ARTICLE

Stability of potato clones resistant to potato virus Y under subtropical conditions

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Abstract: *Brazilian potato production is based on cultivars originating from the USA and Europe; however, these cultivars were developed under different environmental conditions than those found in Brazil. The aim of this study was to evaluate the adaptability and stability of 18 potato clones (MLG), developed by the Universidade Federal de Lavras, and four cultivars in six environments in the state of Minas Gerais, Brazil. The following traits were evaluated: marketable tuber yield (MTY), specific gravity (SG), and tuber appearance (TA). Clones, environments, and the genotype × environment interaction had significant effects on all traits. The GGE-biplot explained 71.78, 98.13, and 62.86 % of the sum of squares from the G+G×E for MTY, SG, and TA, respectively. Three MLG clones had higher adaptability and stability, as well as better performance, than the cultivars, making them good candidates for release as cultivars.*

Keywords*: Genotype × environment, plant breeding, Solanum tuberosum L.*

INTRODUCTION

In 2018, the average yield of potato in Brazil (31.2 Mg ha^{-1}) was much higher than the global average yield (20.9 Mg ha^{-1}); however, it was much lower than in some other countries, such as the USA (49.8 Mg ha^{-1}) and the Netherlands (36.6 Mg ha^{-1}) (FAO 2018). One of the reasons for this lower yield is related to the fact that the cultivars used in Brazil are mostly of European and North American origin and, therefore, are not adapted to the tropical conditions of Brazil (Lambert et al. 2006). Abiotic and biotic factors associated with tropical conditions negatively affect yield; therefore, the cultivars used in Brazil are not able to express their full yield potential (Teixeira et al. 2015).

Potato virus Y (PVY) is a major disease in the Brazilian potato production chain, and it can cause losses of more than 80% (Kreuze et al. 2020). Depending on the PVY strain, losses may also occur through damage to tubers, which may show the symptom of necrotic ringspot (MacKenzie et al. 2019). Most cultivars used in Brazil are susceptible to PVY, limiting their yield potential. Clones may react differently to PVY infection, showing susceptibility (with symptoms and yield loss), tolerance (no symptoms, with yield loss), or resistance (MacKenzie et al. 2019). Beyond direct losses, PVY may lead to indirect losses from the need to purchase seed potatoes each season and the need for control of the PVY vector (*Myzus persicae* aphid), causing increased costs.

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Potatoes are produced in different regions of Brazil, mostly in the Southeast region in the states of Minas Gerais and São Paulo, and are grown throughout the year, in three different seasons. Thus, the potato crop is exposed to different climatic conditions. The genotype by environment interaction (G×E), i.e., the differential performance of genotypes in different environments, increases under such conditions. A significant G×E requires that different cultivars be recommended for specific crop seasons and regions (Bernardo 2020).

In this context, one of the most important objectives of phenotypic analysis of stability is to identify genotypes whose performance remains stable under diverse environmental conditions. A methodology extensively used to study the G×E in various crops is GGE biplot analysis, developed by Yan (2001), which is a useful method to study the pattern of different genotypes tested in a set of environments. The aim of this study was to assess the adaptability and stability of advanced clones from the potato breeding program (PROBATATA) that are resistant to the PVY, through use of the GGE biplot method.

MATERIAL AND METHODS

Guedes et al. (2016) selected 18 clones with good tuber appearance that carried the allele Ry_{adg}, which confers extreme resistance to PVY. These 18 clones, named MLG, and four check cultivars commonly cultivated in the state of Minas Gerais (Agata, Cupido, Asterix, and Atlantic) were used to perform this study. The treatments were numbered as follows: the MLG clones - G1 to G18, and the check cultivars - G19 to G22.

Trials were conducted in six different environments (combination of locations and crop seasons) and were numbered E1 to E6 (Table 1). A randomized complete block design, with three blocks, was used in all trials. Each plot consisted of five plants, which is sufficient to achieve good precision (Pereira et al. 2017). The plot size was one 1.5-m row, with 0.8 m between rows, 0.3 m between plants, and 0.5 m between plots (total plot area - 1.6 m^2). Fertilization at planting consisted of 1.5 Mg ha^{-1} of 08-28-16 (N-P_2O_5-K_2O), and side dressing of 0.400 Mg ha^{-1} of 20-05-20 (N-P_2O_5-K_2O) was applied 30 days after planting. Supplemental irrigation was provided with a sprinkler system according to crop needs and depending on rainfall.

