PERFORMANCE OF SWEET SORGHUM (*Sorghum bicolor* L.) GERMPLASM RESOURCES FOR THEIR INDUSTRIAL TRAITS UNDER EGYPTIAN CONDITIONS

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ABSTRACT

Sweet sorghum is an emerging versatile crop species that offers grain for human consumption, fodder for livestock and ethanol for transportation purposes. The knowledge on industrial characters including juice quality traits and sugar components is an indispensable task for improving the crop at commercial level and establish sustainable value chain. In the current study a set of 68 sweet sorghum genotypes comprising land race collections and improved cultivars were evaluated for their fresh biomass yield, stripped stalk yield, dry matter yield, juice yield and quality traits (Purity%, Glucose Recovery%, Reducing sugar%, Sucrose%, and Total soluble sugar). The genotypes showed significant level of variation at p≤ 0.01 for all the eleven industrial traits regarding the five juice quality parameters measured. The juice purity of the genotypes ranged between 46.04% and 100%. The total soluble solids of the test genotypes had displayed a maximum value of 24.5 and a minimum of 10. The sucrose percent (pol) was found to range between 7.2% and 17.76% percent. This indicates the presence of promising possibility for the future improvement of the crop. The test genotypes were found to be clustered into five distinct clusters. Conclusively, the tested sweet sorghum genotypes displayed a broad range of variability in terms of all the measured industrial crops. The juice quality parameters in the test genotypes were found to be significantly higher as compared to different commercial improved cultivars. This indicates the presence of promising possibility for the future improvement of the crop. The test genotypes were found to be clustered into five distinct clusters. In conclusion, the present study demonstrates that the evaluated sweet

sorghum genotypes had superior performance in terms of their juice yield and quality traits.

Hence, they could be exploited in the future improvement of the crop as an industrial crop.

Keywords: Brix, TSS, Purity, Sucrose

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is among the top globally important cereals standing 6th in terms of its production (63.9 million MT) and 5th in area harvested (58 million hectares) (FAO, 2019) (*http://faostat3.fao.org/browse/Q/QC/E*). Due to its versatility and unique ability of abiotic stress tolerance it remains to be a staple food crop in the semi-arid tropics of Africa and India where low-input subsistence farming is the main stay. On the other hand, countries like the USA, Mexico, Argentina, Australia and China produce sorghum on a commercial basis, principally for feed, export and recently also biofuel (ethanol). Although sorghum is principally cultivated on marginal sites which are too dry for other crops such as maize and wheat, grain yields of 20 t ha^{-1} and dry matter yield of 80 t ha^{-1} (Packer & Rooney, 2014) have been reported in the US under optimal conditions.

In Egypt, sorghum holds fourth place in use and production after wheat, maize and rice mostly concentrated in Assiut and Sohag governorates where the atmospheric temperature is high (Al-Naggar *et al.,* 2007). In 2017 the area of cultivation for grain sorghum in Egypt was estimated about 148,460 hectares with annual production of 804,000 tons (FAOSTAT, 2017) and average yield of 5.42 t/ha (Khaled *et al*., 2019).

Currently, there is a growing interest to cultivate sweet sorghum for the production of sugar or ethanol in tropical and subtropical areas which are too dry or where winters are too cold for sugarcane (Burks *et al.*, 2015, Mocoeur *et al.,* 2015, Regassa & Wortmann 2014). The sorghum crop could also be potentially exploited as a multipurpose crop to produce multitudes of products under dessert ecologies with minimal water requirement.

Sweet sorghum has also a potential of producing comparable or even higher sugar and biomass yield to sugarcane in a short growth cycle (120–130 days), while displaying unique stress tolerance capacity (Almodares and Hadi, 2009; Rooney *et al*. 2007; Wu *et al*., 2010) and wider adaptability which makes sweet sorghum remains to be an ideal bioenergy crop of exceptional qualities. In

addition to higher biomass yield, the sweet sorghum accumulates higher levels of non-structural soluble sugars mostly sucrose in the stem which renders the crop to be an ideal bioenergy crop and a good genetic model for related species like sugarcane (Wang *et al.,* 2013). Moreover, it is a well-established fact that sweet sorghum is a carbon neutral crop as the amount of carbon dioxide that sweet sorghum fixes is equal to the amount that it emits during the entire process of crop growth and processing.

Evaluation and characterization of germplasm are the pre-requisite for the utilization of the available diversity in the crop improvement program. Despite its growing importance, sweet sorghum has been receiving relatively little attention in terms of improving sweet sorghum sugar yields, suggesting that rapid genetic improvement is the way forward (Burks *et al.,* 2013). Hence, sweet sorghum improvement should be geared towards increasing sugar and juice yield and quality. This calls for extensive characterization of sweet sorghum germplasm resources for their industrial traits including sugar and juice quality analysis.

