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Original Research

Assessment of Harvest Age of some Sugarcane Genotypes by using AMMI Biplot and Principal Component Analysis

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ABSTRACT: Two field trials were conducted in Upper Egypt conditions at Kom Ombo Agricultural Research Station, (latitude of 24o 28'N and longitude of 320. 57' E), Aswan Governorate, Egypt during 2019/2020 and 2020/ 2021 seasons (plant cane and first ratoon) to determine the optimum harvest age of the major sugarcane promising genotypes (G. 2003-47, G. 2004-27, G. 2005-47, G. 84-47 and G.T.54-9). The AMMI (Additive main effects and multiplicative interaction) analysis and PCA (principal components biplot) analysis, were utilized to examine and understand the relationship between genotype and environment (G x E). The experimental design was a split plot with three replications. Results showed that harvest ages significantly varied among all studied traits in plant cane as well as first ratoon season. Harvest age of 13 months recorded the highest mean values of stalk length, stalk diameter, stalk weight, brix%, cane and sugar yields, except richness%, sucrose% and sugar recovery% in first ratoon crop and across crops where it recorded the highest values at age of 12-months. By contrast, reducing sugars % and purity% in plant cane, first ratoon and over crops where it recorded the greatest values at age of 10-months and 12-months, respectively. The G. 84-47 genotype surpassed the other genotypes and produced the highest values of brix%. G. 2003-47 genotype surpassed the other genotypes and produced the highest values of sucrose%, purity% and sugar recovery%. Results of the Principal Component Analysis (PCA) showed that the first two components had an Eigen value > 1 and explained about 84.37 % of the total variation among all analyzed variables. The first component (PC1) explained 50.8, 54.2, 45.7, and 57% of the total variation among the tested sugarcane genotypes assessed by different harvesting ages (10, 11, 12 and 13 months) measured for the plant cane and first ratoon seasons and the second component (PC2) explained 38.5, 35.8, 42.6, and 34.6% of the total variation measured by the same variables, respectively. The PC1 had a strong negative correlation with brix% measured at all harvesting ages. The PC1 had a moderate negative correlation with sucrose and sugar recovery and a moderate positive correlation with stalk diameter, reducing sugars and sugar yield calculated based 10, 11 and 12 months. Results display positive correlation and highly significant between cane yield, stalk weight, then cane yield and stalk length followed by cane yield and stalk diameter. Based on the AMMI analysis: the five sugarcane genotypes under investigation could be divided into three groups, early maturity (G 2003-47 and G 84-47) , mid maturity (G2004-47) and late maturity (G 2005-47 and GT 54-9).

Keyword: Sugarcane, PCA, AMMI, genotype, correlation, positive, harvest

INTRODUCTION

One of the most crucial elements determining sugarcane productivity is harvest age. When making decisions about harvesting, it is important to take into account variations in growth and maturity rates. The best time to harvest sugarcane depends on a variety's maturity rate as well as environmental factors. For sugar industries to avoid poor quality during the crashing season, knowledge on the maturity stage and precise timing of ripping for promising sugarcane types is crucial.

Mid-season harvesting results in the highest sugar yield for a crop, although not all crops can be harvested at this age. Because plant cane is typically older than 12 months, Genotype-by harvesting age has less of an impact on cane yield than it does on ratoon cane (Di Bella et al. 2008; Mehareb and Abazied 2017). Significant effects of the interaction between varieties and harvest ages on quality, yield, and yield components have been widely reported (Ahmed, 2003; Hagos et al., 2014; Ahmed and Awadalla 2016; Mehareb and Abazied 2017 and Gamechis and Ebisa 2021). According to Donaldson *et al.* (2008), one of the most significant influences on productivity is the harvesting age. So, Sundara, 2000 and Verma, 2004 divided types into early, mid, and late maturing depending on the length of time it took for them to reach maturity. A primary goal in breeding programs is to evaluate for early maturity and target high sucrose content at an early age in sugarcane, as required by the sugar industries (Domaingu *et al.* 1998, Mehareb and Abazied 2017). To maximize possible genetic advantages, plant-breeding programs must choose cultivars that function well within a harvesting age schedule (Di Bella *et al* 2007). Breeders frequently employ principal component analysis, a smart breeding tool, to identify traits that could be used to identify elite varieties.

Planning a successful breeding programme will require careful consideration of the variability among the traits that contribute to high yielding (Yan and Kang, 2003, Johnson 2012, Abo Elenen *et al*. 2019 and Mehareb and El-Mansoub 2020). The original connected qualities could be converted into independent composite indicators using PCA.

According on the variance contribution rate, breeders might assess the composite indicator in breeding. Analyzing the harvesting ages of different kinds by means of multivariate analysis using the PCA and AMMI, has many benefits, including the following: it enables us to evaluate the harvesting ages of varieties using multiple and several characters; then, it improves the accuracy of the rankings of varieties when they are evaluated at different growth stages with harvesting ages of varieties; as well as, It reveals intricate relationships between the varieties in a more comprehensible way; in addition, It observes the relationship between characters; Also, It enables the ranking of varieties easily under harvesting ages of varieties different growth stages simultaneously; finally, It enables us to recognize superior varieties for conditions of harvesting ages. The superiority indices can be utilized to help the AMMI model in identifying varieties with both narrow and broad adaptation (Kaya et al 2006). AMMI method is able to estimates the harvesting age, the genotypes and G × H using a value that estimate genotype stability under harvesting age taking into account the sugar and cane yield. Based on the observation and G × H analysis in different-environment, sugar and cane yield traits are very important for selection, evaluation of crop cultivars. AMMI technique was beneficial to define the best genotypes for multi – environments. Multi-environment trials are crucial for the accurate ranking of candidate cultivars and for identifying typical conditions for selection or production (Yan et al. 2007). According to Yan and Holland (2010), this could increase breeding effectiveness and boost yield production's competitiveness.

