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Stability Study of Sweet Potato Yield and its Component Characters under Different Environments by Joint Regression Analysis

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Abstract: Six sweet potato cultivars; namely Abees, Minufiya 2, Minufiya 6, Minufiya 10, Minufiya 66 and Beauregard, were planted under four environments, consisted of the combinations among 2 locations x 2 years. The two locations used were at Sabaheya Horticultural Research Station Farm, Alexandria governorate, North West of Egypt and at a newly reclaimed area, at El-Sadat city, of the Environmental Studies and Research Institute Farm, Minufiya University, Minufiya Governorate, Egypt. The two years of the study were 2008 and 2009. The objectives of this study were to estimate the genotypic and phenotypic variabilities for some morphological, yield and quality characters of the six different sweet potato cultivars. The adaptability and performance's stability were also measured, in addition to the broad-sense heritability. There was considerable variation in morphological, tuber root yield, yield components and quality characteristics within both main factors; i.e. cultivars and environments. Genotype by environment interaction (G X E) was present for most of the studied traits, specially, for yield character which is considered as the most important economic character. The obtained results showed that the major component for differences in stability was due to the deviation from the linear function and not to the linear regression it self. Broad-sense heritability estimates ranged from 14.47 to 30.54 % for the morphological characters, 33.33 % for tuber root yield trait and from 0.67 to 88.1 % for the quality attributes.

Key words: Sweet potato (*Ipomoea batatas, L.)* · Genotype x Environment interaction · Stability analysis · Regression coefficient · Deviation from regression · Broad-sense heritability

INTRODUCTION

When several crop cultivars are grown in a range of environments, there sometimes exist genotypes X environments interactions which, usually, pose serious problems in comparing the performance of the individual cultivars across environments and reduce the efficiency of genetic progress through selection [1]. So; genotype X environment (G X E) interaction is of primary concern to plant breeders. The effect of G X E interactions in breeding programs is to reduce correlations between phenotype and genotype resulting in invalid or biased conclusions about genetic variance [2]. Sweet potatoes (*Ipomoea batatas*, L.) are grown around the world in diverse environments and ranks the world's seventh most important food crop; after wheat, rice, maize, Irish potatoes, barley and cassava [3]. This crop has great potentials to alleviate wide spread malnutrition and poverty in developing countries [4]. It is a good source of vitamin A and starch. Fresh sweet potatoes provide about 50 % more calories than Irish potato [5]. Many traits of interest to sweet potato breeders have been shown to be sensitive to environmental changes; as shown by previous G X E studies on several traits [2, 6-8, 1, 9]. Recently, many breeders are concerned with this type of interaction in sweet potato (G X E) [10, 11]. In this respect, the combined analyses of variance detecting genotype x environment interactions, when cultivars are evaluated at different environments, do not describe the different responses of the individual cultivars to the various environments. Also, it has been observed that the magnitudes of the G X E interactions are a linear function of the environmental effects [12]. Thus, differences in response by individual cultivars to a wide range of

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environments, often, follow an orderly pattern which can be measured as differences between coefficients of linear regression of individual cultivar response on the mean response of all cultivars in the environments [1]. So, Joint regression, in which cultivar's response is regressed on an environmental index, is an important supplementary approach for elucidating the response of the individual cultivar to a particular environment.

The regression technique for testing the genotype X environment interaction was first suggested by Yates and Cochran [13]. This technique was used and modified by Finlay and Wilkinson [14] to analyze the adaptation of number of barley cultivars, grown at different environments. In 1966, Eberhart and Russell [15] proposed the use of two statistical parameters, a regression coefficient (b_i) and the deviation from regression (S^2d_i), to estimate the stability of numeral cultivars. They defined a stable cultivar as one having a regression coefficient of unity ($b_i = 1$) and the minimum deviation from regression ($S^2d_i = 0$).

The Present Study Was Carried out to Achieve the Following Goals:

- Determining the magnitude of genotype X environment interaction variation in sweet potato, regarding economical and quality characters.
- Determining adaptability and stability of sweet potato crop under different environments of Egypt.
- Estimating the heritability degrees for studied sweet potato characteristics.

MATERIALS AND METHODS

Six sweet potato cultivars; namely, Abees, Minufiya 2, Minufiya 6, Minufiya 10, Minufiya 66 and Beauregard; were planted under four environments, which were the combinations of 2 locations x 2 years. Four cultivars, i.e. Minufiya 2, 6, 10 and 66, were obtained from El-kanater Research station; Minufiya governorate. The cultivar Beauregard was obtained from Agro Food Farm Co. at El-Nubariya region, Behera governorate. While the cultivar Abees was obtained from the local market of Abees region, Alexandria governorate. The two locations were Sabaheya Horticultural Research Station Farm; Alexandria governorate, North West of Egypt; and the second location was the Environmental Studies and Researches Institute Farm, Minufiya University, at El-Sadat city, Minufiya Governorate, in western desert of Egypt. The two years were the summer seasons of 2008 and 2009.

