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PHENOTYPIC STABILITY OF POTATO (*Solanum tuberosum* L.) CULTIVARS GROWN UNDER DIFFERENT ENVIRONMENTAL CONDITIONS IN THE SOUTHERN REGION OF THE STATE OF MINAS GERAIS, BRAZIL*

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ABSTRACT

We evaluated the phenotypic stability of 14 potato cultivars (Achat, Agria, Apuã, Baraka, Baronesa, Bintje, Bronka, Clarissa, Dunja, Frisia, Itararé, Monalisa, Radosa, and Ruta) for marketable tuber yield and its components (number of marketable tubers per plot and mean tuber weight). The contribution of environmental effects to the genotype x environment interaction was also evaluated. Trials were carried out in nine environments (locations, years and planting dates) in a fully randomized block design with four replications. The cultivars Bronka, Monalisa and Clarissa were the most stable for marketable yield. Cultivars Baraka, Bronka and Monalisa were the most stable for mean marketable tuber weight. Bintje and Achat, which are among the three cultivars most frequently planted in the region, proved to be highly unstable both for yield and for mean tuber weight. For number of marketable tubers per plot, the regression model was not satisfactory to evaluate the phenotypic stability of cultivars due to the low values for the determination coefficients (average r^2 - 0.47). Among the environmental effects that contributed to the genotype x environment interaction, planting date was more important than location and the effect of location was greater than years. Mean marketable tuber weight was the trait least affected by genotype x environment interaction.

INTRODUCTION

In the state of Minas Gerais, potato culture occupies approximately 30 thousand ha, corresponding to about 19% of the total planted area and 26% of the Brazilian

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production (IBGE, 1989). A large part of the potato crop is concentrated in the South and is distributed among three different harvests, i.e., the rainy season, the dry season, and winter. Farmers usually utilize the same cultivars for the different crops and three of them (Achat, Bintje and Baraka) occupy approximately 87.5% of the cultivated area. Unfortunately, these cultivars are quite susceptible to major diseases (EMATER-MG, mimeograph) and have shown little stability for tuber yield (Maluf *et al.*, 1983; Cordeiro *et al.*, 1983). Thus, additional cultivars are needed to provide more options, and to reduce risks, by a reduction in genetic uniformity.

The objective of the present study was to evaluate the stability of 14 potato cultivars for marketable tuber yield and yield components (number of marketable tubers/plot and mean marketable tuber weight) and to determine the contribution of environmental effects to the magnitude of genotype x environment interaction.

MATERIAL AND METHODS

Fourteen cultivars common to all environments were utilized. Three of these materials are Brazilian (Apuã, Baronesa and Itararé) and 11 are of European origin. The trials were conducted in Lavras (910 m altitude, Dystrophic Red Dusk Latosol), Maria da Fé (1276 m altitude, Silica clay soil) and Lambari (845 m altitude, Dystrophic Gley Humic soil), with planting at different times of year, i.e., during the rainy season (August 18 to October 23), during the dry season (March 29 to April 18), and in winter (May 16 to June 1) in 1989 and 1990, for a total of nine different environments. The design used was a fully randomized block with four replications. Each experimental plot consisted of two 3.5 m long rows spaced 0.80 m apart. The seed potatoes used in the first trials were obtained from the National Potato Cultivar Trial set up at the Experimental Farm of EPAMIG in Maria da Fé, and those used in the remaining trials were obtained from the first trials of the present study. In all trials, the soil was fertilized with 3,000 kg/ha 4-14-8 (N, P_2O_5, K_2O) and with 15 kg/ha zinc sulfate at planting time, and with 300 kg/ha ammonium sulfate for additional surface nitrogen fertilization, 40 days after planting. Irrigation, weeding and pest control were performed whenever necessary.

Data were collected on marketable tuber (more than 23 mm crosswise diameter) and large tuber (more than 45 mm crosswise diameter) yield in kg/ha, number of marketable tubers/plot, and mean marketable tuber weight, in grams. Since the data did not present additivity they were transformed to log (x+2) for number of tubers/plot and mean tuber weight and to $\sqrt{(x + 0.5)}$ for yield (Steel and Torrie, 1980). To determine environmental effects which contribute to the cultivar x environment interaction, we opted for joint analysis of variance for all combinations of pairs of environments. The genetic covariances of x and y ($COV_{(G(x,y))}$) were estimated from the joint analyses of variance of pairs of environments by the following equation:

$$COV_{G(x,y)} = \frac{MS_c - MS_{ce}}{r - n}$$

where:

MS_c = cultivar mean square;
MS_{ce} = cultivar x environment mean square;
r = number of replications (r = 4);
n = number of environments (n = 2).