The goals of this study were to: 1) use multivariate analysis approaches to define new commercial cultivars in terms of their harvest age adaptability, and 2) describe the environmental characteristics of various harvest seasons and obtain understanding of how cultivars react to those variables, and 3) To ascertain how sugarcane production components are impacted by various harvest timings.

MATERIALS AND METHODS

In this study Two field trials were conducted at farm of Kom Ombo, Agricultural Research Station, (latitude: 24°28′N, longitude: 32°57′E), Aswan Governorate, Sugar Crops Research Institute, Agricultural Research Center (ARC), Egypt including plant cane and the 1st ratoon crops grown during 2019/2020 and 2020/2021.The study included twenty treatments represent the combination of five promising sugarcane varieties: G. 84-47, G.2003-47, G. 2004-27 G. 2005-47 and G.T. 54-9 and four harvesting ages (10, 11, 12, and 13 months). Utilizing a split plot design with three replicates, sugarcane varieties were distributed at random inside the sub plots while harvesting ages were assigned to the main plots. The sub plot had a 35 m^2 area, with 5 ridges that were each 7 m long and 1 m wide. In the first week of March, various sugarcane genotypes were planted (Table 1). To apply harvesting ages on the first ratoon, a second trial was planted in March 2019 and harvested in the same month (March, 2020).

After planting, the field was watered, and all other agronomic procedures for growing sugarcane were done as recommended by the Sugar Crops Research Institute. Plant cane was allowed to first ratoon. Harvest took place 10, 11, 12 and 13 months after planting (for plant cane) or harvesting date (for first ratoon). Meteorological data recorded at the experimental location are shown in (Figure 1). The following traits were measured for sugarcane genotypes.

Table 1. Promising genotypes of sugarcane and harvest times used in the experiment.

Co	Genotypes	Co	Harvest age
G1	G 2003-47	H1	10 Months
G2	G 2004-27	H2	11 Months
G3	G 2005-47	H3	12 Months
G4	G 84-47	H4	13 Months
G5	GT 54-9		

The recorded data

A. Millable cane traits

At each harvesting date, twenty five millable cane were collected at random to determine the following traits:

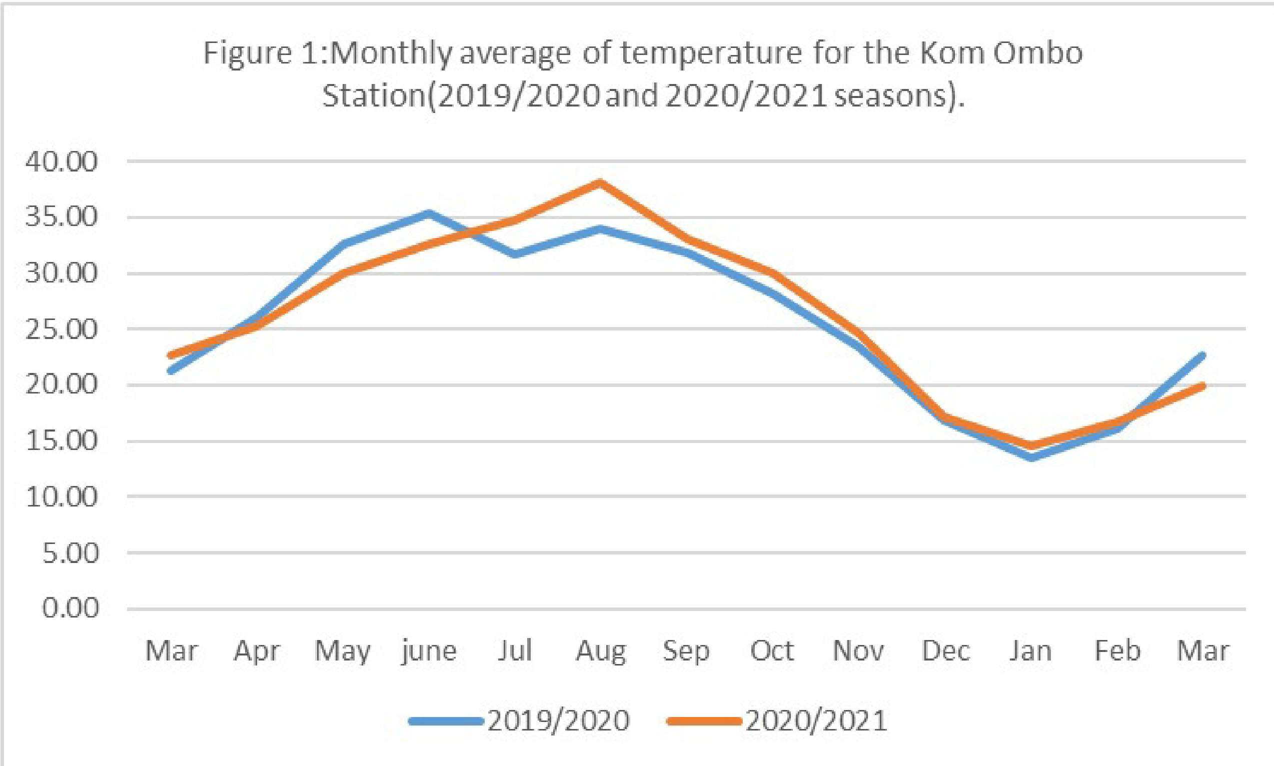

Figure 1:Monthly average of temperature for the Kom Ombo Station(2019/2020 and 2020/2021 seasons).