Several studies revealed that the existence of significant natural genetic variability in sweet sorghum in different industrial traits such as juice yield, sugar content (Brix), and biomass yield (Almodares & Sepahi, 1996; Makanda, Tongoona, & Derera, 2009). This signifies the fact that there is a significant potential in the improvement of the crop for industrial and commercial level of cultivation.

Hence, this study is designed to analyze sugar and juice quality traits of sweet sorghum genotypes of different origins. And quantify the performance of sweet sorghum germplasm materials for industrial traits like stem fresh weight, stripped cane weight, dry matter yield, brix, and juice yield.

MATERIALS AND METHODS

Field Experiment
Study Site

A field experiment was conducted at the Agricultural Research Farm of the University of Sadat city located at 30.60^0 N and 30.22^0 E. The experiment was conducted in two consecutive summer cropping seasons (2018 and 2019) starting from early June to October each year. The area is characterized by semi-arid to arid climatic conditions (desert condition) with long and hot

summer season and warmer winter with very low precipitation of about 10 mm/year. The soil generally of dry siliceous coarse sand.

Plant material

Sixty-eight sweet sorghum genotypes comprising 49 landraces (accessions) and 5 cultivars from Ethiopia, and 14 cultivars obtained from the sugar crops research institute (ARC) in Egypt (Table 1) were used. The term landrace refers to variable populations adapted to local agro- climatic conditions which are named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological need while accessions are samples collected from the landraces from farmers' fields for research purposes (Teshome *et al.,* 1997).

Experimental design and crop husbandry

The experiments were laid out using randomized complete block design with three replications in both years. Dimensions of the plots were three rows each 8 m long and the seeds were drilled with 0.75 m spacing between rows. Crop husbandry practices were done according to the recommended guidelines of the agricultural research center. Nitrogen fertilizer was added at the rate of 238 kg/ha as Urea (46.5% N) in split application comprising two equal doses. The first dose during the first irrigation and the second after 35 days of emergence. Superphosphate fertilizer (15% P2O5) was added at the rate of 70 kg P2O5/ha as soil application before sowing during planting. Potassium fertilizer at the rate of 57 kg K2O/ha was also applied during planting in a form of potash (48% K2O). Other cultural practices were carried out following the recommendations of ARC. The plots were irrigated at two weeks interval using drip irrigation and kept weed free during the growing period. All the standard crop husbandry practices were done according to the recommended guidelines.

Data collection

Data were recorded on the following industrial traits related to juice and biomass yield and quality traits. Fresh Biomass yield (FBY) was recorded by weighing five plants randomly selected from the central row cut at the base and the mean was taken. Stripped stalk weight (SSW) was recorded after removing the leaf and panicles of the sampled plants. Dry Stover yield (DSY): the five plants (without panicles) were chopped, mixed

and a handful of sub-samples were weighed and saved in a paper bag were dried for 3 days at 60ºC. The dry Stover yield was calculated by dividing the dried Stover weight by fresh Stover weight multiplied by fresh biomass yield. Juice was extracted from the selected plats to measure the juice yield and quality parameters during the hard dough stage. The tagged plants were cut at the middle internodes and pressed using a garlic press to measure the brix degree using a handheld digital refractometer (Digital hand-held pocket refractometer PAL-1, Atago, Tokyo, Japan). Other juice quality traits were analyzed using saccharimeter for determination of sucrose and Redutec® for determination of reducing sugars. The juice quality variables were computed as detailed below using formulas adapted from Paulo- Consecana (2006).

Juice yield (JY) was taken after the juice was extracted from the remaining three plants by a three-roller motorized digester and weighed. Juice extraction rate (%): was computed by dividing weight of fresh juice by fresh stalks weight of the three plants and multiplying by 100. Juice yield (Mg ha^{-1}) was computed by multiplying juice weight from 10 plants by plants per hectare. Brix was measured using handheld digital refractometer. The refractometer was calibrated according to the manufacturers manual and thoroughly rinsed using distilled water and dried with tissue paper between consecutive measurements. Brix is a measure of dissolved sugar to water mass ratio of a liquid where one-degree Brix is equivalent to 1 g of soluble sugars in 100 g of solution. The recorded brix values were corrected by using the Schmitz's table as described in A.O.A.C (2005).

Laboratory analysis

The juice quality analysis was performed at the Sugar Crops Research Institute, Agricultural Research Center, Giza, Egypt.