The genetic correlations were estimated using the following equation:

$$r_G = \frac{COV_{G(x,y)}}{\sqrt{V_{Gx} - V_{Gy}}}$$

The stability parameters associated with each of the 14 cultivars were estimated by the methodology proposed by Cruz *et al.* (1989).

RESULTS

Cultivar x environment interaction

The joint analyses of variance for all traits tested were significant for cultivars, environments and cultivar x environment interaction (Table I). Environments differed markedly from each other, representing the main source of variation.

Table I - Summary of joint analyses of variance for 14 potato cultivars in the nine environments, 1989/1990.

Sources of variation	d.f.	Marketable tuber yield	No. of marketable tubers/plot	Mean marketable tuber weight
		Mean squares*		
Cultivars	13	3,370.326	0.105	0.195
Environments	8	32,515.153	0.240	0.153
Cult. x Env.	104	1,039.406	0.045	0.022
Mean error	351	162.312	0.007	0.005
CV (%)		10.43	3.91	3.94

*All sources of variations were significant at the 1% level by the F test.
CV: Coefficient of variation.

Cultivar and cultivar x environment mean squares and genotypic correlation coefficients estimated for all pairwise combinations of environments for marketable tuber yield are presented in Table II.

The contribution of year effect to interaction was evaluated, excluding location and planting date effects by the estimates obtained for the paired environments LVW-89/LVW-90, LVR-89/LVR-90, MFR-89/MFR-90 (Table II). The effect of cultivar x environment interaction tended to be less than cultivar effect, with a consequent tendency towards positive correlations between cultivars. The exception was the MFR-89/MFR-90 pair which presented a very low correlation, probably due to the fact that the MFR-90 trial, the last to be set up, presented a higher incidence of viral diseases, since climatic conditions were similar to those occurring during the MFR-89 trial.

Location effect was tested using the environmental pairs LBR-90/LVR-89, LVR-89/MFR-89, LBR-89/MFR-89, MFD-90/LVD-90 and LVR/MFR-90. The contribution of location effect to the interaction was a little higher than that of year effect since interaction mean squares were higher, in some cases exceeding cultivar mean squares. In contrast to year effect, genetic correlations tended to be low.

Planting date effect, excluding year and location effects, was determined using environments LVW-89/LVR-89, MFD-90/MFR-90, LVD-90/LVW-90, LVD-90/LVR-90 and LVW-90/LVR-90. In this case, interaction mean squares were higher than, or closer to, cultivar mean squares. For pair LVD-90/LVW-90, which presented a high and positive correlation, the probable cause was that the dry season planting was carried out in April when environmental conditions were most similar to those for the winter planting (June).

Despite numerous environmental factors (years and locations, years and planting dates, or locations and planting dates), when climatic conditions (temperature in particular) were more or less similar, the correlation tended to be higher, as clearly shown for the following environmental pairs: LVW-89/LBR-89 ($r_G = 0.923$), LVW-89/LVD-90 ($r_G = 0.772$), and LVD-90/MFR-90 ($r_G = 0.837$) (Table II). In contrast, when climatic conditions were more contrasting, correlation tended to be much weaker, as was the case for pairs LVW-89/LVR-90 ($r_G = -0.088$) and LVW-89/MFR-90 ($r_G = -0.074$) (Table II).

In general, the environmental effects that most contributed to marketable tuber yield were planting dates, locations and years, in decreasing order of importance.

Estimates of number of marketable tubers/plot for the same pairs of environments gave results similar to those obtained for yield. Even though location effect was greater for this trait than for yield, planting date effect continued to make a greater contribution to interaction.

In contrast to the above traits, planting date, location and year effects contributed less intensely to interaction in terms of mean marketable tuber weight. When planting date, location and year effects were calculated using the same pairs as for yield, in none

Table II - Estimated mean squares for cultivars (MSC), cultivar x environment interaction (MSCE) and genotypic correlation coefficients (r_G) obtained by pairwise analysis of environments for marketable tuber (more than 23 mm) yield.

Environments		LBR-89	MFR-89	LVR-89	MFD-90	LVD-90	LVW-90	LVR-90	MFR-90
	MSC	3431.443	2231.536	2361.485	1885.694	2180.357	2215.190	2373.454	1755.889
LVW-89	MSCE	476.237	1257.524	3104.785	1515.574	1091.846	1023.685	2780.490	1952.191
	r_G	0.923	0.443	-0.146	0.172	0.772	0.686	-0.088	-0.074
	MSC		1222.501	1790.633	1049.636	939.855	924.481	1580.762	879.443
LBR-89	MSCE		473.723	1882.801	558.797	539.512	521.558	1780.346	1035.801
	r_G		0.553	-0.029	0.370	0.462	0.376	-0.070	-0.095
	MSC			1691.298	812.680	652.072	675.281	1647.118	752.559
MFR-89	MSCE			1563.517	377.133	539.512	352.139	1295.371	744.065
	r_G			0.059	0.479	0.408	0.440	0.179	0.005
	MSC				1591.030	1770.742	1600.415	3878.100	2302.429
LVR-89	MSCE				1215.992	1267.215	1604.214	1041.598	1171.405
	r_G				0.349	0.365	-0.002	0.624	0.434
	MSC					554.721	473.815	1602.545	762.712
MFD-90	MSCE					418.235	465.812	1252.152	646.121
	r_G					0.234	0.011	0.182	0.106
	MSC						633.575	1828.907	942.272
LVD-90	MSCE						176.987*	896.725	337.495^{NS}
	r_G						0.968	0.739	0.837
	MSC							1380.383	598.156
LVW-90	MSCE							1311.920	648.283
	r_G							0.044	-0.056
	MSC								2732.771
LVR-90	MSCE								428.737^{NS}
	r_G								0.969

