appendix Table 1) and classified as alfisol.

2.2 Experimental design of field trials

In this study, we used four sorghum varieties/accessions of species *Sorghum bicolor* (L.) Moench, namely "Super 1," "Keler," "Lepeng," and "Rio," which were collected by ICABIOGRAD, the Ministry of Agriculture in Bogor, West Java of Indonesia. The variety of "Super 1" was released by the Ministry of Agriculture of Indonesia in 2013 as an improved cultivar or superior sweet sorghum [2,10]. The variety of "Super 1" was used as a control, whereas the other three varieties as traditional cultivars were chosen for this study due to high plant biomass potencies from an earlier study. Thus, the potential use of those varieties needs to be explored further, not only plant biomass value but also grain production and sugar content of stem juice.

The seeds were sown at either two, four, or six seeds per hole. The experiments were conducted in a randomized complete block design with the two factorials and with three replications; hence, in total, 36 plots were prepared. The plots were 5 m × 5 m in size and placed 4 m apart. Sorghum seeds were planted in the holes 25 cm apart with 75 cm between the rows. Therefore, the plant densities of sorghum treatments were 106,667, 213,333, and 320,000 plants ha^{-1}, respectively.

The soil was plowed and applied with 10 kg compost per plot before planting. Triple superphosphate (150 kg ha^{-1}) and potassium chloride (150 kg ha^{-1}) were applied as fertilizer 100% at the time of planting; furthermore, urea fertilizer (300 kg ha^{-1}) was also applied 50% at the time of planting and 50% at 1 month after planting.

2.3 Measurement of parameters

Plant growth parameters were analyzed at the flowering period, including plant height (cm), leaf number, leaf length (cm), and stem diameters (cm). Production-related parameters were analyzed at harvest, including the dry weight of plant (g), panicle weight (g), grain weight (g), and content of sugar in stem juice (°Brix). Plant growth parameters were measured with ten randomly selected individuals from each plot. Stem diameter was measured at 30 cm above soil level using a digital caliper LCD Screen 150 mm (MOLLAR). Production-related parameters and sugar content were measured with three randomly selected individuals. Sugar contents were measured in triplicate with juice taken from the middle part of the stem using the digital refractometer (Minolta, Palette Series, ATAGO Limited Company).

2.4 Statistical analysis of the data

All the parameters were compared between the treatment using analysis of variance (ANOVA) followed by *post hoc* LSD Tukey test using Minitab 14 (Minitab Inc. Pennsylvania, USA, 2006). The analysis comprises solely the effect of sorghum varieties (“Super 1,” “Keler,” “Lepeng,” and “Rio”) and the effect of the number of seeds sowing (two, four, and six seeds per cultivation hole), as well as the interaction between sorghum variety and the number of seeds sowing.

3 Results

3.1 Growth-related parameters

The varieties of sorghum tested significantly affected all related growth parameters, that is, plant height, leaf length, leaf number, and stem diameter (Tables 1 and 2, Appendix Tables 2–5). However, the plant density treatment also affected all related growth parameters except the plant height parameter (Tables 1 and 3, Appendix Tables 2–5). There was no significant interaction effect between the variety and plant number per hole in all growth parameters (Table 1, Appendix Tables 2–5).

“Super 1” exhibited the highest values in leaf length (96.1 cm), whereas “Keler” had the shortest leaves (71.0 cm). The variety “Keler” produced the fewest number of leaves (9.8 leaves) as compared to those of the other sorghum varieties, which varied from 11.5 to 12.1 leaves.

“Lepeng” showed the shortest plant (337.6 cm) but with the highest stem-diameter size (2.3 cm). The stem diameter of all varieties, except that of “Lepeng” variety tested was in between 1.63 and 1.84 cm. “Lepeng” had shorter leaves (84.7 cm) than those of “Super 1” (96.1 cm) but longer leaves than those of “Keler” (71.0 cm). “Lepeng”

Table 1: ANOVA results of different plant growth parameters

Source	Plant height (cm)		Leaf length (cm)		Leaf number		Stem diameter (cm)	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Varieties (*V*)	6.29	0.003**	90.05	0.0000**	12.38	0.0000**	27.88	0.000**
Plant number (*N*)	2.79	0.081 ns	5.86	0.0080**	6.38	0.0060**	28.84	0.000**
*V**N*	1.30	0.294 ns	2.04	0.1230 ns	1.36	0.269 ns	0.84	0.836 ns

Note: ns, not significantly different; *, significantly different at $p < 0.05$; **, significantly different at $p < 0.01$.