1- Stalk length (cm) was measured from soil surface up to the top visible dewlap.
2- Stalk diameter (cm) was measured at the middle part of the cane.
3- Stalk weight (kg) was calculated by dividing cane yield per plot by number of stalks per plot.

B. Juice quality traits

4- Brix (total soluble solids percentage) was determined using Brix Hydrometer according to A.O.A.C. (2005).
5- Sucrose percentage of clarified juice was determined by using automated sacharimeter according to A.O.A.C. (2005).
6- Purity percentage: It was calculated according to the following formula of Singh and Singh (1998).

7- Reducing sugars percentage: It was determined using Fehling method according to A.O.A.C. (2005).
8- Richness % was calculated according to the equation described by E.S.I.I.C. (1981).
9- Sugar recovery% (SR) was calculated according to the formula described by Yadav and Sharma (1980).
SR= [Sucrose% - 0.4 (Brix – Sucrose %)] x 0.73
C. Cane and sugar yields

1-Cane yield (ton/fad.) was determined from the weight of the guarded rows of each plot converted into ton per fad.

1-Sugar yield (tons/fad.): was calculated according to the following equation as described by Mathur (1981).
Sugar yield (ton /fad.) = cane yield (ton/fad) x sugar recovery %.
To compare treatment means, the data were put through the proper statistical analysis of variance using a split plot design, as described by Snedecor and Chochran (1981). L.S.D. at a 5% level of significance was utilized, as recommended by Steel and Torrie (1980). Furthermore, the additive main effects and multiplicative interaction model (AMMI) (Romagosa and Fox 1993) was applied on the cane and sugar yields. The AMMI biplot method of stability analysis was implemented utilizing the GeneStat-18 program. The components were extracted using the principal component analysis (PCA) method as outlined by Harman (1976). PCA was carried out using the Minitab 14 program.

RESULTS AND DISCUSSION

Results offered in (Tables 2,3,4 and 5) showed that harvest ages significantly varied in millable cane length, diameter, weight, Brix%, Sucrose%, Reducing sugars%, Purity%, Richness% Sugar recovery%, Cane and sugar yield in plant cane as well as first ratoon season. Harvest age of 13 months recorded the highest mean values of millble cane length, millble cane diameter, millble cane

Table 2: Millable cane length (cm), diameter (cm) and weight (kg) of five sugarcane genotypes as affected by the age at harvest during plant cane 2019/2020 and first ratoon2020/2021 seasons.

Genotypes	Harvest time (Months)	Stalk Length			Stalk Diameter			Stalk weight		
		PC	FR	Mean	PC	FR	Mean	PC	FR	Mean
G 2003-47	10	272.50	275.00	273.75	2.40	2.33	2.37	1.07	1.11	1.09
	11	280.50	283.00	281.75	2.45	2.43	2.44	1.13	1.15	1.14
	12	285.50	291.00	288.25	2.50	2.43	2.47	1.14	1.18	1.16
	13	287.00	294.00	290.50	2.57	2.50	2.54	1.13	1.19	1.16
	Mean	281.38	285.75	283.56	2.48	2.42	2.45	1.12	1.16	1.14
G 2004-27	10	280.00	282.00	281.00	2.45	2.43	2.44	1.14	1.17	1.16
	11	289.00	290.00	289.50	2.55	2.50	2.53	1.17	1.19	1.18
	12	302.50	305.00	303.75	2.63	2.60	2.62	1.19	1.20	1.20
	13	311.17	315.00	313.09	2.63	2.60	2.62	1.24	1.25	1.25
	Mean	295.67	298.00	296.83	2.57	2.53	2.55	1.19	1.20	1.19
G 2005-47	10	283.50	287.00	285.25	2.50	2.43	2.47	1.15	1.18	1.17
	11	294.00	298.00	296.00	2.55	2.53	2.54	1.20	1.24	1.22
	12	306.50	308.00	307.25	2.62	2.57	2.60	1.24	1.26	1.25
	13	315.17	318.00	316.59	2.65	2.63	2.64	1.28	1.29	1.29
	Mean	299.79	302.75	301.27	2.58	2.54	2.56	1.22	1.24	1.23
G 84-47	10	279.00	280.00	279.50	2.28	2.20	2.24	1.04	1.07	1.06
	11	284.00	285.00	284.50	2.33	2.30	2.32	1.08	1.10	1.09
	12	295.00	298.00	296.50	2.43	2.40	2.42	1.13	1.13	1.13
	13	300.17	300.33	300.25	2.43	2.40	2.42	1.14	1.16	1.15
	Mean	289.54	290.83	290.19	2.37	2.33	2.35	1.10	1.12	1.11
GT 54-9	10	271.00	273.33	272.17	2.33	2.33	2.33	1.05	1.14	1.10
	11	278.33	281.67	280.00	2.43	2.43	2.43	1.03	1.15	1.09
	12	283.33	291.67	287.50	2.57	2.47	2.52	1.10	1.17	1.14
	13	293.33	306.67	300.00	2.63	2.53	2.58	1.12	1.23	1.18
	Mean	281.50	288.34	284.92	2.49	2.44	2.47	1.08	1.17	1.12
Harvest time	10	277.20	279.47	278.33	2.39	2.34	2.37	1.09	1.13	1.11
	11	285.17	287.53	286.35	2.46	2.44	2.45	1.12	1.17	1.14
	12	294.57	298.73	296.65	2.55	2.49	2.52	1.16	1.19	1.17
	13	301.37	306.80	304.08	2.58	2.53	2.56	1.18	1.22	1.20
	Mean	289.58	293.13	291.35	2.50	2.45	2.47	1.14	1.18	1.16
LSD at 5%										
Harvest time (H)		5.88	4.55		0.02	0.07		0.06	0.02	
Varieties (V)		6.50	3.60		0.05	0.07		0.07	0.03	
H x V		12.54	7.44		0.10	0.13		0.13	0.05	