Planting was on the first of June in both years. Stem cuttings of 25 cm length were planted in rows at spacing of 0.25 m. The experimental unit at Sabaheya Farm consisted of 3 rows, 0.60 m apart and 4 m long, having an area of 7.2 m^2. At El-Sadat city, the experimental unit consisted of 3 rows, 0.75 m apart and 10 m long, having an area of 22.5 m^2 under a drip irrigation system. Spacing between plants within rows was at 25 cm at the both locations.

The description of the experimental locations is presented in Table (1). Some monthly meteorological data of the experimental locations, during the two growing years, are listed in Table (2). The physical and chemical analyses of the soil, of the two used experimental cites, are presented in Table (3). All the agricultural practices used for commercial sweet potato production were carried out in both experiments.

Measured Characters:

Vegetative Growth and Yield Parameters: Five whole plant samples per plot were randomly used, 80 days after planting, for the determination of the vegetative growth (plant length (m), number of branches and plant fresh weight (kg)). Another five random plants were used for determining plant tuber root yield (kg). Tuber root yield was determined in weight and number of all tuber roots per plant.

Tuber Physical Characteristics: Random samples of 10 tuber roots per treatment were randomly used to measure the physical characteristics of the tubers; tuber length and diameter were measured to calculate the tuber shape index by dividing the former by the latter.

Table 1: Description of the two experimental locations (Sabaheya and El-Sadat city).

	Sabaheya	El-Sadat city
Region	South Mediterranean	Western Desert
Coordinates	31.2°N, 29.9°E	30.6°N, 30.22°E
Altitude (m a.s.l.)	7 m	40 m
Climate type	Mediterranean	Dry semi-arid

Table 2: Some monthly meteorological data of the experimental locations during the two years (2008 and 2009) of the study.

Meteorological characters	Locations	June	July	August	September
		2008			
Temperature (°C)	Sabaheya	26.0	28.0	28.0	27.0
	El-Sadat city	29.0	29.0	30.0	29.0
Rainfall (mm)	Sabaheya	0.0	0.0	0.0	0.0
	El-Sadat city	0.0	0.0	0.0	0.0
Relative humidity (%)	Sabaheya	66.0	66.16	71.22	65.2
	El-Sadat city	46.9	59.2	60.4	56.5
Wind speed (Km/h)	Sabaheya	12.0	16.0	14.0	13.0
	El-Sadat city	13.0	12.0	11.0	12.0
		2009			
Temperature (°C)	Sabaheya	27.0	28.0	27.0	27.0
	El-Sadat city	30.0	30.0	29.0	28.0
Rainfall (mm)	Sabaheya	0.0	0.0	0.0	0.0
	El-Sadat city	0.0	0.0	0.0	0.0
Relative humidity (%)	Sabaheya	63.1	70.2	71.6	67.2
	El-Sadat city	45.6	57.5	58.0	56.6
Wind speed (Km/h)	El-Sabaheya	14.0	16.0	14.0	15.0
	El-Sadat city	13.0	12.0	11.0	12.0

Table 3: Physical properties and chemical analyses of the experimental soils:

Soil analyses of Sabaheya Farm

Mechanical analysis

Sand%	Silt%	Clay%	Texture	pH	EC. dS/m	$CaCo_3$%	O.M.%
23.90	42.50	33.60	coarse clay shales	8.33	1.8	22.00	0..57

Chemical analysis

Cations (meq/L)						Anions (meq/L)			
N^+	P^+	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^-	HCO_3^-	CL^-	SO_4^{--}
27.5	19.7	0.94	0.39	081	895.0	zero	1.83	0.45	2.00

Soil analyses of El-Sadat city

Mechanical analysis

Sand%	Silt%	Clay%	Texture	pH	EC. dS/m	$CaCo_3$%	O.M.%
90	5	5	Sandy	7.26	6.00	5.5	0.80

Chemical analysis

Cations (meq/L)						Anions (meq/L)			
N^+	P^+	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^-	HCO_3^-	CL^-	SO_4^{--}
Traces	0.40	53.75	23.75	17.1	2.16	Zero	8.0	68.0	20.76

Tuber Root Quality:

Tuber Dry Matter (%): Was determined by weighing a random sample of fresh tubers and then dried.

$$\text{Dry matter \%} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

Determination of Reducing and Non-Reducing Sugars Content (%): A known mass (5 g) of fresh tuber root was taken to determine reducing and non-reducing sugars, using sulphuric acid and phenol (5%); then they were colourimetrically determined, according to the method of Dubios, *et. al.* [16].

Determination of Starch: Tuber root starch content (%) was determined colourimetrically using a sample of 1 g of fresh tuber, according to the method described in A.O.A.C. [17].

