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Comparison of methods of determining stability and adaptation of sweet potato*

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Summary. Four methods were used to determine stability and adaptation of sweet potato (*Ipomoea batatas* L. Lam.). Data from 14 sweet potato clones evaluated over 14 environments were used. Regression coefficients provided little information with regard to stability but did provide information on response of individual clones. Stability parameters using three of the four methods were highly correlated. The fourth presented different ranking patterns of stability than the other methods. However, the top five stable clones identified by the four methods were almost the same. Two methods were more effective and convenient in discriminating sweet potato clones based on their stabilities. Clones W151, 'Resisto', and W192 were more stable for no. 1 root yields. W151 and W192 were also stable for total root yields.

Key words: *Ipomoea batatas* L. Lam. – Genotype-environment interactions – Stability – Variances

Introduction

The importance of genotype-environment interactions (G×E) in crop improvement has been known for decades (Hanson 1970). It is well documented that in the presence of G×E, relative ranking of genotypes and/or the magnitude of differences between genotypes change from one environment to another. Thus, genotype-environment interactions present major problems in comparing performance of genotypes across environments, particularly if large numbers of genotypes and environments are involved. Statistics for assessing the stability (consistency) of genotypic performance in different environments are necessary to aid breeders in the selection of superior cultivars in terms of yield and stability.

One of the early attempts to measure stability was made by Plaisted and Peterson (1959) who estimated the variance component of cultivar×location interactions for each of the possible pairs of cultivars tested. The average of the estimates for all combinations using a common cultivar was considered a stability measure. Wricke (1962) proposed the use of ecovalence, which is the contribution of a genotype to the G×E sum of squares. Shukla (1972) also developed a method which partitioned the G×E sum of squares into components attributable to individual cultivars. He proposed a criterion for testing the significance of the stability variance of each cultivar and extended the model to allow for the removal of linear effects due to covariates. Kang and Miller (1984) evaluated the methods of Plaisted and Peterson (1959),Wricke (1962), and Shukla (1972) in determining the stability of sugarcane (*Saccharum* spp.) cultivars. The method of Plaisted and Peterson (1959) was found to be cumbersome. Hence it would have little significance when a large number of varieties were evaluated. Wricke's (1962) and Shukla's (1972) methods were equally effective but, Shukla's method is more effective than Wricke's in the presence of covariates.

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Other stability measures make use of the regression approach. Finlay and Wilkinson (1963) used linear regression of mean individual yield, measured on a logarithmic scale, on the mean yield of all cultivars for each environment. Cultivars with low b values were considered stable and those with high b values were unstable. Eberhart and Russell (1966) regressed mean yield on an environmental index calculated as mean yield of all genotypes in an environment minus the mean of all environments. The sum of squared deviations (s_d^2) from linear regression was included in the measure of stability. A stable cultivar was defined as one with $b=1.0$ and $s_d^2=0$. Tai (1971) developed a method similar to that Eberhart and Russell (1966) in the sense that both analyses attempted to determine the linear response of a variety to environmental effects. However, the procedures in estimating the parameters differ. Tai used parameters $\hat{\alpha}$ for the linear response of the ith variety to environmental effects and $\hat{\lambda}$ for the deviation from the linear response. A perfectly stable cultivar was defined as one with $\hat{\alpha}=-1.0$ and $\hat{\lambda}=1.0$. A cultivar with $\hat{\alpha}=0$ and $\hat{\lambda}=1.0$ was regarded to have average stability.

Hanson (1970) proposed that relative stability be measured as the euclidian distance of a cultivar from the linear response of an ideal genotype in a space whose coordinate axes were environments and whose origin was the genotypic mean. He also proposed measurement of comparative stability between genotypes as the euclidian distance between the genotypes compared. Sukarso and Engle (1983) developed a model in which an ideal genotype was defined as having maximum performance in all environments, and a high degree of homeostatic properties within a specific condition, thus stable.

Sweet potato has long been observed to be very sensitive to environmental changes. Carpena et al. (1982) reported that sweet potato cultivars in the Philippines were sensitive to genotype environment interactions. Few breeding programs in sweet potato employ stability measures as selection criteria, and most of the aforementioned methods to measure stability have not been studied in sweet potato. This study was conducted to compare the effectiveness of different stability parameters in determining the stability and adaptability of sweet potato clones and to identify sweet potato clones with high stability.