weight, brix%, cane yield and sugar yield except richness%, sucrose% and sugar recovery% in first ratoon crop and across crops where it recorded the highest values at age of 12-months, while 10 months recorded the lowest ones. In contrast, reducing sugars % and purity% in plant cane, first ratoon and over crops recorded the highest values at age of 10-months and 12-months, respectively. These results are in coinciding with those obtained by Hagos *et al* (2014) and Mehareb and Abazied (2017) who stated that harvest age indicated highly significant effect on brix, sucrose and purity percentages. The results in (Table 2) displayed that the evaluated genotypes significantly varied in millable cane diameter. G2005-47 genotype had the highest value, while G84-47 had the lowest ones compared to other genotypes in plant cane and first ratoon seasons. This outcome may be due to genetic variations in the genotypes. This result is in agreement with those obtained by Yousif *et al.* (2015), Abo Elenen et al (2018) and Abo El-hamd *et al.,* (2019) they found significant variance among studied genotypes in millable cane diameter in both seasons. Data in (Table 2) exposed that millable cane diameter was significantly affected by harvesting age. Where it significantly increased with increasing the age at harvest until 13 month of the five studied genotypes. Correspondingly, result showed that the increase in millable cane diameter at age of 13 months amounted to 7.95 %, 8.12% and 8.02 % over that of 10-month in the plant cane, first ratoon and across seasons, respectively. Such an effect could be attributed to the genotypes that show significant increase in terms of millable cane diameter at the best of age at harvest. Ahmed and Awadalla (2016), Mehareb *and Abazied al* (2017) and Gamechis and Ebisa (2021) who stated that late harvesting age significantly increased millable cane diameter. Results in (Table 2) display that evaluated genotypes significantly varied in millable stalk length and weight. G. 2005-47 genotype had the highest value compared to other genotypes in plant cane and 1^{st} ratoon seasons. The results exposed that millable cane length and weight were significantly affected by the harvesting age. Millable cane length and weight significantly increased with increasing harvesting age until 13 month of the five studied genotypes.

Table 3 : Brix, sucrose and Purity percentages of five sugarcane genotypes as affected by the harvesting age during plant cane 2019/2020 and first ratoon 2020/2021 seasons.

Genotypes	Harvest time (Months)	Brix%			Sucrose%			Purity%		
		PC	FR	Mean	PC	FR	Mean	PC	FR	Mean
G 2003-47	10	20.90	21.64	21.27	18.37	19.15	18.76	87.62	88.03	87.83
	11	21.61	21.78	21.70	19.05	19.27	19.16	88.12	88.42	88.27
	12	21.98	22.10	22.04	19.52	19.64	19.58	88.68	88.65	88.67
	13	22.46	22.36	22.41	19.71	19.50	19.61	87.73	87.20	87.47
	Mean	21.74	21.97	21.85	19.16	19.39	19.28	88.04	88.08	88.06
G 2004-27	10	19.79	20.27	20.03	16.64	17.75	17.20	84.02	87.57	85.80
	11	20.12	20.65	20.39	17.47	18.15	17.81	86.77	87.89	87.33
	12	20.33	20.98	20.66	17.89	18.46	18.18	87.90	87.83	87.87
	13	21.68	21.38	21.53	18.71	18.25	18.48	86.20	85.22	85.71
	Mean	20.48	20.82	20.65	17.68	18.15	17.92	86.22	87.13	86.68
G 2005-47	10	20.02	20.34	20.18	17.31	17.86	17.59	86.82	87.81	87.32
	11	21.42	21.46	21.44	18.80	18.89	18.85	87.75	88.07	87.91
	12	21.60	21.68	21.64	19.00	19.14	19.07	87.95	88.28	88.12
	13	22.51	22.09	22.30	19.65	19.00	19.33	87.26	86.00	86.63
	Mean	21.39	21.39	21.39	18.69	18.72	18.71	87.45	87.54	87.49
G 84-47	10	20.90	20.95	20.93	17.08	17.36	17.22	80.93	81.29	81.11
	11	21.81	21.85	21.83	18.59	18.62	18.61	85.15	85.13	85.14
	12	21.90	21.94	21.92	18.75	18.80	18.78	85.69	85.87	85.78
	13	22.31	22.00	22.16	18.64	18.08	18.36	84.07	83.18	83.63
	Mean	21.73	21.69	21.71	18.27	18.22	18.24	83.96	83.87	83.91
GT 54-9	10	19.65	20.03	19.84	16.40	17.20	16.80	83.42	85.90	84.66
	11	20.52	21.40	20.96	18.14	18.82	18.48	88.39	87.94	88.17
	12	21.59	21.61	21.60	19.12	19.04	19.08	88.54	88.12	88.33
	13	22.01	21.80	21.91	19.13	18.47	18.80	87.26	85.78	86.52
	Mean	20.94	21.21	21.08	18.20	18.38	18.29	86.90	86.94	86.92
Harvest time	10	20.25	20.65	20.45	17.16	17.86	17.51	84.56	86.12	85.34
	11	21.10	21.43	21.26	18.41	18.75	18.58	87.24	87.49	87.36
	12	21.48	21.66	21.57	18.86	19.02	18.94	87.75	87.75	87.75
	13	22.19	21.93	22.06	19.17	18.66	18.91	86.50	85.48	85.99
	Mean	**21.26**	**21.42**	**21.34**	**18.40**	**18.57**	**18.49**	**86.51**	**86.71**	**86.61**
LSD at 5%										
Harvest time (H)		0.11	0.29		0.23	0.49		0.23	0.30	
Varieties (V)		0.26	0.41		0.24	0.32		0.46	0.53	
H x V		0.47	0.77		0.48	0.70		0.84	0.98	