Sucrose content (Pol percent): corresponds to sucrose concentration in the juice (POL, in %), which is the measure of the amount of sucrose in the sugar mixture. This was directly measured using NIR Saccharimeter 880D (Optical Activity Limited, Cambridge shire, UK) without using lead acetate clarification was calculated from 100 cm^3 of juice. Sucrose content was calculated as follows:

Sucrose percentage = Direct reading of Saccharimeter $\times$ 1.04; Where, 1.04 is a factor depending on the length of Saccharimeter's tube (A.O.A.C. 2005).

Juice Purity (Purity): was calculated using the following equation: as = (sucrose percentage / Brix reading) x 100.

Theoretical sugar recovery (SR): was calculated according to the formula described by Legendre and Henderson (1972): Sugar recovery percentage = [S - 0.4 (B - S)] × 0.73; Where: B= Brix percentage, S= sucrose percentage, 0.4 and 0.73 constant factors.

The total soluble sugars (TSS): were determined using automatic digital refractometer as juice brix measured from pooled juice extracted from sample plants.

The theoretical ethanol yield was estimated following the procedures of (Wortmann, 2010)   assuming 75% of the brix as fermentable sugars and 80% juice extraction efficiency.

$$CSY = (SCY - DSY) \times \frac{Brix}{100} \times 0.75 \quad Jy = [SCY - (DSY - CSY)] \times 0.8$$

$$SY = JY \times \frac{Brix}{100} \times 0.75$$

$$TETOHY = SY \left({kg}/{ha} \right) \times 0.585$$

Where: CSY is conservative sugar yield (kg ha^{-1}), SCY is stripped cane yield (kg ha−1), DSY is dry stalk yield (kg ha^{-1}), JY is juice yield (kg ha^{-1}) assuming 80% extraction rate, and SY is sugar yield (kg ha^{-1}) assuming 75% of the brix to represent fermentable sugar. TETOHY is the theoretical ethanol yield and 0.585 is the correction factor (liter per kilogram of sugar) derived from the theoretical maximum yield of ethanol after complete fermentation of sucrose and native glucose equivalent to 3.8 L of ethanol for every 6.7 kg of sugar (Lueschen *et al.,* 1991).

Analysis of variance (ANOVA)
The data collected for each character was subjected to analysis of variance (ANOVA) using procglimms in SAS (2014) to test the variations among genotypes for agro-morphological traits. One-way ANOVA for the juice quality traits was conducted using the ANOVA function in Microsoft Excel at the 0.05 significance level. Mean separation was conducted with Duncan multiple range testing (DMRT) at 5% probability levels using SAS (2014).

Estimates of variance components:
    The total variability present in the population which is attributed to of genotype (δ_G^2), environment in our case variance over years (δ_E^2) and their interaction (δ_{GxE}^2) together with coefficient of variation for each character as percentage of means were estimated. The variance components were

estimated using COVTEST in SAS (Version 14.1). The phenotypic variance among genotypes grown in r replications and n environments (years) was computed based on formula Syukur *et al.* (2012) using the above values as:

$$\delta_P^2 = [\delta_G^2 + \left(\frac{\delta_{GXE}^2}{n}\right) + \left(\frac{\delta_E^2}{nr}\right)$$

Where, δ_G^2= Genotypic variance, δ_{GxE}^2= variance due to the interaction between genotype x environment; δ_E^2= experimental error variance.

The genotypic coefficient of variation $GCV = \frac{\sqrt{\delta_G^2}}{x}$; phenotypic coefficient of variation $PCV = \frac{\sqrt{\delta_P^2}}{x}$ where: X is grand mean of a character.

Estimation of heritability and genetic advance

Broad sense heritability (h^2) of all the traits was calculated according to the formula as described by Allard (1960) as follows:

$$h^2 = \frac{\delta_G^2}{\delta_P^2} \times 100$$

Where: h^2 = Heritability in broad sense, Genetic advance (GA) was determined as described by Johnson *et al.* (1955) as follows:

$$GA = K\delta_p \, h^2,$$

Where: K = The selection differential (K = 2.06 at 5% selection intensity); σ_p = the phenotypic standard deviation of the character; h^2 = broad sense heritability. The genetic advance as percentage of the mean (GAM) was calculated as follows:

$$GAM = \frac{GA}{x}X100,$$

Where: GAM = genetic advance as percentage of the mean, GA= genetic advance, and x = grand mean of a character. Traits were categorized depending on the degree of heritability percentage as low (< 40%), medium (40– 59%), moderately high (60-79%) and very high (≥80%) as reported by Singh 2001.

Cluster analysis

Distance based hierarchical cluster analysis was performed to group genetically similar genotypes together through a repetitive process that results in cluster formation by using Darwin software version 6.0.21 (Perrier and Jacquemoud-Collet,2006) using dissimilarity index based on Euclidean distance of the standardized variables.