Materials and methods

Fourteen sweet potato clones and experimental selections were tested over four locations during the 1983 and 1984 planting seasons. The four locations were Clayton, Clinton, and Castle Hayne, N.C., and Charleston, S.C. In each location, the clones were evaluated in fertilized and unfertilized plots. Fertilization was according to recommended grower practices (Wilson et al. 1980). Unfertilized plots had no nutrient applications before or during the growing season. All unfertilized plots followed corn (*Zea mays* L.) in rotation. Other than fertilization, cultural practices were as uniform as possible and as required by the particular environment.

A randomized complete block design with four replications of single-row plots of 25 plants each was used. Plots were spaced 105 cm and plants within plots 30 cm. Plants were harvested approximately 120 days after planting. Storage roots were sorted into four grades based on size and physical condition. Weight of roots for each grade and total number and weight of roots were obtained. Total root yields and US no. 1 root yields are reported.

Analyses of variance were computed for each test and combined analyses of variance were computed for US no. 1 root yields and total root yields. Environment effects were considered random and cultivar effects were fixed. The 1984 tests (fertilized and unfertilized) in Charleston, S.C., were excluded in the combined analyses of variance due to high error variances.

The following stability parameters were estimated: a) b and s_d^2 (Eberhart and Russell 1966); b) $\hat{\alpha}$ and $\hat{\lambda}$ (Tai 1971); c) D^2 (Sukarso and Engle 1983); d) $\hat{\sigma}^2$ and s^2 (Shukla 1972). Stability variances for the 14 cultivars were computed according to equation number 11 of Shukla (1972). Effects of covariate were removed using Eq. 16 of Shukla (1972).

Spearman rank correlation coefficients were calculated between pairs of all stability parameters used. Significance of rank-correlation coefficient differences were tested according to Steel and Torrie (1980).

Results and discussion

Combined analyses of variance for US no. 1 and total root yields are given in Table 1. The mean squares for environments, clones, and G×E were significant ($P<0.01$) for both traits, indicating differential response of clones relative to each other at different environments. The magnitude of variance components due to G×E (σ^2_{ge}) was twice the magnitude of variance due to clones (σ^2_g) for US no. 1 root yield and about equal for total root yield (Table 1). Mean yields of the 14 clones across environments are shown in Table 2. For US no. 1 root yield W151, Pope, NC727, and W192 had the highest yields. For total root yields, 'Redmar' had the highest yield followed by W151, Pope, NC727, and W192. 'Tinian' gave the lowest yield for both grades. Yields ranged from 5.03 to 14.22 t/h for US no. 1 roots, and 9.46 to 26.56 t/h for total yield. A high correlation of total and US no. 1 root yields ($r=0.96$) was observed. This suggests that the bulk of total yield was composed of US no. 1 roots, or that cultivars which had high US no. 1 root yields also gave high yields of other root grades.

Estimates of stability parameters are given in Table 3 for US no. 1 root yields and in Table 4 for total root yields. Results based on regression coefficients (b) alone indicate that a majority of clones have b values

Table 1. Analyses of variance and variance components for US no. 1 and total root yields of 14 sweet potato clones

Source	df	Mean square		Variance components	
		US no. 1	Total	US no. 1	Total
Environment (E)	13	3,702.20*	6,274.41*	65.84	111.02
Rep/E	42	14.71*	57.38*	0.36	2.36
Clone (G)	13	341,69*	1,161.92*	5.11	20.31
GxE	169	55.05*	92.53*	11.34	17.07
Error	546	9.66	24.26	9.66	24.26

* Significant at 5% level of confidence

Table 2. US no. 1 and total root yields (t/h) of 14 sweet potato clones averaged over 14 environments[z]

Clone	US no. 1	Clone	Total
W192	14.22^{a}	Redmar	26.56^{a}
W151	14.21^{a}	W151	25.82^{a}
Redmar	13.27^{abc}	W192	25.24^{abc}
NC727	13.87^{ab}	NC727	25.01^{abc}
Pope	14.00^{a}	Pope	24.66^{abcd}
W199	12.66^{cd}	W199	23.80^{bcd}
W152	11.96^{de}	W152	23.39^{cde}
Resisto	12.42^{cd}	Resisto	22.82^{def}
Jewel	12.92^{abcd}	Jewel	22.76^{def}
NC Porto Rico 198	10.63^{fg}	NC Porto Rico 198	21.71^{ef}
NC915	10.96^{ef}	NC915	20.93^{f}
NC939	9.68^{g}	NC939	17.52^{g}
W190	10.51^{fg}	W190	17.22^{g}
Tinian	5.03^{h}	Tinian	9.46^{h}
Mean	11.88		21.92