Similarly, result showed that the increase in millable stalk length and stalk weight at age of 13 months amounted to 8.72%, 9.78% and 9.25% over that of 10-month 8.26%, 7.96% and 8.11% in the plant cane, first ratoon and across seasons, respectively. These findings are consistent with those of Ahmed and Awadalla (2016) and Mehareb and Abazied (2017), who found that increasing harvesting age increased millable stalk weight considerably.Data given in (Tables 3 and 4) displayed that harvest age along crushing season (from10 to 13 months old) had a significant influence on richness percentage, sucrose% and sugar recovery% in the plant cane. However 12 months had the highest values of richness %, sucrose% and sugar recovery in first ratoon crops and across crops, while reducing sugars gave the lowest ones. Jadhav *et al* (2000) and Mehareb and Abazied (2017) observed significant variances among harvesting ages in reducing sugars%. Hagos *et al* (2014) observed that increasing harvest age significantly influenced richness % trait.

Genotype effects on cane and sugar yield characters

Results presented in (Tables 2, 3 and 4) indicated that richness, sucrose, sugar recovery, brix, purity, and reducing sugars percentages were significantly affected by the studied sugarcane genotypes in the plant cane, first ratoon and over crops. Sugar cane genotype G.2003-47 recorded the highest richness sucrose, sugar recovery, brix and purity percentages. in the other hand, sugarcane genotype G. 2005-47 recorded the highest stalk diameter, stalk length, stalk weight, cane yield and sugar yield in the plant cane, first ratoon and across crops. Genotype variations may result from variations in how each genotype grows and reacts with its environment. These results are in line with those obtained by Besheit *et al* (1999); Ahmed (2003); Mehareb *et al* (2018), Fahmy *et al* (2021) and Mehareb *et al* (2022) _who found significant differences among genotypes for sucrose%, brix%, purity%, sugar recovery% cane yield and sugar yield.

Table 4: Reducing sugars%, Sugar Recovery% and Richness% of five sugarcane genotypes as affected by the age at harvest during plant cane 2019/2020 and first ratoon 2020/2021 seasons.

Genotypes	Harvest time (Months)	Reducing sugars%			Sugar Recovery%			Richness%		
		PC	FR	Mean	PC	FR	Mean	PC	FR	Mean
G 2003-47	10	0.44	0.39	0.42	12.67	13.25	12.96	15.45	15.86	15.66
	11	0.35	0.26	0.31	12.65	12.33	12.49	15.68	15.93	15.81
	12	0.23	0.18	0.21	13.43	13.62	13.53	16.07	16.19	16.13
	13	0.25	0.21	0.23	13.31	13.40	13.36	16.12	16.05	16.09
	Mean	0.32	0.26	0.29	13.02	13.15	13.08	15.83	16.01	15.92
G 2004-27	10	0.72	0.69	0.71	11.25	12.22	11.74	14.02	14.84	14.43
	11	0.56	0.56	0.56	11.97	12.52	12.25	14.55	15.13	14.84
	12	0.47	0.44	0.46	12.19	12.74	12.47	14.97	15.39	15.18
	13	0.49	0.46	0.48	12.79	12.41	12.60	15.46	15.19	15.33
	Mean	0.56	0.54	0.55	12.05	12.47	12.26	14.75	15.14	14.94
G 2005-47	10	0.45	0.31	0.38	11.74	12.11	11.93	14.52	14.79	14.66
	11	0.41	0.33	0.37	12.26	12.04	12.15	15.52	15.60	15.56
	12	0.35	0.24	0.30	13.13	13.23	13.18	15.66	15.76	15.71
	13	0.32	0.28	0.30	13.51	12.97	13.24	16.07	15.62	15.85
	Mean	0.38	0.29	0.34	12.66	12.59	12.62	15.44	15.44	15.44
G 84-47	10	0.59	0.49	0.54	10.77	11.29	11.03	13.95	14.04	14.00
	11	0.45	0.40	0.43	12.61	12.61	12.61	15.05	15.30	15.18
	12	0.37	0.28	0.33	12.79	12.85	12.82	15.11	15.41	15.26
	13	0.33	0.32	0.33	12.53	12.05	12.29	14.84	14.74	14.79
	Mean	0.44	0.37	0.40	12.18	12.20	12.19	14.74	14.87	14.81
GT 54-9	10	0.60	0.52	0.56	11.64	11.73	11.69	13.98	14.52	14.25
	11	0.49	0.45	0.47	12.54	12.99	12.77	15.26	15.86	15.56
	12	0.43	0.34	0.39	13.27	13.15	13.21	16.05	16.02	16.04
	13	0.39	0.38	0.39	13.35	12.75	13.05	16.07	15.66	15.87
	Mean	0.48	0.42	0.45	12.70	12.66	12.68	15.34	15.52	15.43
Harvest time	10	0.56	0.48	0.52	11.61	12.12	11.87	14.38	14.81	14.60
	11	0.45	0.40	0.43	12.41	12.50	12.45	15.21	15.56	15.39
	12	0.37	0.30	0.33	12.96	13.12	13.04	15.57	15.75	15.66
	13	0.36	0.33	0.34	13.10	12.72	12.91	15.71	15.45	15.58
	Mean	**0.43**	**0.38**	**0.41**	**12.52**	**12.61**	**12.57**	**15.22**	**15.40**	**15.31**
LSD at 5%										
Harvest time (H)		0.05	0.05		0.16	0.39		0.26	0.50	
Varieties (V)		0.04	0.05		0.32	0.50		0.26	0.51	
H x V		0.09	0.10		0.59	0.94		0.51	1.00	