RESULTS AND DISCUSSION

Industrial Ƥerformance of the genotypes

The juice purity of the genotypes ranged between 46.04% and 100 % (**Table 1**). Three Sweet sorghum cultivars were characterized for Juice brix, Total soluble sugar, reducing sugar%, Sucrose% and Purity% (Rao and Kumar, 2013).), SSV74(17.78, 15.36, 1.16, 13.49, 75.64), SPSSV30 (20.73, 15.81, 0.45, 14.59, 72.02) and CSH22SS (16.48 13.50 1.29 11.68 70.70). These commercial varieties were found to be outperformed by the landrace collections tested in this study for all the five parameters showing that there is a good possibility to breed sweet sorghum cultivars with better juice quality traits. The sucrose percent (pol) of the genotypes was found to range between 7.2 and 17.76 percent. This is higher than the values reported to commercial sweet sorghum varieties (Rao *et al.,* 2013) who reported a range of sucrose percent between 8.3 and 11.2 for three varieties (SSV84, SSV74, and CSV19SS) and one hybrid (CSH22SS). Another study in Turkey also reported a sucrose percent of values ranging between 8.02 and 10.63 in a study that is conducted on nine genotypes and four commercial varieties (Erdurmus *et al., 2018*). The total soluble solids of the test genotypes had displayed a maximum value of 24.5 and a minimum of 10 and these values are significantly higher when compared to varieties commercial varieties like CV147, CV198 and BRS508 (Silva *et al.,* 2016).

Analysis of juice quality on the sweet sorghum variety Mn 4080 indicated mean values of sucrose percent and total soluble solids of 11.2 and 16.72 respectively, which is significantly lower than the value reported in the current work (Soha *et al.,* 2019). This indicates the fact that there is a huge variation in the juice quality traits of the studied genotypes that can be used for future improvement of sweet sorghum juice qualities.

This result confirmed the fact that ample amount of variability is displayed for these characters that can be exploited in the future improvement of sweet sorghum. The same finding is also reported by different authors (Lekgari and Dweikat, 2014; Alina, 2019; Yücel *et al.,* 2020). The variation due to years and the interaction between year and genotypes were found to be non-significant for all the measured characters. This may not reflect the absence of environmental and genotype X environment interaction on the recorded traits because our experiment was performed at a single location, same season (date of sowing) and under fully irrigated condition limiting the variation of the two experiments. Otherwise, significant genotype by

Table 1. Juice quality analysis of sweet sorghum Genotypes of different origins

Genotypes	FBY	SSWt	DSY	Brix	J.yld	Etoh	P	GR	SR	SC	TSS
Acc371st	138.12	111.07	0.39	16.943	706	5763.95	82.72	23.32	3.125	13.4	16.2
Acc402nw	95.56	66.5	0.249	13.343	654	2532.98	85.56	20.29	3.125	15.4	18
acc392st	134.13	99.54	0.448	13.943	568	4130.69	88.16	15.3	2.05	13.4	15.2
acc213st	123.41	108.15	0.688	16.443	488	3698.67	84.35	29.4	4.166	14.17	16.8
acc42sw	96.23	78.24	0.463	15.043	398.45	2591.03	58.04	45.43	4.166	9.17	15.8
acc1-1sw	133.28	110.72	0.457	13.093	526.14	4261.16	85	16.34	2.5	15.3	18
acc282st	121.82	96.24	0.522	15.343	417.17	3554.99	87.86	25.41	3.125	12.3	14
acc222st	108.78	87.44	0.423	14.193	514.17	3391.03	76.9	24.19	3.125	12.92	16.8
acc001et	147.39	115.33	0.358	18.043	802.67	6474.19	79.88	18.41	2.5	13.56	17
acc31sw	119.95	96.43	0.419	16.543	447.54	4517.65	76	36.54	4.166	11.4	15
acc002et	127.85	101.72	0.437	15.343	441	4380.23	77.85	26.94	3.125	11.6	14.9
acc421nw	128.06	107.2	0.419	14.343	715.5	3985.67	70.37	32.89	3.125	9.5	13.5
acc251st	107.78	94.44	0.412	10.643	409.95	2541.31	59.06	39.19	4.166	10.63	18
acc221st	189.22	160.06	0.585	12.443	571.16	5542.17	68.5	22.81	2.5	10.96	16
acc1331sw	129.42	102.97	0.429	16.843	483.9	5167.69	67.33	41.25	4.166	10.1	15
acc61sw	119.1	97.61	0.419	15.843	460.29	4172.92	51.98	49.48	4.166	8.42	16.2
acc264st	103.67	83.56	0.523	19.043	463	3682.48	68.25	22.89	2.5	10.92	16
acc301st	166.28	138.95	0.528	15.643	601.38	6452.8	76.59	40.29	4.166	10.34	13.5
acc201st	88.52	71.72	0.312	16.293	679.17	3373.96	69.06	37.7	4.166	11.05	16
acc412nw	139.56	117.02	0.601	17.643	310.17	5113.04	77.5	31.5	3.125	9.92	12.8
acc1-1sw	164	133.95	0.512	15.593	607.48	5779.45	73.57	30.34	2.5	8.24	11.2
acc71sw	118.95	97.61	0.585	17.343	256.17	3770.74	62.4	33.39	3.125	9.36	15
acc725sw	118.89	91.53	0.436	16.043	705.17	3673.7	61.74	23.54	2.5	10.62	17.2
acc32sw	141.19	123.81	0.482	14.643	527.71	5499.78	67.29	27.32	3.125	11.44	17