Table 2: Growth parameters observed in sorghum plants affected by varieties treatment

Varieties	Plant height (cm)	Leaf length (cm)	Leaf number	Stem diameter (cm)
"Super 1"	349.9 ± 11.45[b]	96.1 ± 4.23[c]	12.0 ± 0.96[b]	1.81 ± 0.22[a]
"Keler"	351.9 ± 10.37[b]	71.0 ± 2.59[a]	9.8 ± 1.11[a]	1.63 ± 0.31[a]
"Lepeng"	337.6 ± 7.95[a]	84.7 ± 4.36[b]	11.5 ± 1.02[b]	2.30 ± 0.27[b]
"Rio"	355.2 ± 9.72[b]	82.0 ± 4.48[b]	12.1 ± 1.34[b]	1.84 ± 0.26[a]

Note: Values represent means ± standard deviation. Different letters in the same column indicate a significant difference at $p < 0.05$.

Table 3: Growth parameters observed in sorghum affected by the number of seeds per hole treatment

Number of plants per hole	Plant height (cm)	Leaf length (cm)	Leaf number	Stem diameter (cm)
2	350.41 ± 15.88[a]	84.3 ± 11.20[b]	12.1 ± 1.63[b]	2.17 ± 0.25[b]
4	351.97 ± 8.67[a]	85.1 ± 10.10[b]	11.2 ± 1.41[a]	1.84 ± 0.32[a]
6	343.62 ± 7.95[a]	80.9 ± 8.28[a]	10.8 ± 0.98[a]	1.67 ± 0.33[a]

Note: Values represent means ± standard deviation. Different letters in the same column indicate a significant difference at $p < 0.05$.

showed a higher leaf number (11.5 leaves) than that of "Keler" (9.8 leaves) but no differences from that of "Super 1" and "Rio" (12.0 and 12.1 leaves, respectively). "Rio" exhibited higher plant (355.2 cm) than that of "Lepeng" (337.6 cm) but similar to that of "Super 1" and "Keler" (349.9 and 351.9 cm, respectively). "Rio" also showed similar leaf length (82.0 cm) and leaf number (12.1 leaves) to those of "Lepeng" (84.7 cm and 11.5 leaves, respectively).

Plant height was not affected by the plant density. Plants in the treatment with two or four plants per hole had significantly longer leaves (84.3 and 85.1 cm, respectively) than those of the plants in the treatment with six plants per hole (80.9 cm). Plants in the treatment with two plants per hole had significantly more leaves (12.1 leaves) and larger stem diameter (2.17 cm) than those of plants in the treatment with four or six plants per hole, which were from 10.8 to 11.2 leaves and from 1.67 to 1.84 cm, respectively. These results suggest that increasing the number of plants per hole led to a decrease in plant growth.

3.2 Production-related parameters

The variety significantly affected grain weight and sugar content in stem juice but did not affect the dry weight of plant biomass, dry weight of stem biomass, and panicle weight (Tables 4 and 5, Appendix Tables 6–10). However, the plant density treatment affected all the related production parameters except for sugar content (Tables 4 and 6, Appendix Tables 6–10). There was no significant interaction effect between the variety and the plant density treatments.

Similar to the case of growth parameters, "Super 1" exhibited a higher grain production (33.6 g) although the grain weights of "Keler" and "Rio" were not significantly different from that of "Super 1" (30.8 and 32.7 g, respectively). However, "Lepeng" produced the lowest amount of grain within the varieties examined (22.3 g). In terms of sugar content in stem juice, "Super 1" was ranked as the first (13.9°Brix), followed by "Rio" (10.8°Brix), "Keler" (8.5°Brix), and "Lepeng" (8.0°Brix) (Table 5).