Agronomic evaluations

The number of plants per plot was assessed at 60 days after planting, and this number was used to calculate production per plot, which was determined by dividing the total plot production by the number of plants in the plot. The potato vines were killed on average 90 days after planting. The entire plot was hand-harvested, using a hoe, which occurred on average 100 days after planting.

After harvest, the following evaluations were performed: total tuber yield (TTY) (g $plant^{-1}$), determined by weighing all the tubers in the plot; marketable tuber yield (MTY), represented by tubers with a transversal diameter ≥ 45 mm (g $plant^{-1}$); and tuber specific gravity (SG), tuber weight in air/(tuber weight in air - tuber weight in water), which was obtained using a hydrostatic balance and a sample of approximately 1.5 kg. In addition, overall tuber appearance (TA), tuber skin texture (ST), tuber shape (TS), and eye depth (ED) were calculated based on an average of scores attributed by three evaluators for the entire plot. For the TA, the scores ranged from 1 (tubers with poor appearance) to 5 (tubers

Table 1. Environmental conditions in the six environments investigated: location, crop season, altitude, accumulated rainfall, and temperature (mean, minimum, and maximum)

Environment	Location[†]	Crop season	Altitude (m)	Rainfall[‡] (mm)	Min. (ºC)	Mean (ºC)	Max. (ºC)
E1	LV	Feb/Jun – 2014	919	255	16.4	22.0	28.3
E2	SA	Oct/Dec – 2014	1505	735	15.5	25.9	30.5
E3	LV	May/Sep – 2015	919	120	13.7	18.4	26.2
E4	LM	May/Sep – 2015	887	113	17.2	18.8	33.4
E5	SA	Aug/Dec – 2015	1505	600	17.0	22.3	31.6
E6	BR	Aug/Nov – 2015	1371	570	17.3	22.2	31.0

[†] LV – Lavras; SA – Senador Amaral; LM – Lambari; BR – Bom Repouso.

with excellent appearance); for the characteristics ST, TS, and ED, the diagrammatic scale proposed by Guedes et al. (2020) was used.

Statistical analysis

In each trial, the homogeneity of the mean square error was examined by the Bartlett test and normality of errors via the Shapiro-Wilk test. Individual analyses of variance were performed, and the Hartley test was applied to check the homogeneity of the variances of the errors among trials. Since the variances were homogeneous, a combined analysis of variance was carried out using the following model:

$$Y_{ijk} = \mu + C_i + E_k + B_{j(k)} + CE_{ik} + e_{ijk},$$

where Y_{ijk} is the phenotypic value for clone *i* in block *j* in environment *k*; μ is the overall mean; C_i is the fixed effect of clone *i*; E_k is the fixed effect of environment *k*; $B_{j(k)}$ is the random effect of block *j* within environment *k*, $B_{j(k)} \sim_{N(} (0; \sigma^2_b)$; CE_{ik} is the fixed effect of the interaction between clones and environments; and e_{ijk} is the random error associated with each observation, $e_{ijk} \sim N(0; \sigma^2)$.

Selective accuracy was estimated for each one of the individual analyses, following Resende and Duarte (2007):

$$\hat{r}_{\hat{g}g} = [1 - (1/F)1/2],$$

where F is the value of the F test for clones in the analysis of variance.

The mean values of the clones in the six trials were grouped by the Scott-Knott test ($p < .05$). The G×E component of variance was decomposed into its simple and complex parts following the Cruz and Castoldi (1991) methodology. Adaptability and stability were analyzed using the GGE biplot method (Yan 2001) for the MTY, SG, and TA traits, following the basic model:

$$Y_{ik} - \mu - E_j = \sum_{l=1}^{r} \lambda_l \Upsilon_{il} \eta_{lk} + e_{ik}$$

where Y_{ik} is the mean of clone *i* in environment *k*; μ is the overall mean; E_j is the principal effect of the environment; λ_l is the eigenvalue associated with principal component (PC) *l*; Υ_{il} is the eigenvector of clone *i* for PC *l*; η_{lk} is the eigenvector of environment *k* for PC *l*; and e_{ik} is the error associated with clone *i* in environment *k*.