Experimental Design and Statistical Analysis: The used experimental layout was arranged in a randomized complete blocks design (R.C.B.D), with three replicates. Collected data of the experiments were subjected to a combined analysis of the variance as outlined by Miller, *et al.* [18], in which, replications, locations and years were considered as random; while, the cultivars were fixed. The data were also analyzed for the stability studies, using the model, described by Eberhart and Russell [15]. Comparisons among the means of different treatments were carried out, using Duncan's multiple range test procedure at p = 0.05 level of significance, as illustrated by Snedecor and Cochran [19]. Heritability, in the broad sense, was estimated for the various studied characters, as illustrated by Collins, *et al.* [2], according to the following formula:

$$H\% = \delta^2_g / (\delta^2_g + \delta^2_m) \text{ X } 100$$

here; $\delta^2_m = \delta^2_{gl} / l + \delta^2_{gy} / y + \delta^2_{gly} / ly + \delta^2_e / rly$

where; δ^2_g is the genetic variance; δ^2_m is the expected variance of a genotypic mean; δ^2_{gl} / l is the variance due to interaction of genotypes x locations; δ^2_{gy} / y is the variance due to interaction of genotypes x years; δ^2_{gly} / ly is the variance due to interaction of genotypes x locations x years; and δ^2_e / rly is the error variance.

RESULTS AND DISCUSSION

Sweet Potato Morphological and Yield Characters:

Mean Performances of the Sweet Potato Vegetative Growth, Yield and its Components Characters: Data presented in Table (4) indicated clearly that, all of the studied morphological, yield and its components characters showed significant differences among the evaluated cultivars. The cultivar Beauregard possessed the tallest plants; but, on the other hand, gave the lowest value for branches number, foliage fresh weight, tuber roots yield and tuber roots number. The cultivar Minufiya 6 produced the highest tubers root yield, accompanied with the highest number of tuber roots and average tuber roots weight characters, followed with the cultivar Minufiya 66. The cultivar Minufiya 2 possessed the highest value for the foliage fresh weight character with insignificant differences from those of the cultivars Minufiya 66, Abees and Minufiya 6, respectively (Table, 4).

Genotype X Environment Interaction: Data presented in the Table (5) showing, the combined analyses of variance, indicated that, most of the studied traits reflected clear effects for the environmental factors, with the exception of No. of branches /plant character which did not show

Table 4: Mean performances of the morphological, yield and yield components characters of the six sweet potato cultivars, calculated from the combined data over the four environments (2 years x 2 locations).

Cultivars	Plant length (cm)	No. of Branches /plant	Foliage fresh weight/plant (Kg)	Tuber root yield/plant (Kg)	No. of tuber roots /plant	Tuber root weight /plant (Kg)
Abees	127.55 b	6.27 b	0.66 a	0.785 de	3.80 abc	0.20 c
Minufiya 2	121.13 c	6.66 b	0.71 a	0.990 c	4.03 ab	0.25 b
Minufiya 6	121.13 c	7.10 ab	0.63 a	1.490 a	4.39 a	0.34 a
Minufiya 10	84.30 e	6.22 b	0.39 b	0.872 d	3.36 bc	0.26 b
Minufiya 66	109.63 d	8.00 a	0.69 a	1.170 b	3.56 bc	0.33 a
Beauregard	181.86 a	4.36 c	0.32 b	0.682 e	3.19 c	0.21 c
Mean ($\bar{X}$)	124.27	6.44	0.57	0.95	3.72	0.25

Means followed by a common letter (s) within each column do not significantly differ, using Duncan's Multiple Range Test at 0.05 level of significance.

Table 5: Combined analysis of variance for the studied morphological and yield components of sweet potato.

S. O. V.	D.F.	Plant length (cm)	No. of branches/plant	Foliage fresh weight/plant (Kg)	Tuber root yield/plant (Kg)	No. of tuber roots /plant	Tuber root weight /plant (Kg)
Locations	1	17020.40**	1.92	0.04	1.87**	8.71 **	0.033 **
Years	1	956.80	2.64	0.13*	5.91**	43.43 **	0.047 **
Locations X Years	1	19044.70**	308.35 **	1.36**	0.15 **	2.12	0.081 **
Repl. /L/Y	8	520.09	2.86	0.02	0.03	0.86	0.003
Cultivars	5	11804.12 **	17.58 **	0.34 **	0.97**	1.89 *	0.025 **
Cultivars X Locations	5	7067.46 **	15.08 **	0.15	1.36**	4.27 **	0.057 **
Cultivars X Years	5	4458.64 **	8.02	0.24	0.63 **	2.43**	0.015 **
Cultivars X Locations X Years	5	1429.90 *	12.44 **	0.45 **	0.05 *	1.06	0.000
Pooled error	40	413.99	3.54	0.07	0.02	0.65	0.002

*, ** Significant and highly significant at 0.05 and 0.01 levels, respectively.

any significant differences for both locations and years factors. The highly significant environmental main effects (locations and years) indicated that there were some obvious fluctuations in the environmental conditions throughout the different experiments of the present study. Variability among locations and years could mainly be related to differences in soil type, temperature and soil moisture conditions, during the various growing seasons, which was also suggested by Nguyen, *et al.* [20].