Table 4: ANOVA results of plant dry weight, stem dry weight, panicle weight, grain weight, and sugar content

Source	Plant dry weight (g)		Stem dry weight (g)		Panicle weight (g)		Grain weight (g)		Sugar content (°Brix)	
	F value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Varieties (*V*)	0.93	0.441 ns	2.42	0.091 ns	0.65	0.590 ns	4.00	0.019*	72.20	0.000**
Plant number (*N*)	5.79	0.009**	4.35	0.024*	4.55	0.021*	20.96	0.000**	1.00	0.384 ns
*V***N*	0.49	0.806 ns	0.52	0.790 ns	0.82	0.567 ns	1.92	0.119 ns	2.29	0.069 ns

Note: ns, not significantly different; *, significantly different at $p < 0.05$; **, significantly different at $p < 0.01$.

Table 5: Production and sugar content parameters observed in sorghum plants affected by varieties treatment

Varieties	Plant dry weight (g)	Stem dry weight (g)	Panicle weight (g)	Grain weight (g)	Sugar content (°Brix)
"Super 1"	738.81 ± 195.57^{a}	387.74 ± 101.19^{a}	185.37 ± 61.41^{a}	33.6 ± 11.44^{b}	13.9 ± 1.26^{c}
"Keler"	611.64 ± 163.81^{a}	290.79 ± 87.46^{a}	210.30 ± 48.79^{a}	30.8 ± 17.26^{b}	8.5 ± 1.02^{a}
"Lepeng"	697.19 ± 187.13^{a}	295.06 ± 73.85^{a}	225.57 ± 49.88^{a}	22.3 ± 7.88^{a}	8.0 ± 1.12^{a}
"Rio"	686.72 ± 234.28^{a}	289.98 ± 122.30^{a}	193.02 ± 112.52^{a}	32.7 ± 8.59^{b}	10.8 ± 0.74^{b}

Note: Values represent means ± standard deviation. Different letters in the same column indicate a significant difference at $p < 0.05$.

Table 6: Production and sugar content parameters observed in sorghum affected by the number of plants per hole treatment

Number of plants per hole	Plant dry weight (g)	Stem dry weight (g)	Panicle weight (g)	Grain weight (g)	Sugar content (°Brix)
2	570.90 ± 106.42^{a}	245.7 ± 51.3^{a}	168.9 ± 44.95^{a}	41.2 ± 11.96^{b}	10.03 ± 2.23^{a}
4	670.73 ± 167.00^{a}	311.7 ± 100.4^{ab}	192.6 ± 61.81^{ab}	26.1 ± 6.61^{a}	10.34 ± 2.59^{a}
6	824.97 ± 218.67^{b}	373.6 ± 118.3^{b}	249.2 ± 82.07^{b}	22.3 ± 8.08^{a}	10.57 ± 3.00^{a}

Note: Values represent means ± standard deviation. Different letters in the same column indicate a significant difference at $p < 0.05$.

Table 6 shows the detail of significant effects of the plant density on production-related parameters. Plants in the treatment with six plants per hole or 320,000 plants ha^{-1} produced higher biomass dry weight, stem dry weight, and panicle weight (824.97, 373.6, and 249.2 g, respectively) than those in the treatment with two or four seeds per hole (from 570.90 to 670.73 g, from 245.7 to 311.7 g, and from 168.9 to 192.6 g, respectively). However, grain weight was significantly higher in two-seed plots (41.2 g) than that in the four- or six-seed plots (26.1 and 22.3 g, respectively). These results suggest that increasing the number of seeds per hole could lead to an increase in biomass production per area, but it could cause a decrease in grain production (Table 6).

4 Discussion

Statistical analysis of the results showed that there were significant differences between varieties in growth (plant height, leaf length, leaf number, and stem diameter), grain production, and sugar content of stem juice (Tables 1 and 4). These results could be caused by the different morpho-agronomic characters of the varieties tested. Meanwhile, there was no significant difference between varieties in plant biomass, stem biomass, and panicle weight (Table 4). This result suggests that even though there were the different morpho-agronomic characters of the four varieties tested in this study, all of the varieties are equally useful as the source of biomass for energy production. However, regarding the grain production, "Lepeng" was inferior to the other three varieties (Table 5). Another study on 36 Indonesian local sorghum varieties selected 15 as promising accessions based on their grain production potential [9], which could also be promising as the varieties for grain production. "Super 1," "Keler," and "Rio" produced grains at around 30 g per hole (having plants from two to six seeds). These three varieties might also be useful and prospective to be developed in the case where grain is the intended product.