Data revealed that the values of richness, sucrose and sugar recovery percentages were significantly differed among the tested sugarcane genotypes in the plant cane, first ratoon and over crops. The genotype of G.2003-47 surpassed the other in these characters. The variation of these characters between the tested genotypes may be due to varietal characteristic. These results are in agreement with those obtained by Hagos *et al* (2014) who stated that there were significant variances of quality traits among sugarcane genotypes. The improved sucrose%, purity and sugar recovery% of the G.2003-47 variety may have contributed to the rise in sugar production. Data in (Table 5) displayed that the studied sugarcane genotypes differed significantly in cane yield with a superiority of the check (G.2005-47) over the other four genotypes in cane yield in both the plant cane and first ratoon, where recorded 16.72%, 16.58% and 16.62% higher than that given by genotype G.84-47 in plant cane, the first ratoon and over crops, respectively. The results showed that harvesting ages had a marked effect on cane yield of sugarcane genotypes in both plant cane and first ratoon. It was found that applying harvesting age at 13 months resulted the highest cane yield, which led to a significant increase of 11.68%, 9.65% and 10.64% higher than that applying harvesting age at 10 months in the plant cane, the first ratoon and across seasons, respectively. Results in (Table 5) showed that the tested sugarcane genotypes varied significantly in sugar yield with a superiority of the two genotypes G. 2005-47 and G.T.54-9 over the other three genotypes in sugar yield in both the plant cane and first ratoon, recording 22.75% and 8.82% higher than that given by genotype G.84-47 in plant cane and 30.36% and 13.09% in the first ratoon, respectively. It was found that applying harvesting age at 13 months resulted the highest sugar yield, which led to a significant increase of 27.29% higher than that applying harvesting age at 10 months in the plant cane, correspondingly, 17.99% in the first ratoon, respectively, additionally to the rise in sugar yield, these results may be explained by an increase in sucrose and sugar recovery percentages, which had an impact on sugar yield as a final product. Likewise, the results of cane yield might also be explained by an increase in growth, which would result in an expected increase in cane yield.

Table 5: Cane and sugar yields of five sugarcane genotypes as affected by the age at harvest during plant cane 2019/2020 and first ratoon 2020/2021 seasons.

Genotypes	Harvest time (Months)	Cane yield			Sugar yield		
		PC	FR	Mean	PC	FR	Mean
G 2003-47	10	45.85	47.20	46.53	5.82	6.25	6.04
	11	47.56	48.11	47.84	6.26	6.41	6.34
	12	48.41	48.78	48.60	6.51	6.65	6.58
	13	49.33	50.05	49.69	6.57	6.71	6.64
	Mean	47.79	48.54	48.16	6.29	6.51	6.40
G 2004-27	10	46.61	47.92	47.27	5.22	5.86	5.54
	11	51.28	51.69	51.49	6.04	6.47	6.26
	12	51.82	52.14	51.98	6.36	6.64	6.50
	13	53.34	53.77	53.56	6.99	7.01	7.00
	Mean	50.76	51.38	51.07	6.15	6.50	6.32
G 2005-47	10	50.50	51.60	51.05	5.94	6.25	6.10
	11	54.17	54.63	54.40	6.91	7.12	7.02
	12	55.38	55.90	55.64	7.10	7.40	7.25
	13	56.65	57.25	56.95	7.90	7.92	7.91
	Mean	54.18	54.85	54.51	6.96	7.17	7.07
G 84-47	10	45.20	46.40	45.80	5.29	5.24	5.27
	11	45.68	46.21	45.95	5.77	5.85	5.81
	12	46.76	47.22	46.99	5.48	5.07	5.28
	13	48.04	48.38	48.21	6.12	5.85	5.99
	Mean	46.42	47.05	46.74	5.67	5.50	5.58
GT 54-9	10	43.50	45.33	44.42	5.01	5.31	5.16
	11	48.33	49.00	48.67	5.85	6.36	6.11
	12	49.67	50.00	49.84	6.65	6.58	6.62
	13	51.33	52.00	51.67	7.16	6.63	6.90
	Mean	48.21	49.08	48.65	6.17	6.22	6.19
	10	46.33	47.69	47.01	5.46	5.78	5.62
	11	49.40	49.93	49.67	6.17	6.44	6.30
	12	50.41	50.81	50.61	6.42	6.47	6.44
	13	51.74	52.29	52.01	6.95	6.82	6.89
	Mean	**49.47**	**50.18**	**49.82**	**6.25**	**6.38**	**6.31**
LSD at 5%							
Harvest time (H)		0.283	0.666		0.168	0.430	
Varieties (V)		0.447	0.606		0.207	0.285	
H x V		0.830	1.210		0.393	0.624	

Table 6: Eigenvalue, cumulative variability, and factor loadings of the first two principal components (PCs) of cane components and quality traits for sugarcane genotypes as affected by the harvest age.