The results in Table (5) reflected highly significant effects for the environmental combinations (locations X years) on the performances of most studied characters, with the exception of number of tuber roots /plant character. The presence of the effect of such interaction suggested that climate was a significant factor in location differences affecting these characters from year to year. Similar explanation was also reached by Harris [21]. Similar results were also reported by Grüneberg, *et al.* [10] and Caliskan, *et al.* [11]. All studied morphological and yield characteristics showed significant or highly significant genotypic differences (Table, 5), indicating that, the evaluated cultivars differed in their genetic potentials, concerning these characters. The first-order interaction (cultivars X locations and cultivars X years) appeared to be highly significant for most of the studied traits (Table, 5), indicating that the evaluated cultivars tended to rank differently when grown at different locations or at different years, as mentioned by Abd El-Moneim and Cocks [22]. The obtained results revealed that, for evaluating these characters, the experimental trials should be repeated over locations and years. On the other hand, the insignificant estimates for the effects of the first order interactions (cultivars X locations and cultivars X years) on the character foliage fresh weight /plant and of cultivars X years interaction on the character No. of branches/ plant suggested that, the evaluated cultivars responded similarly when grown under different environments. The second-order interaction (cultivars X locations X years), which was considered as the genotypes X environment interaction, reflected significant different effects on the characters; plant length, no. of branches/plant, foliage fresh weight/plant and tuber root yield/plant (Table, 5). Such a result, generally, suggested that the evaluated cultivars showed different responses, with regard to the mentioned characters, when grown under variable environments. Similar results were also reported by the investigators Collins, *et al.* [2]; Ngeve [23, 1]; Manrique and Hermann [9] and Caliskan, *et al.* [11]. Accordingly, it seemed obvious that these characters should be measured over multiple locations and years, to separate cultivars X environment interaction components from total genotypic variance, as stated also by Yildirim and Caliskan [24], on potato crop.

Thus, the findings of the present study seemed to fulfill the basic requirements for stability analysis, for the various studied characters, with the exception of No. of tuber roots/plant and average tuber root weight/plant (Table, 5).

Phenotypic Stability Analysis: The analyses of variance for estimating stability parameters of the studied morphological and yield characters are shown in Table (6). The method of Eberhart and Russell [15] was utilized for estimating stability of the individual genotypes, for the studied characters which, already, exhibited significant differences for genotypes X environment interaction. According to this method, the stable and desirable genotype would have approximately: 1- Regression coefficient (b_i) = 1.0, 2- Deviation from regression (S^2d_i) = 0.0 and 3- A high mean value; where, the regression coefficient measures the response of a genotype to a given environment and the deviation from regression measures the stability of performance.

Table 6: Analysis of variance for the estimated stability parameters, for the morphological and yield components characters, calculated from the data averaged over all replications (#).

S. O. V.	D.F.	Plant length (cm)	No. of branches/plant	Foliage fresh weight/plant (Kg)	Tuber root yield/plant (Kg)
Cultivars	5	4126.678 *	5.855	0.115	0.323
Envi. + (Cult. X Envi.)	18	1984.879	9.085 *	0.107	0.335
Envi. (linear)	1	13126.780 **	34.768 **	0.508 *	2.646 **
Cult. X Envi. (linear)	5	2479.781	4.499	0.136	0.308
Pooled deviation	12	850.185**	3.061*	0.061**	0.153 **
Abees	2	310.089	0.241	0.114**	0.335 **
Minufiya 2	2	965.880**	3.195	0.055	0.092 *
Minufiya 6	2	956.231**	1.956	0.079*	0.204 **
Minufiya 10	2	337.085	0.559	0.017	0.155 **
Minufiya 66	2	360.887	4.206*	0.063	0.055**
Beauregard	2	2170.942 **	8.209**	0.037	0.079 **
Pooled error	40	138.000	1.181	0.020	0.006

*,** Significant and highly significant at 0.05 and 0.01 levels, respectively.

Table 7: Stability parameters of morphological and yield components characters of the six evaluated sweet potato cultivars.

	Plant length (cm)				No. of Branches/plant			
Cultivars	$\bar{X}$	b_i	S^2d_i	Stable	$\bar{X}$	b_i	S^2d_i	Stable
Abees	127.55	0.38	172.09**	N	6.27	0.81	-0.94	N
Minufiya 2	121.13	0.96	827.88**	Y	6.66	1.31	2.01**	N
Minufiya 6	121.13	0.67	818.23**	N	7.10	1.76	0.77	Y
Minufiya 10	84.30	0.61	199.09**	N	6.22	0.64	-0.62	N
Minufiya 66	109.63	0.26	222.89**	N	8.00	1.13	3.02**	N
Beauregard	181.86	3.12**	2032.94**	Y	4.36	0.34	7.03**	N