The sugar content of stem juice was highest in "Super 1," followed by "Rio" (Table 5). Higher sugar content could be a merit as the feedstock for biofuel production [33]. The accumulation of sugars in the stem is influenced by several metabolic and transport processes as well as consumption within the sink cell [34]. Because higher sugar contents in the stem indicate that more carbohydrates are retained in the stem instead of being transported to the maturing seed kernels, there could be a trade-off among biomass, grain, and sugar production. Nonetheless, in this study, "Super 1" exhibited the highest values in both grain and sugar production among the varieties (Table 5). As such, this variety could be used for both sugar and grain production.

Examination of the effects of plant density indicated that the practice made difference in plant growth (leaf length, leaf number, and stem diameter) and production (plant biomass, stem biomass, and grain weight) but not in sugar content (Tables 1 and 4). Results shown in

Table 6 demonstrate that the more plants per hole, the more plant biomass, stem dry weight, and panicle weight. The produced biomass dry weight 571, 671, or 825 g per hole corresponds to 30.4, 35.8, or 44.0 t ha^{-1}, respectively. Similar findings regarding the seed number and biomass production have been reported by several previous studies [18,21,24,25]. The seed rate of 45 kg ha^{-1} recorded maximum dry matter accumulation as compared to that of 30 and 35 kg seed ha^{-1} for fodder or biomass production [19]. Such an increase in biomass production per area via increasing plant density tends to occur when actual yields are close to potential yields [27,35], that is, under the situation where the environmental factors such as nutrients or water are not limiting. Under such conditions, light is the major limiting factor of biomass production [36]. Faster canopy closure and/or greater radiator interception with narrower row spacing configurations may be the physiological mechanism underlying the net increase in production [27,31,36,37].

However, the growth of individual plants (leaf length and leaf number) and grain production were decreased by increasing the plant density (Tables 3 and 6). The weight of grain produced in two-, four-, or six-seed per hole plots corresponds to 2.2, 1.4, and 1.2 t ha^{-1}, respectively. The panicle weight per hole was increased by increasing the number of seeds per hole. Therefore, the number of panicles per area was increased in plots with six-seed per hole treatment, but the panicles might have fewer or smaller seeds than those in two-seed per hole plots. The result of another study exhibited the highest seed vigor when a single seed was sown in a hole, as compared to the case of sowing multiple seeds per hole [38]. The results of the effect of plant densities on the leaf size, leaf number, and grain production of some sorghum varieties tested could be ascribed to the morpho-agronomic character of the varieties and competition for resources such as nutrients, water, and especially solar radiation among plants [27,31,36]. The result was also in accordance with Tabri [39], which suggests growing sorghum at two plants per hole or 106,667 plants ha^{-1} to get maximal grain yield. Hence, the number of seeds per hole should be limited if the intended product is grain as food or fodder.

5 Conclusion

All four varieties examined (“Super 1,” “Rio,” “Keler,” and “Lepeng”) were comparable in terms of biomass production and could be used as biomass production sources. “Super 1” was found to be a superior variety having the highest potential in sugar and grain production among the varieties examined in this study. “Keler” and “Rio” should be useful and could be developed for grain production purposes. It is recommended to sow two seeds per hole or 106,667 plants ha^{-1} to gain high grain production. However, the plant density could be increased up to 320,000 plants ha^{-1} to get the highest biomass production.

Future studies should examine additional sorghum varieties. Findings from the study would provide information that is useful in the cultivation of this crop to utilize the marginal lands.

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Appendix

Table 1: Results of soil analysis prior to the study

No	Parameter		Method	Unit	Result	Category
1	Organic C		Walkey & Black/Gravimetry	%	1.75–3.30	Low–high
2	Total N		Kjeldahl	%	0.12–0.25	Low–medium
3	C/N ratio		Calculation	—	8–18	Low–high
4	Available P_2O_5		Bray/Olsen	ppm	7.29–201	Medium–high
5	Cation exchange capacity		N NH_4OAc	cmol kg^{-1}	13.93–23.21	Low–medium
6	Soil water content		Gravimetry	%	6.71–12.39	—
7	pH(H_2O)		Potentiometry	—	5.20–6.22	Rather acid
8	Soil texture	Sand	Pipet	%	7–30	Clay
		Silt			22–37	
		Clay			43–60	

Table 2: ANOVA of sorghum plant height parameter (two-way ANOVA: plant height versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	1,599.49	533.162	6.29	0.003
Plant number	2	473.40	236.701	2.79	0.081
Interaction	6	662.05	110.342	1.30	0.294
Error	24	2,034.84	84.785		
Total	35	4,769.78			

S, 9.208; *R*-Sq, 57.34%; *R*-Sq (adj), 37.79%.