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acc161st	118.68	94.53	0.579	17.043	479.17	3677.81					
acc41sw	127.1	98.61	0.417	14.843	407.45	3962.43	54.3	29.14	2.5	8.58	15.8
acc171st	103.63	58.58	0.427	17.443	377	2114.81	68.8	40.37	4.166	10.32	15
acc101nw	106.48	94.67	0.422	15.943	545.87	4138.36	66.65	34.34	4.166	12.13	18.2
acc381st	160.11	127.98	0.489	15.243	560.12	5619.57	65.75	39.6	4.166	10.52	16
acc351st	129.06	102.17	0.574	16.843	513	4262.64	61.21	50.54	6.125	12.12	19.8
acc141nw	105.11	89.11	0.436	13.943	589	3155.15	100	40.6	4.166	10.26	10.26
acc52sw	92.22	70.28	0.515	18.693	424	2696.3					
acc174st	114.53	97.5	0.312	14.943	606	4508.49	57.87	48	4.166	8.68	15
acc32sw	138.57	118.07	0.427	14.043	667	4913.55	60.49	42.51	4.166	9.8	16.2
acc18st	132.33	160.78	0.545	18.043	715	7217.79	78.25	19.97	3.125	15.65	20
acc91nw	103.44	127.67	0.402	18.843	798	5812.03	69.33	33.76	4.166	12.34	17.8
acc151nw	106.41	122.61	0.313	15.393	803	5342.95	68.53	24.32	2.5	10.28	15
acc312st	74.34	89.06	0.471	16.243	360	2919.62	84.57	17.6	3.125	17.76	21
acc342st	102.72	122.41	0.558	12.393	402.67	2944.53	65.26	25.2	3.125	12.4	19
acc31sw	94.53	116.09	0.419	15.343	467.71	3920.73	69.16	38.86	4.166	10.72	15.5
acc122nw	81.61	105.9	0.376	13.643	373.67	3150.48	54.55	57.86	4.166	7.2	13.2
acc362st	108.33	134.5	0.544	14.393	557.67	4460.01	57.74	32.22	3.125	9.7	16.8
acc391st	94.33	114.45	0.406	16.893	383.35	4662.17	50.91	37.2	3.125	8.4	16.5
acc241st	86.34	107.5	0.391	16.243	427.12	3753.39					
acc243st	92.38	119.11	0.344	13.843	716.67	3572.05	61.19	43.28	3.125	7.22	11.8
acc151sw	92.72	122.81	0.673	11.843	658.67	2183.47	66.67	31.25	3.125	10	15
Mn13B3	30.78	42.27	0.175	13.043	169.52	946.91	100	25.57	3.125	12.22	12.22
Ramada	37.11	49.77	0.203	13.443	190.96	1211.34	85	24.47	2.08	8.5	10
Gkahoo	20.06	31.13	0.142	12.643	59.83	511.04					