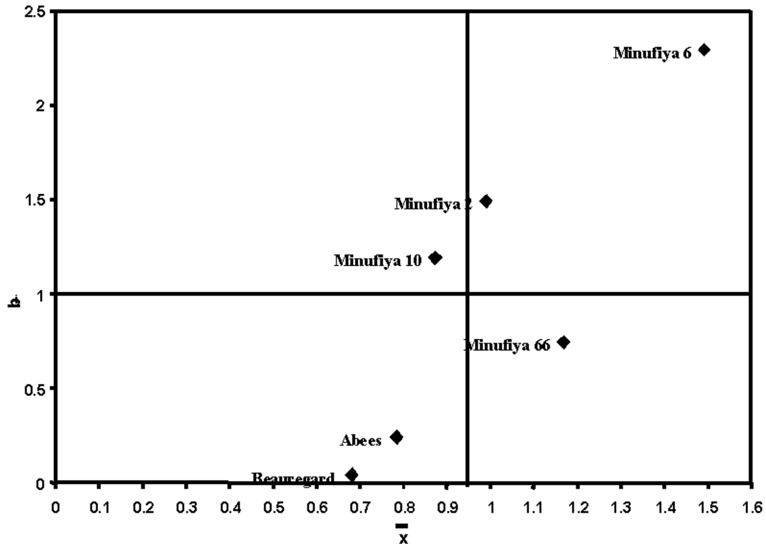
	Foliage fresh weight/plant (Kg)				Tuber root yield/plant (Kg)			
Cultivars	$\bar{X}$	b_i	S^2d_i	Stable	$\bar{X}$	b_i	S^2d_i	Stable
Abees	0.66	0.02	0.09	N	0.785	0.24	0.33**	N
Minufiya 2	0.71	2.90*	0.03	Y	0.990	1.49	0.09	Y
Minufiya 6	0.63	1.99	0.06	N	1.490	2.29*	0.20	Y
Minufiya 10	0.39	0.44	-0.01	N	0.872	1.19	0.15	N
Minufiya 66	0.69	1.18	0.04	Y	1.170	0.75	0.05	Y
Beauregard	0.32	-0.48	0.01	N	0.682	0.04	0.07	N

*,** Significant and highly significant at 0.05 and 0.01 levels, respectively.

The differences among the genotypes; i.e. evaluated cultivars ; were high enough to reach the used significance level with respect to plant length trait; whereas, the remained studied characters did not reflect any significant differences (Table, 6). The estimated values for the parameter environment (linear) were found so pronounced to be significant or highly significant, for all studied morphological and yield characters. The studied characters did not possess any clear differences regarding the parameter cultivars X environment (linear), reflecting insignificant differences for linear response among the cultivars across various environments. These results indicated clearly that the predictions of the performances of these characters, for the evaluated cultivars in different environments, would be difficult, as explained by Guilan Yue *et al*. [25]. Pooled deviation appeared to be either significant or highly significant for the studied characters, indicating that the major component of differences in stability was due to the deviation from the linear function and not to the linear regression itself, as illustrated by Rai, *et al*. [26].

Stability Parameters: Three parameters of stability, i.e. mean ($\bar{X}$), regression coefficient (b_i) and deviation from regression (S^2d_i); were estimated for the various studied characters and presented in Table (7).

The individual cultivars, with respect to plant length, did not show a linear relationship except the cultivar Beauregard. The presence of a non-linear component (S^2d_i) was obvious for all the studied cultivars. These cultivars were unstable, thus the predictions for them across various environments would not be possible.



(Mean = 0.95)

Fig. 1: Scattered diagram for mean tuber root yield / plant and regression coefficient (b_i) over all environments

The cultivar Beauregard had a high b_i value (b_i = 3.12) with a highly significant S^2d_i, indicating that this cultivar might reflect a higher response potential, for this particular character, under the more favorable environmental conditions, as illustrated also by Langer, *et al.* [27]. The cultivar Minufiya 2 appeared to be desirable cultivar, where this cultivar have b_i close to unity and high average performance ($\overline{X}$ = 121.13),while Minufiya 10 was the least favorable cultivar because its lower mean performance ($\overline{X}$ = 84.3). Regarding the trait No. of branches/plant, the cultivars Minufiya 2, Minufiya 66 and Beauregard were unstable because there S^2d_i values were found significant.

The other cultivars did not show significant linear or non-linear components; but, the cultivar Minufiya 6 was the most desirable one because it had the highest mean value. None of the studied cultivars showed significant effect regarding the non- linear portion, regarding the character foliage fresh weight / plant. The cultivar Minufiya 2, which possessed significant estimated (b_i) value and larger than one (i.e. b_i > 1), seemed to be candidate to perform well under the more favorable environmental conditions. The cultivars, Minufiya 10 and Beauregard appeared to be not desirable for this character because its lower mean performances. The cultivar Minufiya 66 proved to be the most desirable one, because of its high detected mean performance ($\overline{X}$ = 0.69). For tuber root yield /plant character, values of regression coefficients (b_i) ranged from 0.04 up to 2.29 with insignificant differences among the evaluated cultivars, except for Minufiya 6, which possessed b_i value > 1; suggesting that this cultivar might be more responsible under the favorable environmental conditions. On the other hand, values of deviation from regression (S^2d_i) were insignificant for the evaluated cultivars, except for Abees cultivar. Eberhart and Russell [15] proposed that, the most important stability parameter appeared to be the deviation mean squares from regression and considered cultivars with the lowest deviation being the most stable. Keeping in view the three parameters of stability ($\overline{X}$, b_i and S^2d_i) illustrated in Table (7) and, Fig. (1); the cultivar Abees considered unstable cultivar (S^2d_i value is significant). Minufiya 10 and Beauregard cultivars seemed to be undesirable cultivars because its lower production compared with the average of mean performance of the studied cultivars (0.95). On the hand, the cultivar Minufiya 66 seemed to be the most favorable cultivar; since this cultivar possessed a relatively high yield (1.17 Kg tuber root yield/ plant), insignificant bi value and S2di value close to zero, followed with the cultivar Minufiya 2.