The genetic correlation between the different environments for MTY, SG, and TA was calculated using the follow expression (Bernardo 2020):

$$r_{Gxy} = \frac{COV_{Gxy}}{\sqrt{\sigma^2_{G_x} . \sigma^2_{G_y}}}$$

where COV_{Gxy} is the genetic covariance between two environments, *x* and *y*, for the same trait; $\sigma^2_{G_x}$ is the genetic variance in environment *x*; and $\sigma^2_{G_y}$ is the genetic variance in environment *y*.

The clones were classified in the different market segments (fresh, chips, and frozen French fries), and the independent culling method (Bernardo 2020) was used. The levels were established based on the means from the check cultivars. For the fresh market, clones should yield above the overall mean; have oval to elongated TS; SG between 1.060 and 1.075; and ED, ST, and TA scores greater than or equal to those of Agata. For the chip segment, potato clones should yield greater than or equal to the overall mean, have round TS, SG higher than Atlantic, and ED scores greater than or equal to those of Atlantic. For the frozen French fry industry, clones should yield greater than or equal to the overall mean, have elongated TS, SG higher than Asterix, and ED scores greater than or equal to those of Asterix.

RESULTS AND DISCUSSION

The $\hat{r}_{\hat{g}g}$ in the individual analyses ranged from 76.3 to 90.1, 74.4 to 88.2, 84.7 to 92.1, and 67.7 to 92.5 for TTY, MTY, SG, and TA, respectively (data not shown). According to Resende and Duarte (2007), these results represent values with moderate to very high precision (except for environment E4 for TA, which showed low accuracy).

The result of combined analysis of variance (Table 2) indicated that for all traits, there were significant differences ($p < .05$) among clones and environments. The G×E was also significant ($p < .05$) for all traits. These results indicated environmental heterogeneity and differences among clones and indicated that the responses of these clones were inconsistent among the environments tested.

Decomposition of the G×E variance component indicates that the complex part of the G×E accounted for most of the variation for MTY and TA (Figure 1). On average, the complex part corresponded to 79% for MTY, 44% for SG, and 78% for TA. The presence of the complex part in the G×E indicates a low genetic correlation between environments (Elias et al. 2016). These results indicated that there were changes in the ranking of the clones among the different environments (crossover interactions) for all traits, and this effect was stronger for MTY and TA.

The estimates of genetic correlation for the MTY, SG, and TA traits among the environments (Figure 1) reaffirm the presence of the G×E. On average, genetic correlation was low for MTY, with an average of 0.29, ranging from -0.13 to 0.93, and for TA, which showed an average genetic correlation of 0.28, ranging from -0.29 to 0.89. For SG, genetic correlation showed higher values, with an average of 0.79 (0.62 to 0.96). The results found for genetic correlation followed those found for decomposition of the G×E variance, where the traits MTY and TA were more affected by the G×E (high proportion of complex part of the G×E and low genetic correlation) than the SG trait was.

In the GGE method, PC1 is related to the adaptability of the genotypes, and PC2 is linked to the stability (Yan and Tinker 2006). In the present study, the first two PCs accounted for 71.78% of the G+G×E sum of squares for MTY (Figure 2), a result that coincides with other studies that used the same method to study the G×E in potato (Bai et al. 2014, Muthoni et al. 2015). For SG and TA, the model accounted for 98.13% and 62.86%, respectively (Figures 3 and 4).

The mega-environments (ME) for MTY are shown in Figure 2A (singular value partitioning [SVP] = 2, scale = 0, and centered in the G+G×E). Two ME were formed based on the variation of clones in each environment: ME1 – E1 and E3; ME2 – E2, E4, E5, and E6. This division makes it possible to take advantage of the G×E since we can determine which clones show better responses to specific environments (Yan and Tinker 2006). Temperature might be the main factor responsible for the parting of environments presented in Figure 2A, since temperature is one of the factors that most affect potato crop development (Levi and Veilleux 2007). Environment E1 and E3 had the lowest average temperatures and low maximum temperatures; conversely, environments E2, E4, E5, and E6 had higher average and maximum temperatures (Table 1).