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Gkgaba	13.99	18.73	0.124	12.243	101.54	266.26	81.9	15.26	2.5	16.38	20
Mn1500	30.4	36.08	0.176	12.043	235.21	852.36	79.08	24.32	2.5	10.28	13
Umbrella	30.64	33.13	0.18	12.643	247.14	897.57	74.45	27.08	3.125	11.54	15.5
Honey	29.53	36.2	0.171	14.843	221.88	1040.81	76.47	36.32	4.166	11.47	15
Rona	95.61	119.56	0.248	13.443	475.67	4060.82	60.63	32.22	3.125	9.7	16
EG002	50.74	66.67	0.224	17.443	401.67	2472.39	46.04	36.93	4.166	11.28	24.5
Brandes	112.11	131.93	0.473	16.743	632.54	5327.99	58.65	48	4.166	8.68	14.8
EG004	91.28	123.33	0.409	16.443	468.32	4137.27					
EG005	45	52.89	0.23	15.443	268.81	1777.58					
EG006	66.43	88.58	0.329	19.043	353.79	3373.2	73.03	17.29	2.5	14.46	19.8
Durado	33.18	48.71	0.172	11.743	148.67	1064.35	62.49	29.63	4.166	14.06	22.5
A22672	50.78	53.44	0.248	12.843	356.21	1691.77					
NGTJ-2	62.44	74.11	0.293	17.043	430.04	2892.44					
Karniifma	104.11	129.11	0.448	16.043	611.13	4685.43					
Acc006	27.11	44.78	0.195	11.243	103.67	603.43					
Melkam	49.11	65.44	0.38	20.443	136.17	1965.9					
acc003et	38.78	50.44	0.239	18.043	114.17	1640.94					
acc004et	179.45	203.11	0.996	18.443	572.17	8329.75					
acc005et	161.45	194.45	0.661	21.243	479.17	10143.22					
F-test	22.74**	123.25**	6.72*	22.35**	1245**		48.0**	28.14**	7.43*	31.3**	16.0**
LSD	8.25	56.20	0.09	7.10	968.50	964	14.03	10.33	1.78	3.66	8.03
CV	13.21	15.90	11.00	18.02	14.75	12.02	0.71	18.90	24.94	12.31	10.71

**Significant at 1% of probability (P<0.01); * significant at 5% of probability (0.01=<P<0.05); ns - Not significant (P>=0.05).
FBY: Fresh biomass yield; SSW: Stripped stalk weight; DSY: Dry stalkyield; Brix degree brix; JUde: juice yield; EtOH:
Theoretical Ethanol yield; P-Purity%; GR: Glucose Recovery%; RS: Reducing sugar%; SC: Sucrose%; TSS: Total soluble sugar
L.S.D = Least Significant Difference. C.V = Coefficient of Variation.

environment interactions were reported in many reports with respect to the above traits except for fresh biomass yield and fresh stalk yield (Makanda, 2009; Zou *et al.,* 2011; Elangovan *et al.,* 2014).

Analysis of variance

The genotypes showed significant level of variation at $P \leq 0.01$ for all the eleven industrial traits **(Table 2)** evaluated regarding the five juice quality parameters measured (Purity, Sucrose recovery, Sugar recovery, sucrose content and total soluble solids).

Table 2. Trait mean Squares in a combined analysis of variance over two years of eleven industrial traits in 68 sweet sorghum genotypes.

Trait	Genotype	Replication	Year	Residual
Purity%	524.5**	34.85	32.30	14.13
Glucose Recovery%;	53.54**	9.58	7.35	6.62
Total soluble sugar	465.19**	151.61	82.79	36.68
Fresh biomass yield (Ton/ ha)	9775.913**	435.45	278.88	136.08
Reducing sugar%	4.17**	0.91	0.21	0.14
Stripped Stalk weight (Ton/ ha)	7262.482**	253.62	158.56	73.49
Dry Stalk yield (Kg/plant)	5214**	146.51	101.24	65.73
Brix (%)	6.86*	0.073	0.049	0.0014
Juice yield (gm/plant)	203061.7**	9728.52	1482.04	1888.95
Sucrose%	40.81*	9.86	6.87	3.70
Ethanol yield (liter/ha)	3093.42**	1847.479	577.44	117.29

* Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$

Variance components and genetic parameters

Estimation of variance components and their corresponding heritable portion is very important for future improvement efforts (Zou *et al.,* 2011; Elangovan *et al.,* 2014). Since the phenotypic and genotypic variance estimates depends on the unit by which the character is measured, they cannot be used to compare variations among the different characters. Hence, the phenotypic and genotypic coefficients of variation (PCV and GCV) were used to compare the different characters **(Table 3).** Most of the measured traits showed lower coefficient of variation (CV) except fresh biomass yield

Table 3. Estimates of genetic parameters of thirteen biofuel related quantitative traits in 68 sorghum accessions.