LVW, Lavras-winter; LBR, Lambari-rainy season; MFR, Maria da Fé-rainy season; LVR, Lavras-rainy season; MFD, Maria da Fé-dry season; LVD, Lavras-dry season. NS, Not significant at the 5% level of probability by the F test; *significant at the 5% level of probability; the remaining mean squares were significant at the 1% level of probability by the F test.

of the environmental combinations was interaction mean square higher than cultivar mean square. In most cases, genotypic correlations were high and positive.

The results suggest that cultivar x environment interaction was lower for mean tuber weight, i.e., the cultivars behaved in a more similar manner with respect to this trait in the various environments than yield or number of tubers/plot. The Spearman rank correlations of all environmental pairs tested were relatively high (overall mean, 0.49) and significant, indicating that in general the cultivars with a better performance in a given environment behaved similarly in the other environments.

Stability analysis

When the cultivars were characterized individually for stability parameters (Table III). Only Apuã presented significance for both $B_1 < 1.0$ and $(B_1 + B_2) > 1.0$, i.e., it was stable in unfavorable environments and responsive in favorable environments. In contrast, Apuã had the worst mean yield (B_0 = 12,546 kg/ha) and the predictability of its behavior was impaired by the high value of the mean square of deviation from regression (S^2d_i).

Although Bronka, Monalisa and Clarissa were not ideal in terms of stability, they did not show many changes in performance for either B_1 or $(B_1 + B_2)$, demonstrating general adaptability to both unfavorable and favorable environments. The mean yields were higher than the overall mean and their responses were predictable (low S^2d_i values).

Cultivars Baronesa and Itararé had the highest mean yields, but their behavior could not be predicted as a function of S^2d_i significance. Furthermore, Baronesa was not responsive to favorable environments and, together with Itararé, tended to respond to unfavorable environments. These two cultivars, which are Brazilian and have some advantages over introduced cultivars, could be used by farmers with less technology and who use their own seeds for several generations.

The overall mean yield of large tubers (> 45 mm) was 9,448 kg/ha, representing 59.6% of marketable yield. Some cultivars were outstanding for this trait, as was the case for Baraka, which produced 68.8% of the marketable large tuber yield. Bronka, Ruta, Clarissa and Itararé also presented a high percentage of large tubers (Table III). The percentage of large tubers in relation to marketable yield was 71.6% in favorable environments, as opposed to only 40.9% in unfavorable environments.

Stability parameters estimated for mean tuber weight (Table IV) also were high for Apuã, although it produced tubers with a very low mean weight, an undesirable characteristic since market quotations are based, among other aspects, on tuber size. On the basis of the parameters tested as a whole, cultivars Baraka, Bronka and Monalisa most closely approached ideal stability, since, in addition to producing the highest mean weights, they behaved in a predictable fashion and did not present too many changes in

Table III - Tuber yield (kg/ha), regression coefficient, deviation mean square and determination coefficient for 14 potato cultivars tested in nine different environments.

Cultivar	Mean yield		Regression coefficient	Regression coefficient	Deviation MS	Determination coefficient
	Marketable	Large	(b_1)	($b_1 + b_2$)	(S^2d_i)	(r^2)
Baronesa	19,907	11,279	1.19	0.23**	1,738.60*	0.66
Itararé	19,767	12,608	1.17	1.03	1,687.57*	0.70
Bronka	18,428	12,303	1.24	1.26	670.22	0.88
Monalisa	17,601	10,964	1.08	0.87	478.64	0.87
Clarissa	17,378	11,149	1.14	0.98	826.52	0.82
Baraka	16,296	11,206	1.11	1.22	1,026.33*	0.79
Agria	15,990	9,864	0.84	0.72*	239.69	0.90
Dunja	14,709	8,405	0.90	1.12	563.24	0.83
Achat	14,643	6,924	0.76	1.37	1,594.19*	0.64
Frisia	14,265	7,202	1.21	0.95	539.87	0.88
Radosa	13,692	8,190	0.88	0.85	771.53	0.75
Ruta	13,463	8,818	0.85	0.44**	210.68	0.90
Bintje	13,401	6,474	1.12	0.49**	2,080.98**	0.60
Apuã	12,546	6,889	0.50**	2.56**	1,122.80	0.84
Overall mean	15,863	9,448	1.00	1.00	967.92	0.79

*Significant at the 5% level, and ** significant at the 1% level by the t-test.

performance, thus demonstrating general adaptability to favorable and unfavorable environments.