Clones that are in the vertex of a ME represent the best genotype for that ME. Clone G17 was the best in ME1 and G2 in ME2. Clones in sectors in which none of the environments was clustered are clones which had the lowest mean in at least one of the environments. The checks are among the treatments with the poorest means, which showed the poor adaptation of the checks for MTY. Figure 2D (SVP = 2, scale = 0, and centered in

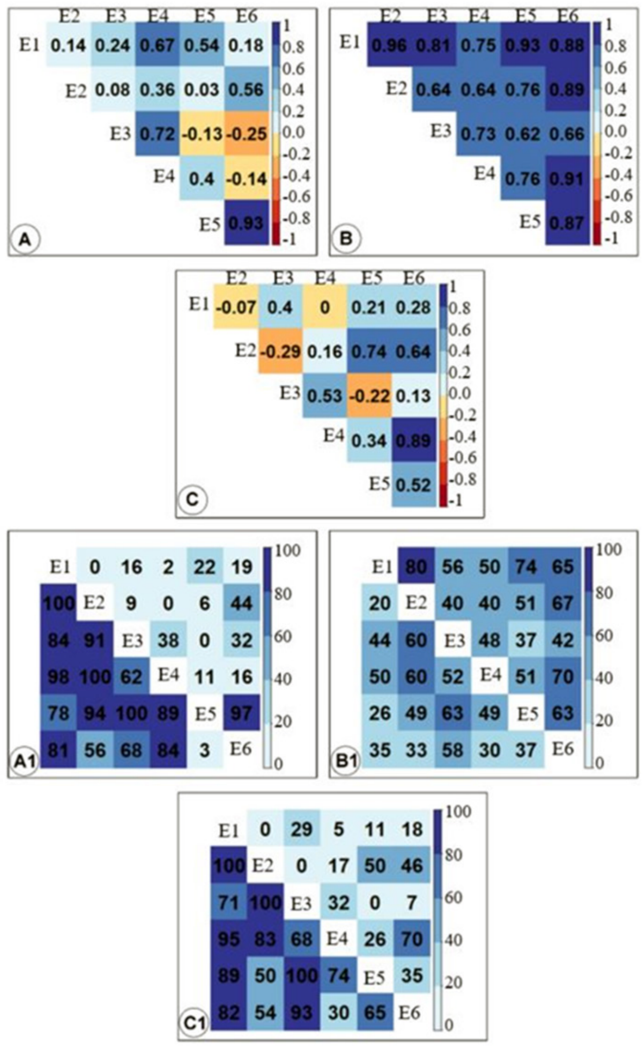

Figure 1. Genetic correlation among six environments (E1 to E6) for the marketable tuber yield (A), specific gravity (B), and tuber appearance (C) traits. Decomposition of the G x E into its simple (upper diagonal) and complex (lower diagonal) parts for the marketable tuber yield (A1), specific gravity (B1), and tuber appearance (C1) traits.