	H1 (10 Months)		H2 (11 months)		H3 (12 months)		H4 (13 months)	
Traits	**PC1**	**PC2**	**PC1**	**PC2**	**PC1**	**PC2**	**PC1**	**PC2**
Cane yield	0.331	0.276	0.379	-0.167	0.43	0.092	0.367	0.173
Sugar yield	0.147	0.399	0.27	-0.37	0.384	0.234	0.385	0.093
Brix%	-0.378	-0.121	-0.351	-0.207	-0.212	0.359	-0.019	-0.443
Stalk diameter	0.228	0.357	0.386	-0.114	0.377	-0.111	0.375	0.088
Purity%	-0.166	0.41	0.216	-0.365	0.265	0.235	0.329	-0.218
Sugar Recovery%	-0.188	0.412	-0.242	-0.275	-0.019	0.458	0.347	-0.251
Reducing sugars%	0.231	-0.323	0.248	0.39	0.257	-0.336	0.042	0.487
Sucrose%	-0.393	0.178	-0.268	-0.373	-0.089	0.45	0.227	-0.417
Stalk length	0.403	0.067	0.357	-0.107	0.393	-0.073	0.246	0.353
Stalk weight	0.366	0.231	0.359	-0.2	0.414	0.111	0.336	0.247
Richness%	-0.327	0.302	-0.127	-0.477	0.1	0.444	0.345	-0.225
Eigenvalue	5.5844	4.2395	5.9585	3.9334	5.0307	4.6844	6.274	3.807
Proportion	50.8	38.5	54.2	35.8	45.7	42.6	57	34.6
Cumulative	50.8	89.3	54.2	89.9	45.7	88.3	57	91.6

These findings are consistent with those of Abd El-Razek and Besheit (2011), Ahmed (2003), and Mehareb and Abazied (2017), who indicated that delaying harvesting from 10 to 13 months increased sugar recovery%, cane yield, and sugar yield.

According to previous data, delaying harvest time from 10 to 13 months enhanced stalk diameter, stalk length, stalk weight, brix%, cane yield and sugar yield percentage, cane and sugar yield/fad in both plant cane and first ratoon.

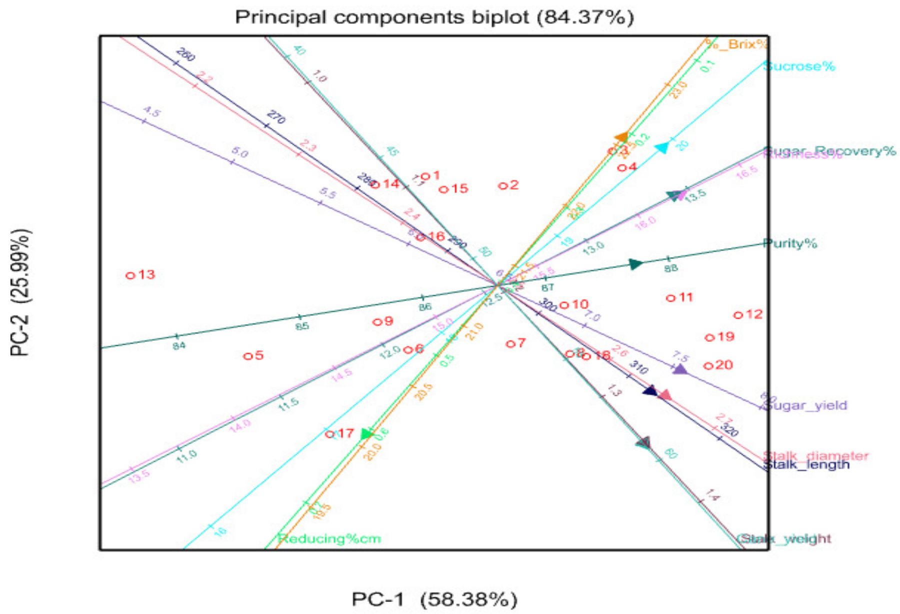

Figure 2: Biplot based on principal component analysis for traits in sugarcane genotypes (G1= G 2003-47, , G2 = G .2004/27,G3 = G. 2005/47 , G4= G 84-47 and G5=GT 54-9as affected by the four time at harvest (H1=10 months , H2=11 months, H3= 12 months and H4=13 months) with 20 combinations; O1= (H1 , G1), O2= (H2, G1) &O3=(H3, G1), O4=(H4 , G1),O5=(H1 , G2), O6=(H2 , G2), O7= (H3 , G2) , O8=(H4 , G2),O9=(H1 , G3), O10=(H2 , G3), O11=(H3 , G3) , O12= (H4 , G3) O13= (H1 , G4), O14= (H2, G4)&O15=(H3, G4), O16=(H4 , G4),O17=(H1 , G5), O18=(H2 , G5), O19= (H3 , G5) and O20=(H4 , G5).

The increase in cane yield for G2005-47 variety may be due to superiority in stalk length and stalk weight which reflected consequently on cane yield. These variations could be linked to the genotypes of sugarcane that were studied in terms of their genetic makeup. Differences between sugarcane genotypes in these characters were also found by Mehareb *and Abazied et al* (2017), and Abo Elenen *el al* (2018), Fahmy *et al* (2021) who carried out studies on dissimilar sugarcane genotypes and found different trend for stalk length, stalk weight and cane yield.

Principal component analysis and AMMI Biplot

Results of the Principal Component Analysis showed that the first two components explained more 88% of the total variation among all analyzed variables (table 6) in all harvest ages. The first component (PC1) explained 50.8, 54.2, 45.7, and 57% of the total variation among the tested sugarcane genotypes assessed by different harvesting ages (10, 11, 12 and 13 months measured under the plant cane and first ratoon seasons. The second component (PC2) explained 38.5, 35.8, 42.6, and 34.6% of the total variation measured by the same variables, respectively (Table 6). These results are in harmony with (Massaoudou *et al.* (2018) and Abo elenen *et al* (2019) and Mehareb *et al* (2021) that indicated four PCs with eigenvalues superior than one, which explained > 75% of the total variance for the traits. Moreover, the PC1 had a strong positive correlation with cane yield and millable cane weight measured at age of 11 and 12 months, millable stalk length and weight measured at harvesting age 10 month, by contrast, sugar yield then millable cane diameter measured at age of 13 months.