The high mean determination coefficients obtained for yield and for mean tuber weight indicate that the variations provoked by environmental effects on these traits are satisfactorily explained by linear regression. For number of tubers/plot, the linear regression model employed in the present study was not satisfactory for the evaluation of cultivar stability.

DISCUSSION

The environments tested differed in soil characteristics, temperature, and disease occurrence, especially viral disease, which was more frequent in the 1990 trials.

Table IV - Mean tuber weight (g), regression coefficient, deviation mean square and determination coefficients for 14 potato cultivars tested in nine different environments.

Cultivar	Mean tuber weight		Regression coefficient	Regression coefficient	Deviation MS	Determination coefficient
	b_0	%	(b_1)	($b_1 + b_2$)	(s^2d_i)	(r^2)
Baraka	88.5	(130)	0.86	0.96	0.016	0.84
Bronka	79.8	(117)	0.81	1.15	0.019	0.82
Monalisa	78.1	(115)	1.01	0.72	0.015	0.87
Agria	74.5	(109)	1.09	1.05	0.021	0.86
Clarissa	73.6	(108)	0.86	0.86	0.031*	0.72
Itararé	73.1	(108)	1.00	0.92	0.022	0.83
Baronesa	70.9	(104)	1.33*	1.39*	0.023	0.90
Ruta	70.3	(103)	1.58**	0.70*	0.020	0.92
Dunja	63.6	(94)	0.83	1.17	0.004	0.96
Radosa	57.0	(84)	0.90	1.39*	0.008	0.93
Frisia	53.5	(79)	0.97	0.53**	0.013	0.87
Apuã	53.5	(79)	0.64**	1.45**	0.005	0.95
Achat	53.4	(79)	1.15	0.81	0.028*	0.82
Bintje	51.7	(76)	0.97	0.90	0.067**	0.60
Overall mean	68.0	(100)	1.00	1.00	0.021	0.85

*Significant at the 5% level, and **significant at the 1% level by the F test.

The trials planted during the rainy season in Lavras were characterized by higher than ideal temperatures for this type of culture. Thus, the performance of certain genetic materials, such as Achat for example, was considerably impaired, this probably being one of the reasons for the low stability observed. Another factor that may have contributed to the instability of some cultivars was the occurrence of viral diseases. Since the seed potatoes used in the last trials originated from the first trials of the study, the incidence of viral diseases increased significantly. Thus, a better relative performance of cultivars more resistant to viral disease was to be expected as the incidence of viral disease increased. This fact may explain the good stability of Monalisa, which presented the lowest levels of PLRV and PVY incidence in a study by Andrade (1989).

Another variable that certainly affected the performance of the cultivars tested was the physiological condition of seed potatoes. In a trial of this kind involving 14 quite divergent cultivars it is practically impossible to have seeds available in the same physiological state. Even though some treatments were performed to break tuber dormancy, we noted that in certain trials there was a delay in budding and, therefore, in the establishment of the culture.

Despite the problems discussed above, the culture system employed in the present study faithfully reflected the culture practices used by many producers in the regions. Thus, the cultivars which proved to be most stable in the present study may represent new options for choice, especially for suboptimal conditions when more traditional cultivars are known to have a less performance.

RESUMO

Avaliou-se a estabilidade fenotípica de 14 cultivares de batata para a produção de tubérculos comerciáveis e seus componentes (número de tubérculos por parcela e peso médio de tubérculos). A contribuição dos efeitos ambientais para a interação genótipos x ambientes também foi avaliada. Os experimentos foram conduzidos em nove ambientes (locais, anos e épocas de plantio) num delineamento de blocos casualizados com quatro repetições. As cultivares Bronka, Monalisa e Clarissa foram as mais estáveis para produção enquanto que Baraka, Bronka e Monalisa foram as mais estáveis para peso médio de tubérculos. As cultivares Bintje e Achat, que estão entre as três cultivares mais plantadas na região, foram altamente instáveis, tanto para produção como para peso médio de tubérculos. Entre os efeitos ambientais que contribuiram para a interação genótipos x ambientes, as épocas de plantio foram mais importantes que locais e estes foram maiores do que anos. O peso médio de tubérculos comerciáveis foi o caráter menos afetado pela interação genótipos x ambientes.

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