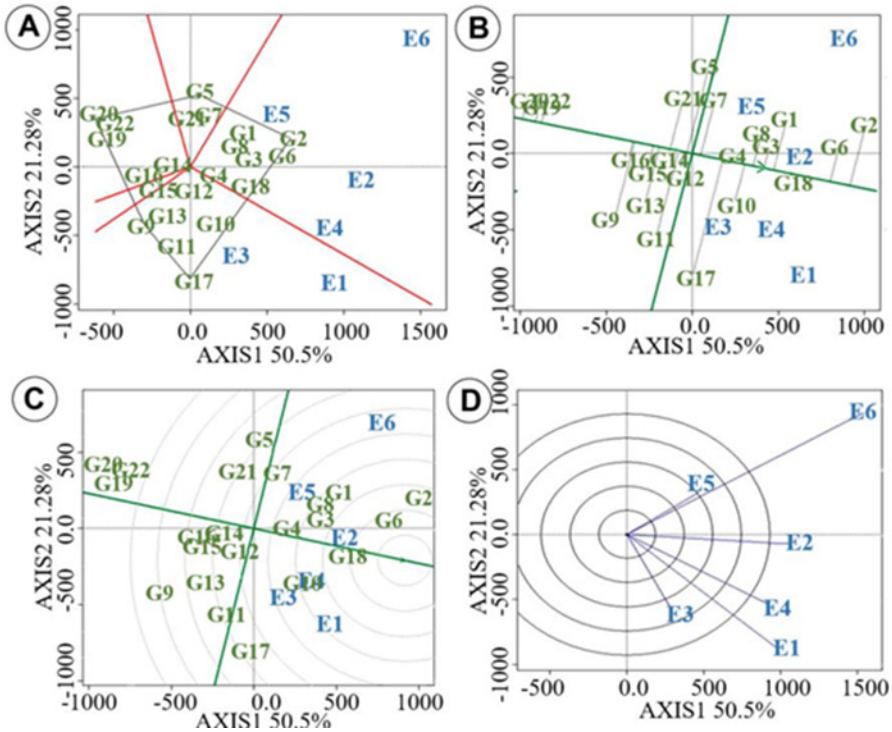

Figure 2. GGE biplot for marketable tuber yield of the 18 potato clones and four potato cultivars in six environments: A) Which-won-where, B) Mean vs. Stability, C) Comparison of genotypes with an ideotype, and D) Discriminative vs. Representative of test environments.

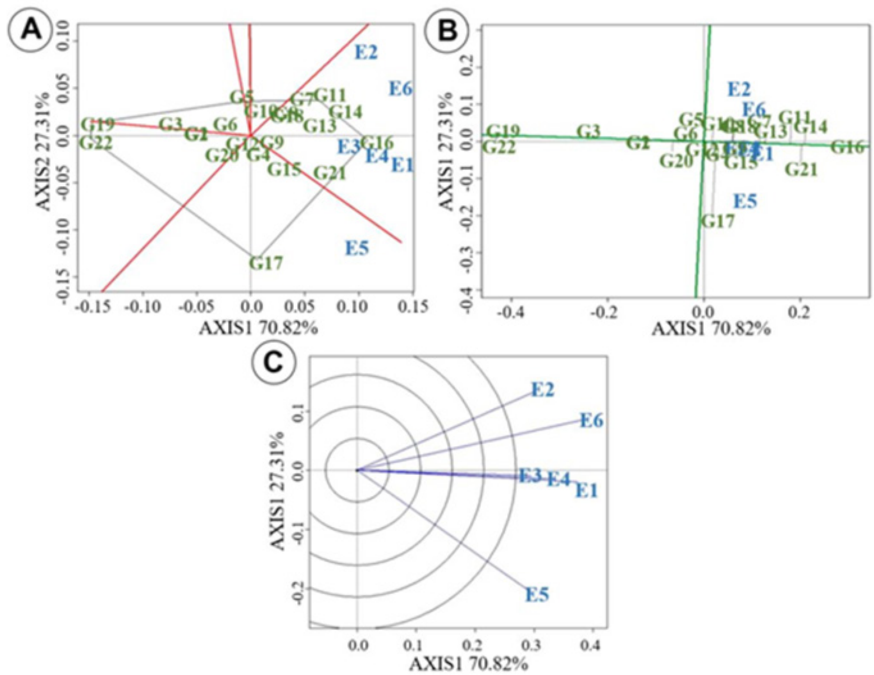

Figure 3. GGE biplot for the specific gravity of tubers of the 18 potato clones and four potato cultivars in six environments showing: A) Which-won-where, B) Mean vs Stability, and C) Discriminative vs Representative of test environments.

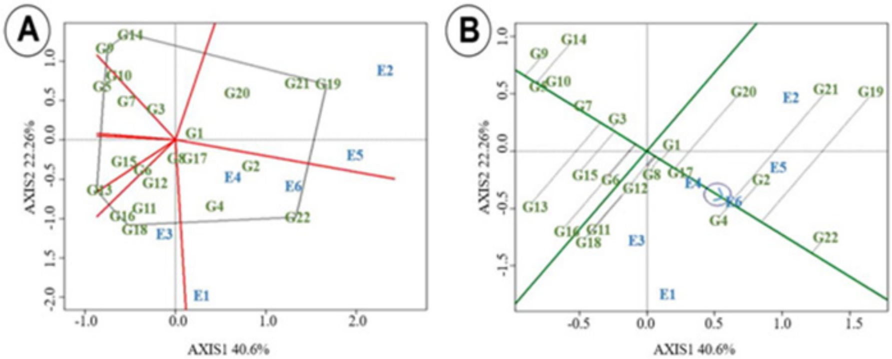

Figure 4. GGE biplot for tuber appearance of the 18 potato clones and four potato cultivars in six environments showing: A) Which-won-where and B) Mean vs. Stability.