[z] Means having letters in common are not significantly different at 5% level as tested by Duncan's Multiple Range Test

not significantly higher than b = 1.0. Thus, other than Redmar, W192, and Tinian the rest of the clones can be considered stable for US no. 1 roots. This observation clearly disagrees with the results from other stability parameters used. Langer et al. (1979) and Bilbro and Ray (1976) emphasized that regression coefficients should be used as a measure of response to varying environments and a logical measure of stability should be deviation from regression. Considering this concept, b values indicate that Redmar and W192 are both adapted to better growing environments and did not perform well in poor environments. Tinian, on the other hand, consistently performed poorly over all environments. For total root yield Redmar, W152, W192, and NC727 performed particularly well in better growing environments. Linear regression accounted for

Table 3. Estimates of seven stability parameters and clone ranks for US no. 1 root yields of 14 sweet potato clones

Clone	Model: Eberhart and Russell[z]				Tai[y]				Sukarso and Engle[x]		Shukla[w]			
	b	Rank	s^2_d	Rank	$\hat{\alpha}$	Rank	$\hat{\lambda}$	Rank	D^2	Rank	$\hat{\sigma}^2$	Rank	s^2_d	Rank
W151	1.04	6	2.84**	1	0.04	6	1.17	1	428.78	2	8.90	1	10.31	1
W152	1.24	9	12.91	10	0.24	9	5.31**	10	800.30*	7	50.12**	9	43.46**	9
W190	1.00	5	5.35	4	0.00	5	2.21**	4	1,124.22*	11	15.92	2	18.62*	3
W192	1.25*	10	4.97	3	0.25+	10	2.04	3	365.06	1	34.43**	7	18.83*	4
W199	0.82	2	7.31	7	-0.18	2	3.01**	7	881.20*	8	30.88**	6	28.05**	7
NC727	1.23	8	22.45	14	0.23	8	9.25**	14	573.31*	4	99.70**	12	95.22**	14
NC915	0.88	3	15.51	12	-0.12	3	6.40**	12	1,237.53*	12	66.93**	11	68.99**	13
NC939	0.88	3	3.57**	2	-0.12	3	1.47	2	1,362.94*	13	16.33	3	13.44	2
NCPR198	1.06	7	6.35	6	0.06	7	2.62**	6	1,040.58*	10	24.57**	5	27.24**	6
Redmar	1.41*	11	16.74	13	0.41+	11	6.88**	13	579.92*	5	109.50**	13	54.33**	12
Pope	1.00	5	11.21	9	0.00	5	4.62**	9	557.30	3	40.40**	8	44.61**	10
Resisto	0.91	4	5.79	5	-0.09	4	2.39**	5	793.68*	6	20.40*	4	22.19**	5
Tinian	0.43*	1	8.25	8	-0.57+	1	3.36**	8	3,445.03*	14	131.90**	14	34.49**	8
Jewel	0.82	2	15.43	11	-0.18	2	6.36**	11	919.36*	9	60.90**	10	53.88**	11

[z] * = b value significantly different than b = 1.0; ** = s^2_d value = 0
[y] + = $\hat{\alpha}$ value significantly different from $\hat{\alpha}$ = 0.0; *,** = $\hat{\lambda}$ significantly different from λ = 1.0 at 5% and 1% level of probability
[x] * = significantly different from the ideal genotype
[w] *,** = significant at 5% and 1% levels of probability

Table 4. Estimates of seven stability parameters and clone ranks for total root yields of 14 sweet potato clones