Sweet Potato Quality Characters:

Mean Performances of the Sweet Potato Quality Characters: Data in Table (8) appeared that, all studied quality characteristics possessed significant differences among the evaluated cultivars. The cultivar Beauregard showed the highest record, with respect to tuber root shape index, indicating that this cultivar possessed a more oblong shape relative to those of the other studied cultivars. The lowest value in this respect was that of the cultivar Abees without any significant differences from Minufiya 10 and Minufiya 66.

Table 8: Mean performances of the quality characters of the six sweet potato cultivars, calculated from the combined data over the four environments (2 years X 2 locations).

Cultivars	Tuber root shape index	Tuber root dry matter (%)	Starch (%)	Reducing sugars (%)	Non- reducing sugars (%)
Abees	2.14 d	24.68 c	15.15 d	3.46 a	2.12 a
Minufiya 2	2.46 bc	29.31 a	19.97 b	2.42 c	2.11 a
Minufiya 6	2.64 b	29.41 a	20.84 a	2.62 bc	2.13 a
Minufiya 10	2.15 d	30.17 a	20.54 ab	2.74 bc	1.92 b
Minufiya 66	2.32 cd	30.05 a	20.69 a	2.94 b	1.78 b
Beauregard	3.16 a	27.40 b	17.57 c	3.29 a	2.13 a
Mean ($\bar{x}$)	2.49	28.51	19.13	2.91	2.03

Means followed by a common letter (s) within each column do not significantly differ using Duncan's Multiple Range Test at 0.05 the level of significance.

Table 9: Combined analysis of variance for the studied quality characters of sweet potato.

S. O. V.	D.F.	Tuber root shape index	Tuber root dry matter (%)	Starch (%)	Reducing sugars (%)	Non- reducing sugars (%)
Locations	1	13.88 **	3.10	5.33 **	0.36	1.84 **
Years	1	0.46 **	69.56 **	50.27 **	1.20 *	3.97 **
Locations X Years	1	0.13	0.08	1.54	1.90 **	0.59 **
Repl./L/Y	8	0.19 **	2.99	1.62 *	0.69 **	0.08
Cultivars	5	1.77 **	54.26 **	63.20 **	1.92 **	0.26 **
Cultivars X Locations	5	1.48 **	1.29	0.77	0.46	0.11 *
Cultivars X Years	5	0.78 **	5.39 *	1.45	1.19 **	0.39 **
Cultivars X Locations X Years	5	0.48 **	3.22	3.65 **	0.30	0.33 **
Pooled error	40	0.05	1.56	0.67	0.20	0.04

*, ** Significant and highly significant at 0.05 and 0.01 levels, respectively.

The highest dry matter content among all cultivars appeared to be that of the cultivar Minufiya 10; followed by those of Minufiya 66, Minufiya 6 and Minufiya 2, without any significant differences. The lowest dry matter content was that of the cultivar Abees. The six cultivars differed in their starch percentages. In this respect;, Minufiya 6, Minufiya 66 and Minufiya 10 scored the highest values, followed by those of cultivars Minufiya 2 and Beauregard, while the cultivar Abees produced the lowest percentage. On the contrary, cultivar Abees possessed the highest value regarding reducing sugars character, with an insignificant difference from that of cultivar Beauregard. Cultivar Minufiya 2 gave the lowest percentage with negligible differences from those of the two cultivars Minufiya 6 and Minufiya 10. The four cultivars Minufiya 6, Beauregard, Abees and Minufiya 2 appeared to have relatively high levels of non-reducing sugars; whereas, the two cultivars Minufiya 66 and Minufiya 10 showed relatively low levels. The detected differences within each of these two groups were insignificant.

Genotype X Environment Interaction: Data presented in Table (9) indicated that, most of the studied sweet potato quality characteristics showed a large dependence on the environmental main effects, with exceptions of tuber root dry matter and reducing sugar content regarding the location main environmental factor. The reflected clear effects of environments could be related to soil type, temperature, soil moisture conditions during the various growing seasons, as was also suggested by Nguyen, *et al.* [20]. The highly significant environmental combined effects on the performances of the characters reducing and non-reducing sugars, suggested that there were climatic effects on location differences, reflected on these characters, from year to year. The obtained results were in accordance with those of Collins, *et al.* [2] and Negeve [23, 1].

The insignificant effects of the environmental conditions (locations and locations X years), noticed in Table (9) for particular characters, revealed that selection for this character might be effective under the conditions of this study.