G+G×E) represents the biplot "Discriminative vs. representative" for MTY. The length of the line that goes out from the origin of the graph to each environment represents the standard deviation of the mean values of the clones in that environment, and it is used to measure the discriminatory power of the environment (Yan and Tinker 2006). The best environment for discrimination of the clones for MTY was E6, and E2 best represents this set of environments.

Figure 2B is the graph Mean vs Stability for MTY, which allows identification of clones that are stable and have high mean yield, i.e., the most promising clones, because a low-yielding clone, even if stable, is not useful. The line with the arrow passing through the origin of the graph is the axis of the environment mean and indicates the direction of the highest yields. Clone G2 had the highest yield, though it had low stability. The most stable clones for MTY were G4, G14, and G18; clones G4 and G18 were most prominent, for they allied yield stability with high adaptability. The clone that most contributed to the G×E was G17, which showed high yields in ME1 but low performance in ME2.

The concept of ideotype in the study of the G×E is used to describe a genotype that has average to high yield for a specific trait in a determined group of environments, i.e., a genotype that is stable and adapted. Figure 2C illustrates the ideotype for MTY in this set of environments; the ideotype is represented in the center of the concentric circles. Clone G6 was closest to the ideotype, followed by clones G18 and G2.

The MLG clones had higher MTY compared to the check cultivars. The fact that the MLG clones were selected under tropical conditions may explain this higher MTY; MLG clones proved to be more adapted to tropical growing conditions, showing lower losses than commonly occur for most potato cultivars under these conditions (Lambert et al. 2006, Teixeira et al. 2015, Kim and Lee 2016).

The pattern of environment clustering for SG was different than that found for MTY (Figure 3A) (SVP = 1, scale = 0, and centered in the G+G×E). Two MEs were formed: i) E1, E2, E3, E4, and E6, and ii) E5. The SG results were less affected by the environments than MTY was. For SG, the genetic factors (clones) accounted for most of the variation (Table 2). The lower effect of the environment and the high effect of clones on the SG results may explain the different patterns found between SG and MTY in the formation of the MEs.

The discriminatory power that the environments had for SG was similar (Figure 3C) - Discriminative vs representative (SVP = 2, scale = 0, and centered in the G+G×E). The environment that combined discriminatory power and representativeness was E1, and it should be used for future trials. Therefore, environments that are in the same ME as E1 can be discarded.

According to the results of Mean vs Stability for SG (Figure 3B), clone G16 had the highest value and high stability (SVP = 1, scale = 0, and centered in the G+G×E). Most of the clones and cultivars were stable, except for clone G17. Cultivars G19 and G22 showed the lowest SG mean, as expected, since both cultivars are for fresh market production, which does not require high SG.

The G×E is commonly detected for SG and has already been described in other studies (Teixeira et al. 2015, Wang et al. 2017). Teixeira et al. (2015) discussed the effect temperature has on the SG, where environments that had higher temperatures can cause a decrease in SG compared to environments with mild temperatures. The G×E can be linked to the fact that SG tends to decrease at high temperatures, and some clones exhibit an unequal response to this. In our study, SG was less affected by the interaction (only 12.6% of the total variation). Most of the variation was genetic, accounting for more than 40% of the variation. Clones with stable values for SG have a considerable advantage, because

Table 2. Combined analysis of variance for total tuber yield (TTY), marketable tuber yield (MTY), specific gravity (SG), tuber appearance (TA), tuber skin texture (ST), tuber eye depth (ED), and tuber shape (TS) in 18 potato clones and four cultivars planted in six environments