The PC1 had a strong negative correlation with brix% measured at all harvesting ages. The PC1 had a moderate negative correlation with sucrose % and sugar recovery% as well as a moderate positive correlation with millable cane diameter, reducing sugars and sugar yield calculated based 10,11 and 12 months age (Table 6). These results can be explained by increased growth (millable cane diameter, length and weight), which would lead to an anticipated increase in cane yield. Additionally, the rise in sugar yield might be brought on by higher brix, richness and sugar recovery percentages, all of which had an impact on sugar yield as a final product. These results are agreement with Abd El-Razek and Besheit (2011), Ahmed (2003) and Mehareb and Abazied (2017) who stated that delaying harvesting age from 10 to 13 month increased brix%, sugar recovery%, cane yield and sugar yield. Figure 2 displayed positive correlation and highly significant between cane yield, millable cane weight, then cane yield and millable cane length followed by cane yield and millable cane diameter.

Jamoza *et al.* (2014) found positive correlation between stalk weight and cane yield. Furthermore, (Kumar and Kumar 2014 and Gadallah and Mehareb 2020) observed that millable cane length and diameter presented positively and highly direction effect on cane yield. In contrast, high positive correlation was also observed between millable cane length and weight as well as between millable cane diameter and weight. These results are in coinciding with those mentioned by Gadallah and Mehareb 2020, who observed that millable cane length and weight displayed significant positive correlation. Sugar yield was significantly and positively correlated with purity%, then sugar recovery%, and sucrose% followed by brix%. Negative correlation was detected between sucrose% and reducing sugars%. These results are in harmony with those reported by Tadesse and Dilnesaw (2014), who mentioned that reducing sugars was negatively and significantly correlated with sucrose %. On the other hand, results in (Figure 2) showed that O1=(G1 , H1) and O2 = (G1, H2) were the highest genotypes in richness%, and the other hand, O12=(G3, H4), O19=(G5, H3), O20=(G5, H4) were the highest genotypes in cane yield and sugar yield, while O16 = (G4, H4) was the highest one in brix%. In addition, O8=(G2, H4),O12=(G3, H4), O20=(G5, H4) were the best genotypes in millable cane length.

AMMI Biplot

The IPCA1 and IPCA2 (first and second interaction principal component axis) were highly significant and accounted for 96.29% and 2.56% of the sums of squares for cane yield and 71.13% and 18.18% for sugar yield of the total GEI variation, respectively. The GEI was highly significant implying differential response of genotypes to environments (Mehareb et al 2022 and Al-Naggar et al. 2020), genotype are the one which is on the central circle (Figs. 3 and 4). Thus, Fig. 3 and 4 displays the comparison plot for genotypes, and a model genotype is one which is near or at the middle of the concentric circle. Based on this assumption, (the analysis AMMI), (Figures 3 and 4) displays the comparison plot for genotypes, V1 (G 2003-47) and V4 (G 84-47) were the most ideal genotypes, with high mean cane yield, sugar yield and high stability when harvested after 10 months (H1 and H5) in plant cane and first ratoon, respectively, So, it considered early maturity. The highest values of cane and sugar yield were recorded by the genotypes V3 (G 2005-47) and V5 (GT 54-9) under 13-months old at harvest (H4 and H8) in the both plant cane and first ratoon, respectively, while the following genotype V2 (G 2004-27) recorded the highest cane and sugar yield under 12 months old at harvest (H3 and H7) in plant cane and first ratoon, respectively. Figures 3 and 4 help visualize the distance between each harvest age and the perfect harvest age, ''model tested environment'', which is at the middle of the concentric circles. Thus, H4 and H8 for cane yield and H8 with G3 (for sugar yield, respectively were the superior representative harvest and had the maximum ability for discriminating genotypes with respect to cane yield and sugar yield.

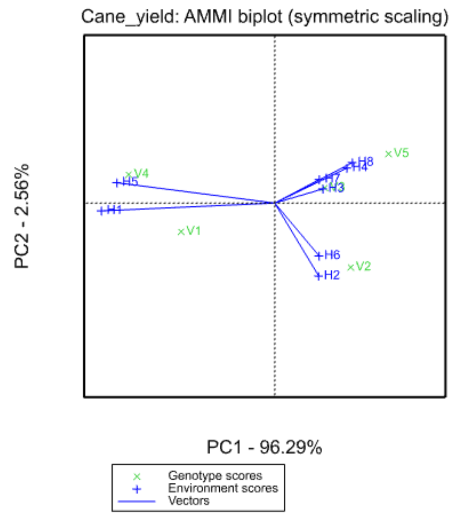

Figure 3: AMMI biplot offering cane yield for five sugarcane genotypes under 8 harvesting age in plant cane and first ratoon.

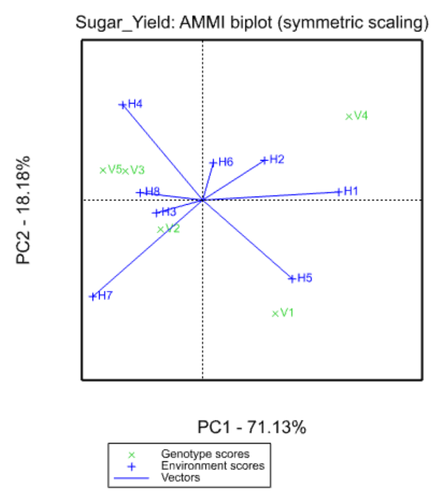

Figure 4: AMMI biplot offering sugar yield for five sugarcane genotypes under 8 harvesting age in plant cane and first ratoon.

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