Table 3: ANOVA of sorghum leaf length parameter (two-way ANOVA: leaf length versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	2,872.74	957.580	90.05	0.000
Plant number	2	124.63	62.313	5.86	0.008
Interaction	6	130.01	21.668	2.04	0.100
Error	24	255.22	10.634		
Total	35	3,382.59			

S, 3.261; *R*-Sq, 92.46%; *R*-Sq (adj), 89.00%.

Table 4: ANOVA of sorghum leaf number parameter (two-way ANOVA: leaf number versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	32.9663	10.9888	12.38	0.000
Plant number	2	11.3224	5.6612	6.38	0.006
Interaction	6	7.2648	1.2108	1.36	0.269
Error	24	21.2971	0.8874		
Total	35	72.8505			

S, 0.9420; *R*-Sq, 70.77%; *R*-Sq (adj), 57.37%.

Table 5: ANOVA of sorghum stem diameter parameter (two-way ANOVA: stem diameter versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	2.27038	0.756793	27.88	0.000
Plant number	2	1.56557	0.782786	28.84	0.000
Interaction	6	0.07367	0.012279	0.45	0.836
Error	24	0.65147	0.027144		
Total	35	4.56109			

S, 0.1648; *R*-Sq, 85.72%; *R*-Sq (adj), 79.17%.

Table 6: ANOVA of sorghum dry weight plant biomass parameter (two-way ANOVA: plant biomass dry weight versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	89,929	29,976	0.93	0.441
Plant number	2	372,436	186,218	5.79	0.009
Interaction	6	95,439	15,906	0.49	0.806
Error	24	771,984	32,166		
Total	35	1,329,788			

S, 179.3; *R*-Sq, 41.95%; *R*-Sq (adj), 15.34%.

Table 7: ANOVA of sorghum dry weight stem biomass parameter (two-way ANOVA: stem biomass dry weight versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	62,078	20,692.5	2.42	0.091
Plant number	2	74,470	37,234.8	4.35	0.024
Interaction	6	26,505	4,417.6	0.52	0.790
Error	24	205,424	8,559.3		
Total	35	368,476			

S, 92.52; *R*-Sq, 44.25%; *R*-Sq (adj), 18.70%.

Table 8: ANOVA of sorghum panicle weight parameter (two-way ANOVA: panicle weight versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	8,746	2,915.2	0.65	0.590
Plant number	2	40,812	20,406.2	4.55	0.021
Interaction	6	22,011	3,668.5	0.82	0.567
Error	24	107,588	4,482.8		
Total	35	179,156			

S, 66.95; *R*-Sq, 39.95%; *R*-Sq (adj), 12.42%.

Table 9: ANOVA of sorghum grain weight parameter (two-way ANOVA: grain weight versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	700.33	233.44	4.00	0.019
Plant number	2	2,445.95	1,222.98	20.96	0.000
Interaction	6	671.78	111.96	1.92	0.119
Error	24	1,400.65	58.36		
Total	35	5,218.70			

S, 7.639; *R*-Sq, 73.16%; *R*-Sq (adj), 60.86%.

Table 10: ANOVA of sorghum sugar content of stem juice parameter (two-way ANOVA: sugar content versus variety; plant number)

Source	DF	SS	MS	*F*	*P*
Variety	3	194.030	64.6767	72.20	0.000
Plant number	2	1.787	0.8937	1.00	0.384
Interaction	6	12.283	2.0472	2.29	0.069
Error	24	21.498	0.8958		
Total	35	229.599			

S, 0.9465; *R*-Sq, 90.64%; *R*-Sq (adj), 86.34%.