		Mean Squares						
Sources of variation	**df**	**TTY‡**	**MTY**	**SG**	**TA**	**ST**	**ED**	**TS**
Block/Environments	12	142368	82422	1.012×10^{-4}	0.312	0.578*	0.198	0.323
Treatments (Trt)	21	720229**	612509**	9.951×10^{-4}*	1.439**	6.343**	0.780**	4.654**
MLG	17	406962**	361989**	4.751×10^{-4}**	0.951**	5.819**	0.390**	2.864**
Checks	3	203575**	491182**	2.702×10^{-3}**	0.670	9.408**	2.776**	16.268**
MLG vs Checks	1	7595714**	5235338**	4.777×10^{-3}**	12.040**	6.059**	1.409*	0.240
Environments (Env)	5	2407571**	2276210**	2.411×10^{-3}**	6.845**	3.308**	3.264**	1.630**
Trt × Env	105	246742**	186035**	6.110×10^{-5}*	0.572**	0.641**	0.227**	0.510**
MLG × Env	85	262160**	198137**	6.240×10^{-5}*	0.438**	0.591**	0.240*	0.532**
Checks vs Env	15	65018**	36907	3.320×10^{-5}	0.650**	0.946**	0.180*	0.398**
MLG vs Checks × Env	5	518511**	398754*	1.180×10^{-4}	2.666**	0.614	0.157	0.448
Error	252	115943	92109	4.270×10^{-5}	0.210	0.318	0.149	0.198
Mean of MLG †		894.34 a	665.96 a	1.0716 a	2.89 b	2.80 a	3.44 a	3.43 a
Mean of checks		528.58 b	354.21 b	1.0624 b	3.35 a	3.12 a	3.59 a	3.31 a

*, ** Denote significant at 5% and 1% of probability, respectively.
† Means followed by the same letter are not significantly different ($p < .05$). ‡ TTY - Total Tuber Yield (g plant^{-1}), MTY - Marketable Tuber Yield (g plant^{1}), SG - Specific Gravity, TA - Tuber Appearance [ranging from 1 (poor appearance) to 5 (excellent appearance)], ST - Tuber Skin Texture [ranging from 1 (rough and matte) to 5 (smooth and shiny)], ED - Tuber Eye Depth [ranging from 1 (very shallow) to 5 (very deep)], and TS - Tuber Shape [ranging from 1 (round) to 5 (long)].

Table 3. Mean values of the 18 potato clones and of the four cultivars for all the traits evaluated in six environments

Clone	TTY‡	MTY	SG	TA	TS	ST	ED	Market†
G1 - MLG-01.02	920.18 B	779.12 B	1.0648 D	3.00 C	3.25 C	3.27 B	3.20 C	FM
G2 - MLG-01.06	1201.56 A	977.03 A	1.0651 D	3.25 B	3.87 B	2.57 C	3.31 B	-
G3 - MLG-02.12	975.69 B	743.93 B	1.0614 D	2.79 C	3.15 C	2.72 C	3.45 B	-
G4 - MLG-03.03	930.23 B	665.64 B	1.0706 C	3.25 B	3.29 C	3.14 B	3.51 A	FF/FM
G5 - MLG-05.01	759.25 C	559.72 C	1.0688 C	2.58 D	3.31 C	2.98 C	3.37 B	FF
G6 - MLG-11.05	1046.15 A	929.39 A	1.0681 C	3.00 C	3.22 C	1.29 F	3.38 B	FF
G7 - MLG-11.45	729.80 C	602.52 C	1.0747 B	2.71 D	2.83 D	1.75 E	3.27 B	-
G8 - MLG-12.16	964.53 B	768.33 B	1.0723 C	2.96 C	3.11 C	2.79 C	3.68 A	FF
G9 - MLG-14.12	632.31 C	465.48 C	1.0716 C	2.56 D	3.20 C	2.77 C	3.14 C	FF
G10 - MLG-17.48	1024.19 A	716.71 B	1.0710 C	2.62 D	3.74 B	2.87 C	3.44 B	FF
G11 - MLG-17.50	788.98 C	588.24 B	1.0771 B	3.09 B	3.51 B	2.98 C	3.42 B	FF
G12 - MLG-20.01	824.88 B	569.62 C	1.0693 C	2.96 C	2.64 E	3.57 A	3.35 B	-
G13 - MLG-20.12	818.36 B	529.30 C	1.0753 B	2.87 C	3.20 C	2.96 C	3.64 A	FF
G14 - MLG-20.14	884.62 B	574.81 C	1.0786 B	2.51 D	3.85 B	2.70 C	3.50 A	FF
G15 - MLG-20.17	700.18 C	572.45 C	1.0724 C	2.81 C	3.31 C	2.25 D	3.46 B	FF
G16 - MLG-22.23	840.88 B	473.98 C	1.0835 A	2.83 C	3.64 B	3.38 A	3.59 A	FF
G17 - MLG-23.24	900.98 B	637.45 B	1.0710 C	3.18 B	4.35 A	3.42 A	3.61 A	FF/FM
G18 - MLG-23.37	1155.23 A	859.81 A	1.0722 C	2.97 C	3.44 C	2.88 C	3.50 A	FF
G19 - AGATA	551.66 D	280.69 C	1.0518 E	3.38 A	3.54 B	3.60 A	3.78 A	FM
G20 - ASTERIX	422.20 D	196.15 D	1.0681 C	3.08 B	4.35 A	3.14 B	3.88 A	FF/FM
G21 - ATLANTIC	671.22 C	563.14 C	1.0774 B	3.38 A	2.01 F	2.05 D	3.00 C	CH
G22 - CUPIDO	469.21 D	259.21 D	1.0523 E	3.54 A	3.31 C	3.64 A	3.68 A	FM