Clone	Model													
	Eberhart and Russell[z]				Tai[y]				Sukarso and Engle[x]		Shukla[w]			
	b	Rank	s^2_d	Rank	$\hat{\alpha}$	Rank	$\hat{\lambda}$	Rank	D^2	Rank	$\hat{\sigma}^2$	Rank	s^2_d	Rank
W151	1.01	9	12.33	5	0.01	9	2.02*	4	733.41	3	45.44*	3	48.56*	5
W152	1.34*	13	15.81	8	0.34+	13	2.57**	7	1,065.77*	5	107.73**	11	67.38**	8
W190	1.05	10	8.53**	2	0.05	10	1.39	2	2,963.61*	13	24.64	1	28.25*	2
W192	1.30*	12	8.56**	3	0.30+	12	1.39	2	614.53	2	77.56**	9	36.29*	3
W199	0.85	3	11.12	4	−0.15	3	1.82*	3	1,213.37*	7	52.50*	5	51.76*	6
NC727	1.37*	14	32.35	13	0.37+	14	5.28**	13	1,012.34*	4	201.70**	13	139.88**	14
NC915	0.92	6	17.84	10	−0.08	6	2.92**	9	192.90*	11	74.60**	7	79.84**	10
NC939	0.87	5	7.51**	1	0.13	5	1.23	1	3,018.75*	12	34.60	2	28.63	1
NC198	0.98	8	14.03	7	−0.02	8	2.30**	6	1,602.20*	9	47.17*	4	53.42**	7
Redmar	1.17*	11	12.76	6	0.17+	11	2.08*	5	491.52	1	59.32**	6	39.35*	4
Pope	0.93	7	26.22	14	−0.07	7	4.30**	12	1,133.69*	6	98.93**	10	109.63**	13
Resisto	0.86	4	17.22	9	−0.14	4	2.82**	8	1,491.69*	8	76.30**	8	77.05**	9
Tinian	0.43*	1	19.56	11	−0.57+	1	3.14**	10	8,078.09*	14	259.35**	14	84.18**	11
Jewel	0.77	2	24.11	12	−0.23	2	3.94**	11	1,706.53*	10	112.78**	12	95.62**	12

[z] * = b value significantly different than b = 1.0; ** = s^2_d value = 0
[y] + = $\hat{\alpha}$ value significantly different from $\hat{\alpha}$ = 0.0; *,** = $\hat{\lambda}$ significantly different from $\hat{\lambda}$ = 1.0 at 5% and 1% level of probability
[x] * = significantly different from the ideal genotype
[w] *,** = significant at 5% and 1% levels of probability

54%–97% and 61%–96% of variation in US no. 1 root yield and total root yield of individual clones, respectively. Low coefficients of determination were obtained for US no. 1 and total root yields of Tinian.

For US no. 1 roots, W151 has the lowest s_d^2 value followed by NC939. Redmar, NC915, and NC727 had highest s_d^2 values. NC939, W190, and W192 had lower s_d^2 values for total yield. Considering the Eberhart and Russell (1966) definition of stability ($b = 1.0$, $s_d^2 = 0$), W151 can be considered as the most stable of the 14 clones tested for US no. 1 yield. Although NC939 also had a regression coefficient equal to 1.0 and s_d^2 equal to 0, root yield was below average. For total yield, W190 and NC939 were the only clones fitting the description of stability based on both parameters. Total yields for both clones were below average. Therefore there is no clone identified of above-average performance which is stable for total root yield with this definition of stability.

Tai's (1971) $\hat{\alpha}$ stability parameter gave similar ranking patterns to Eberhart and Russell's (1966) b stability parameter. Tai's (1971) second stability parameter ($\hat{\lambda}$) identified more genotypes as unstable than the mean squares from regression. W151 and NC939 had $\hat{\lambda} = 1.0$ for US no. 1 root yield and also had nonsignificant $\hat{\alpha}$ values. Based on the definition of stable cultivars by Tai (1971), W151 possesses average stability for US no. 1 root yield. NC939 also possesses average stability but with below-average yield. On the other hand, W151 gave consistently above-average yields. For total root yield, NC939 and W190 had nonsignificant $\hat{\lambda}$ values combined with $\hat{\alpha} = 0$, but gave low yields across environment. Clones with nonsignificant $\hat{\lambda}$ values had significant $\hat{\alpha}$ values, and thus were classified as unstable.

Estimates of D^2 presented in Tables 3 and 4 showed that W151, W192, and Pope have values not significantly different from a stable genotype. All of these clones gave higher US no. 1 root yields. For total root yields W151, W192, and Redmar were identified as stable genotypes.

Shukla's (1972) $\hat{\sigma}^2$ parameter showed that for US no. 1 root yields, W151 was the most stable clone followed by W190 and NC939. 'Resisto' and 'NC PR 198' were shown to be unstable although these clones were ranked among the top five with small $\hat{\sigma}^2$ values. An extension of the model developed by Shukla (1972) to remove the covariate was used (s^2). W190, which was initially identified as stable, was not stable after the covariate was taken into consideration. However, W190 remained in the top five clones with small s^2 values. The ranking pattern of s^2 agreed with those obtained from Eberhart and Russell's (1966) s_d^2 stability parameters. For total root yields, W190 and NC939 were classified as stable based on $\hat{\sigma}^2$ stability parameter. After the removal of the covariate effects, NC939 was stable and the ranking pattern changed.