All studied quality characters showed highly significant genotypic differences among the evaluated cultivars. The effects of the cultivars X locations interactions showed significant differences for the characters tuber root shape index and non-reducing sugars. The interaction cultivars X years reflected significant differences on studied quality traits, except tuber root starch content. The genotype by environment interaction (cultivars X locations X years) showed highly significant mean squares for the characters tuber root shape index, starch content and non-reducing sugars

Table 10: Analysis of variance for the estimated stability parameters, for the tuber root quality characters, calculated from the data averaged over al replications (#).

S. O. V.	D.F.	Tuber root shape index	Starch (%)	Non- reducing sugars (%)
Cultivars	5	0.594 *	21.054 **	0.086
Envi. + (Cult. X Envi.)	18	0.491 *	1.664	0.192
Envi. (linear)	1	4.823 **	20.550 **	2.118 **
Cult. X Envi. (linear)	5	0.477 **	0.231	0.079
Pooled deviation	12	0.136 *	0.686**	0.079**
Abees	2	0.085*	1.121*	0.055*
Minufiya 2	2	0.060*	0.055	0.123**
Minufiya 6	2	0.023	1.363**	0.038
Minufiya 10	2	0.244 **	0.947*	0.173
Minufiya 66	2	0.129 **	0.025	0.078**
Beauregard	2	0.279 **	0.606	0.011**
pooled error	40	0.018	0.223	0.013

*, ** Significant and highly significant at 0.05 and 0.01 levels, respectively.

Table 11: Stability parameters of quality characters of six sweet potato cultivars.

	Tuber root shape index				Starch (%)				Non- reducing sugars (%)			
Cultivars	$\bar{x}$	b_i	S^2d_i	Stable	$\bar{x}$	bi	S^2d_i	Stable	$\bar{x}$	b_i	S^2d_i	Stable
Abees	2.14	0.03*	0.07	N	15.15	0.93	0.90**	N	2.12	0.82	0.04	Y
Minufiya 2	2.46	1.11	0.04	N	19.97	0.95	-0.17	Y	2.11	0.77	0.11	Y
Minufiya 6	2.64	1.85	0.01	Y	20.84	0.70	1.14**	N	2.13	1.26	0.02	Y
Minufiya 10	2.15	1.23	0.23*	N	20.54	0.75	0.72*	N	1.92	1.71	0.17*	N
Minufiya 66	2.32	1.67	0.11	N	20.69	1.67	-0.20	Y	1.78	1.10	0.07	N
Beauregard	3.16	0.12	0.25*	N	17.57	0.85	0.38	N	2.13	0.34	0.00	Y

content (Table, 9). These results suggested that different sweet potato cultivars require different environments to assess the grown ones, regarding the studied quality characters.

Phenotypic Stability Analysis: The results in Table (10) revealed that, the detected differences among the evaluated cultivar were found significant or highly significant for the two characters tuber root shape index and starch content, respectively; and insignificant for non-reducing while non-reducing sugars trait. It was clear that the tested sweet potato cultivars were genetically different in genes controlling the two first traits. The significant mean squares due to environment + (cultivar X environment) for tuber root shape index revealed that the tested genotypes of the cultivars interacted considerably with the changes in the used environmental conditions; which were not reflected on starch and non-reducing sugars contents. The mean squares of the cultivar X environment interaction (linear portion of the interaction) appeared also significant for tuber root shape index trait and explained the large part of interaction. Such a result indicated that this character was highly influenced by the changes in the environmental conditions. On the other hand, the mean squares due to deviation from regression (non-linear portion of interaction) were found significant reflecting differential of genotypic response to stability for the character tuber root shape index. In this respect, Ebrehart and Russell [15] pointed out that the most important stability parameter appeared to be deviation mean squares; where, all types of gene action are involved in this parameter and considered cultivars with the lowest deviation being the most stable.

Stability Parameters: Table (11) shows the means of the quality characters and estimates of stability parameters (b_i and S^2d_i) for the six studied cultivars. Mean values for tuber root shape index trait ranged from 2.14 for Abees to 3.16 for Beauregard with an average of 2.49 (Table, 8). The linear and non-linear components of cultivar X environment interaction were found significant (Table, 10). The cultivars showed different responses to the environmental changes. The cultivars Minufiya 10 and Beauregard showed instability for this trait. Such a significant deviation from linear regression might rise due to specific G X E (Genetic X Environment) interaction. Eberhart and Russell [15] reported that, the magnitude of

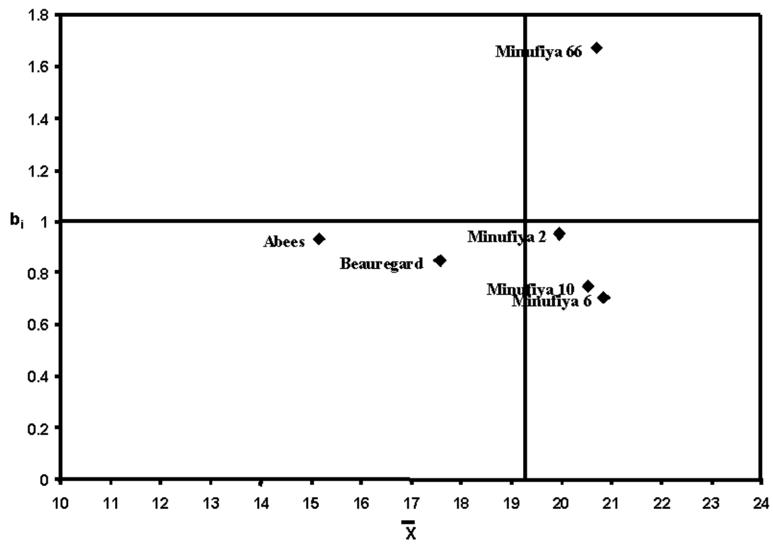


Fig. 2: Scattered diagram for mean tuber starch content and regression coefficient (b_i) over all environments