Mean values followed by the same letter belong to the same group by the Scott and Knott test ($p < .05$).
‡ TTY - Total Tuber Yield (g plant^{-1}), MTY - Marketable Tuber Yield (g plant^{-1}), SG - Specific Gravity, TA - Tuber Appearance [ranging from 1 (poor appearance) to 5 (excellent appearance)], TS - Tuber Shape [ranging from 1 (round) to 5 (long)], ST - Tuber Skin Texture [ranging from 1 (rough and matte) to 5 (smooth and shiny)], and ED - Tuber Eye Depth [ranging from 1 (very shallow) to 5 (very deep)]. † FM = fresh market; FF = frozen French fries; CH = chip industry.

even if they are planted in the rainy season (August-December) under higher temperatures, their SG remains stable, considering that SG values generally decline (Benites and Pinto 2011). Stability for SG is fundamental for the potato industry, since SG is associated with tuber dry matter content, which is related to potatoes with good frying quality; that is, high SG values are associated with good frying quality.

For TA, the Mean vs. Stability graph (SVP = 1, scale = 0, and centered in the G+G×E) (Figure 4B) showed that all the checks had a TA score greater than the mean. The highest score was that of check G22, which not only had a high score but also high stability. Check G19 had excellent appearance, but it was highly unstable. Figure 4A (SVP = 1, scale = 0, and centered in the G+G×E) represents the clustering of environments for TA. There were three MEs: i) E1, E4, and E6, ii) E2 and E5, and iii) E3. Nine (9) of the 18 MLG clones had poor appearance and were not included in any of the ME.

TA determines the marketability of clones for the fresh market. Thus, clones directed to this market segment should not only be high yielding but also have good tuber appearance (Pereira et al. 2017). On average, the MLGs had TA values below those obtained by the checks. The means for all clones and the market segment each clone fit into are shown in Table 3. The MLG clones which showed stability and adaptability and fit in a market segment were G1 for the fresh market and G6 and G18 for the frozen French fry market. Four MLG clones did not fit in any of the market segments. This lack of fit is extremely undesirable since these clones will not be useful for the market, even if a clone has high yield and good stability.

According to the Brazilian Potato Association, in 2017, only seven cultivars represented 95% of the planted area. The Agata cultivar alone represented 60%, which shows the lack of specific cultivars for the different regions and for the different seasons. Given the presence of the G×E for MTY, SG, and TA, cultivars should be chosen on a regional basis, i.e., a specific cultivar for each region/season, seeking to maximize gains. Regionalization in cultivar recommendation is an effective way of dealing with the G×E, diminishing its negative effects on production (Bernardo 2020).

CONCLUSION

The MLG clones proved to be more adapted and stable than the cultivars commonly used by growers in the south of the state of Minas Gerais. The best genotypes were MLG-01-02 (G1), MLG-11-05 (G6), and MLG-23-37 (G18), which have been selected for evaluation as alternatives for release as new cultivars.

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