Conclusion

Four methods were used to provide estimates of stability parameters for 14 sweet potato clones. The Eberhart and Russell (1966) and Tai (1971) methods are related: i.e., $\hat{\alpha}$ is equivalent to b-1 and $\hat{\lambda}$ is equivalent to s_d^2 (MSE/number of replications) when a large number of cultivars and/or a large range of environments are used for a series of trials. Consequently, the rank correlation coefficients of b and $\hat{\alpha}$ values are equal to 1.0. The rank correlations of s_d^2 and $\hat{\lambda}$ were similarly high both for US no. 1 root yields and total yields, suggesting that either of the two parameters would be satisfactory for selecting desirable clones. Eberhart and Russel's b stability parameter did not effectively discriminate the clones according to their stability, but did provide information on whether the clone performed well under better growing environments or in poor environments.

A stability parameter that showed a good association with the Eberhart and Russell (1966) and Tai (1971) models was Shukla's (1972) $\hat{\sigma}^2$ stability parameter. The rank correlations of $\hat{\sigma}^2$ with s_d^2 were 0.84 and 0.74 for no. 1 root yield and total yield, respectively. Shukla's method provides a means of assigning a variance component due to G×E to individual genotypes and a test of significance of the variance component. The variance component and the trait mean of each clone are used for selecting superior cultivars.

The maximum performance model (D^2) (Sukarso and Engle 1983) presented, in general, a different ranking pattern of stability of 14 clones. The model identified NC727, Redmar, and Pope as among the top five desirable clones for no. 1 root yields. These clones were ranked poorly in other methods used in this study due to their large deviations from linear regression. For total yields, the methods also included Redmar, W152, and NC727 in the top five. These clones were considered unstable by other methods. These discrepancies arise because D^2 is a composite index for stability and yielding ability of the cultivar. The method does not take into consideration the deviation of performance of a particular genotype from its linear response on environmental effects. Instead, the model provides measurement of comparative stability based on the deviation of cultivar performance from a regression line established as the ideal slope by the model. In general, the model has the tendency to classify cultivars that perform well in favorable environments as ideal, as in the case of Pope and Redmar. The rank correlation of D^2 with other stability parameters was generally low, ranging from 0.36 to 0.14 for US no. 1 root yields and 0.33 to 0.28 for total yields.

With the exception of b and $\hat{\alpha}$, stability parameters ranked the top five stable cultivars almost identically. For US no. 1 roots, W151, W192, and Resisto were ranked at the top in the four methods used in this study. Therefore, if the objective of the breeder is only to determine the most stable cultivars, any of the stability parameters used in this study can provide the information necessary to accomplish the objective. For total root yield, W151 and W192 were consistently ranked high in the four methods used. If the main criteria for selection are US no. 1 root yield and stability as they are in the United States, then W151, W192, and Resisto will be good selections. In countries in which size and quality restrictions are not stringent, selection is often directed to high total root yield. In such cases, W151 and W192 will also be logical choices. It should be noted that both in US no. 1 root and total root yields, NC939 was ranked highly by the methods of Eberhart and Russell (1966), Tai (1972) and Shukla (1972). However, US no. 1 and total root yields of NC939 were below average. Jewel was not identified as a stable cultivar by any method. Jewel is the major cultivar grown in the United States, and is considered by breeders to be very reliable with regard to performance in a wide range of environments.

The method provided by Shukla (1972) may be preferable over the other methods because it not only provides estimates of stability variance associated with each cultivar, but it can remove covariate effects. The model also provides a means of testing the significance of $\hat{\sigma}^2$ to determine whether the cultivar is stable. However, in the absence of high speed computers, the calculations required to obtain stability variance can become cumbersome. This is particularly true if large numbers of genotypes are involved in the tests.

The methods of Eberhart and Russell (1966), Tai (1971), and Sukarso and Engle (1983) require fewer calculations compared to that of Shukla (1972). Of the three methods, Tai's (1971) method more effectively discriminated clones according to their stability. Although the high rank correlation coefficients of Eberhart and Russell (1966) and Tai's (1971) stability parameters suggest that either of the two methods can be used to select desirable genotypes with almost equal efficiency, Tai's (1971) method provides means of estimating confidence intervals for linear response of a clone to environmental effects as well as for the deviations from the linear response. These methods facilitate classification of clones based on stabilities of their performance.

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