Traits	Grand Mean	Range Min.	Range Max	SE	CV	PCV	GCV	H² (%)	GA	GAM %
Purity %	68.37	46.04	100	3.37	2.13	0.33	0.252	61.05	25.09	36.70
Glucose Recovery (%)	33.54	15.26	57.86	0.75	13.75	0.33	0.252	51.94	10.81	32.23
Sugar recovery (%)	3.49	2.05	6.13	0.09	10.18	0.345	0.264	62.1493	2.14	61.32
Sucrose content (%)	10.83	7.2	17.76	0.17	17.42	1.02	0.792	77.2716	4.68	43.21
Total Soluble Solids (%)	16.03	10	24.5	1.69	14.59	0.87	0.66	52.2801	5.57	34.75
Fresh biomass yield (Ton/ha)	108.73	18.73	203.11	4.65	26.92	0.43	0.41	90.91	87.56	80.53
Stripped Stalk weight (Ton/ha)	87.84	13.99	179.45	4.21	16.55	0.56	0.48	73.47	74.45	84.75
Dry Stalk yield (Kg/plant)	0.41	0.124	0.996	0	19.02	0.34	0.29	82.25	0.26	63.41
Brix (%)	15.43	10.64	21.24	0.18	6.48	0.21	0.2	50.7	6.05	39.21
Juice yield (gm/plant)	461.25	59.83	803	4.4	11.31	0.56	0.51	82.94	441.32	95.68
Ethanol yield (liter/ha)	3719.61	266.26	10143	18.92	22.75	0.54	0.52	61.13	2548.48	68.51

Note: SE= Standard error, CV= Coefficient of variance PCV = Phenotypic coefficient of variation, GCV = Genotypic coefficient of variation, H² = Broad sense heritability, GA= Genetic Advance, GAM= Genetic advance as percent of mean.
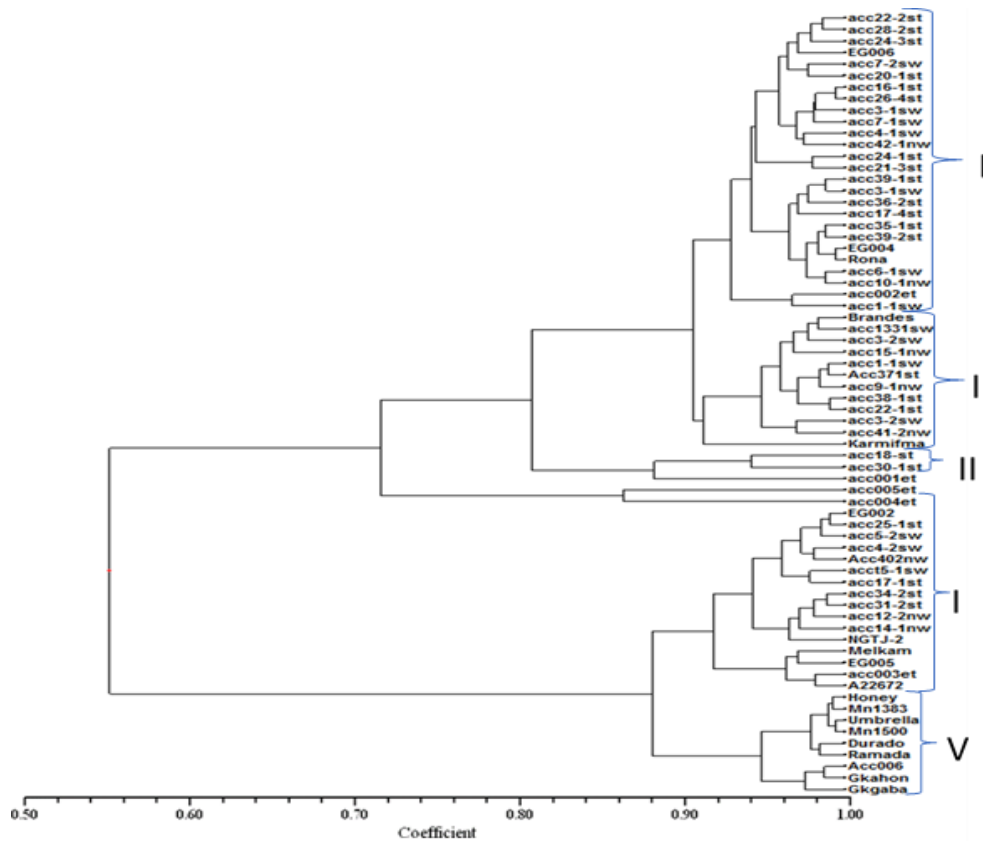
(26.92), stripped stalk weight (16.55) and estimated ethanol yield (22.75) depicting the fact that the environment has got some bearing in the expression of these characters (Sinha and Kumaravadivel, 2016).