Table 12: Genotypic, phenotypic and error variances and heritability (H %) estimates, in the broad- sense, for the studied sweet potato characters.

Characters	Genotypic variance (δ^2_g)	Phenotypic variance (δ^2_{pH})	Error variance (δ^2_e)	Heritability (H%)
Plant length (cm)	142.326	983.67	34.50	14.47
No. of branches/plant	0.576	1.886	0.295	30.54
Foliage fresh weight/plant (Kg)	0.033	0.112	0.006	29.46
Tuber root yield/plant (Kg)	0.081	0.243	0.001	33.33
No. of tuber roots /plant	0.312	1.401	0.054	2.27
Average tuber root weight /plant (Kg)	0.004	0.010	0.000	40.00
Tuber root shape index	0.001	0.149	0.004	0.67
Tuber root dry matter (%)	4.232	4.841	0.130	87.42
Starch (%)	5.385	6.112	0.056	88.10
Reducing sugars (%)	0.047	0.159	0.017	29.56
Non- reducing sugars (%)	0.008	0.058	0.003	13.79

S^2d_i was found to be an important indicator for specific G X E interaction. The examination of stability parameter for starch character showed that, the cultivars Abees, Minufiya 6 and Minufiya 10 gave significant S^2d_i values, indicating the instability of these cultivars (Table, 11 and Fig. 2). The three cultivars Minufiya 2, Minufiya 66 and Beauregard did not show significant estimates for both b_i and S^2d_i, suggesting the stability of the three cultivars, concerning this character, under different environmental conditions. The cultivars Minufiya 66 and Minufiya 2 appeared the most desirable cultivars, where the cultivar Minufiya 66 produced the highest mean value (20.69), while the cultivar Minufiya 2 possessed a relatively high mean value and b_i value close to one (b_i) (Table 11 and Fig. 2). Data presented in Table (11) illustrated that the mean values of the cultivars for non-reducing sugars ranged from 1.78 %, for the cultivar Minufiya 66, up to 2.13 %, for both the cultivars Minufiya 6 and Beauregard. Estimates of stability parameters showed that b_i values did not differ significantly from the unity for all cultivars, exhibiting a general adaptability across different environments. On the other hand, S^2d_i values, significantly, differed from zero for the cultivar Minufiya 10 considering this cultivar as an instable for this character. The most stable cultivars appeared to be Abees, Minufiya 2, Minufiya 6 and Beauregard since these four cultivars did not possess any significant differences for the linear regression or the deviation from regression components.

Heritability Estimates: The values of genotypic, phenotypic and error variances, as well as heritability estimates are presented in Table (12). Heritability percentage in the broad-sense, which specifies the proportion of the total variability that is due to genetic variance, was found low (less than 33.33 %) for most studied characters, indicating that phenotypic selection for these characters did not seem to be effective.

Only one character, average tuber root weight/plant, possessed a moderate heritability value (i.e. > 33.33 % to <66.66 %). Accordingly, it might be stated that phenotypic selection for such a character would be reasonably effective. The higher estimated heritability values (> 66.66 %), for both tuber root dry matter and starch content, indicated that phenotypic selection for these two characters could be highly efficient. The heritability values of tuber yield, tuber shape and tuber number were found to be low, as reported by Wilson, *et al.* [28], who stated also that, the heritability of starch was of moderate to high values. The results of Tsegaye, *et al.* [29] revealed that, in vine traits, 32.4 to 82.5 % of the observable variability was due to genetic variation; while, in root traits this value ranged from 43.04 to 76.81 %, indicating the immense inherent variability among the various genotypes.

However, it should be mentioned that, in stating any estimate of heritability of a character, it must be referred to the particular population in which it was estimated and under what particular conditions, as illustrated by Narian [30].

CONCLUSIONS

The significant and highly significant second-order interactions, cultivars X years X locations, for most of the studied characters, observed in the present data of the combined analysis of variance, indicated that sweet potato, as well as other crops, cultivars often show differential responses when grown under different environmental conditions. The obtained results suggested that sweet potato breeders should be concerned about magnitudes of the genotype by environment (G X E) interaction variances in different populations of breeding material. Knowledge of the magnitudes of (G X E) interaction provides the first step in determining stability of sweet potato cultivars with much emphasis on high yielding cultivars with wide adaptability. It appeared from this study that joint regression analysis could be readily used to characterize the performance's stability of sweet potato characters to different environments.

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