For most of the traits there is a narrow difference between PCV and GCV indicating lower environmental influence in the expression of the traits (Godbharle et al., 2010). Higher values of PCV and GCV in some characters including ethanol yield signifies possibility of effective selection for superior genotypes while lower values of PCV and GCV in traits like purity % and brix indicate the limited possibility of improvement via selection (Elangovan *et al.,* 2014; Reddy, 2009). All the measured characters exhibited moderate to high broad sense heritability ranging from 50.7(brix) to 90.1 (FBY). The juice yield, fresh biomass yield, plant height, days to flowering number of leaves, brix and stem diameter showed higher (>80) value of heritability. The broad sense heritability for these characters is reported to be lower than the value recorded in the present study (Murray *et al.*2008; Shiringani *et al.* 2010; Disassa *et al.,* 2016).Lower heritability estimate was recorded for brix and glucose recovery as compared to other characters and this result is in agreement with Dissasa *et al.,* 2016.

Cluster analysis

The sixty-eight sweet sorghum genotypes were categorized based on the eleven quantitative traits using cluster analysis. The test genotypes were found to be clustered into five distinct clusters **(Figure 1).** The first cluster is composed of twenty-six mostly comprising landrace collections from south Tigray.

The second cluster contain twelve accessions mostly from north and south wollo. Two accessions are grouped together forming the third cluster. Sixteen accessions collected from north wollo and south wollo regions combined with Ethiopian improved accessions were grouped together forming the fourth cluster. The final cluster was found to contain entirely Egyptian cultivars forming the fifth cluster. This showed the presence of population differentiation between Egyptian and Ethiopian cultivars. Three accessions that are collected from Gojam area were remained as outliers at the coefficient of similarity the other clusters were classified this may be because these accessions were collected from distant places in the area.

Figure 1: Dendrogram of 68 sweet sorghum accessions revealed by cluster analysis based on genetic similarity estimatesgenerated by Nei and Li coefficient based on 19 agro-morphological characters.

Cluster analysis based on phenotypic traits could show some level of inconsistency to their genealogy and historic background due to the presence of significant genotype by environment interaction (Da-silva *et al.,* 2017). This is also reflected in the current study where some accessions that do not share similarity and descent were found to end in the same cluster. On the hand most accessions in the preset studies were comprised of accessions sharing the same geographic origin with only minimal mixtures.

Conclusively, the tested sweet sorghum genotypes displayed a broad range of variability in terms of all the measured industrial crops. The juice quality parameters in the test genotypes were found to be significantly higher

as compared to different commercial improved cultivars. This indicates the presence of promising possibility for the future improvement of the crop. The test genotypes were found to be clustered into five distinct clusters.

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أداء مصادر الأصول الوراثية للذرة الرفيعة الحلوة (*Sorghum bicolor* L.) لصفاتها الصناعية في ظل الظروف المصرية

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الذرة الرفيعة الحلوة هي أحد أنواع المحاصيل الناشئة متعددة الاستخدامات التي تقدم الحبوب للاستهلاك البشري وعلفًا للماشية والإيثانول لأغراض النقل. تعتبر المعرفة حول السمات الصناعية بما في ذلك سمات جودة العصير ومكونات السكر مهمة لا غنى عنها لتحسين المحصول على المستوى التجاري وإنشاء سلسلة ذات قيمة مستدامة. في الدراسة الحالية ، تم تقييم مجموعة من 68 نمطًا وراثيًا للذرة الرفيعة الحلوة تشتمل على مجموعة من السلالات والأصناف المحسّنة من حيث إنتاجيتها من الكتلة الحيوية الطازجة ، وإنتاجية الساق المقطوعة ، وإنتاجية المادة الجافة ، ومحصول العصير ، وخصائص الجودة (نسبة النقاء ، واستعادة الجلوكوز ٪ ، والحد من السكر ٪ ، السكروز.٪ ، والسكر الكلي القابل للذوبان).

أظهرت النتائج ان التراكيب الجينية مستوى معنوي من التباين عند 0.01 >P لجميع الصفات الصناعية الإحدى عشر التي تم تقييمها فيما يتعلق بمعايير جودة العصير الخمسة المقاسة. نقاوة العصير للطرز الجينية تراوحت بين 46.04٪ و 100٪. أظهر إجمالي المواد الصلبة الذائبة للأنماط الجينية الاختبارية قيمة قصوى قدرها 24.5 وقيمة دنيا قدرها 10. تراوحت نسبة السكروز بين 7.2 و 17.76 في المائة ، وهذا يشير إلى وجود إمكانية واعدة للتحسين المستقبلي للسكروز لهذا المحصول. تقسمت التراكيب الوراثية المختبرة فى عناقيد مميزة إلى خمس مجموعات.

التوصية: أوضحت الدراسة الحالية أن الطرز الوراثية للذرة الرفيعة المقيمة كان لها أداء متفوق من حيث إنتاجية العصير وصفات الجودة. وبالتالي ، يمكن استغلالها في التحسين المستقبلي للمحصول كمحصول صناعي.