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# Potato improvement for tropical conditions: I. Analysis of stability

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**ABSTRACT** - *The development of cultivars adapted to high tropical temperatures is the chief objective of potato improvement in the tropics. To achieve this goal, it is necessary to select for more stable genotypes adapted to many environments. The objective of this research was to analyze 51 potato clones for stability regarding tuber yield, percentage of large tubers and tuber specific gravity at different sites, years and planting seasons in southern Minas Gerais state, Brazil. Clones with sound stability for all traits were selected. Greater efforts should be invested specifically into simultaneous selection for several traits under environmental stress, targeting above all the absence of physiological defects in tubers, apart from the abovementioned traits.*

**Key words**: *Solanum tuberosum* L., heat tolerance.

## INTRODUCTION

Potato (*Solanum tuberosum* L.) is originally a species from mild climate and was domesticated in temperate regions with long photoperiod. Under tropical conditions the high temperatures, mainly, affect the species besides the shorter photoperiods

High temperatures lead to a reduced tuber yield for several reasons, be it by the reduction in the capacity of photosynthesis, be it in an increase of respiration and the assimilate consumption of the leaves (Prange et al. 1990, Reynolds et al. 1990, Wolf et al. 1990) and decrease in assimilate partitioning to tubers (Sarquís et al. 1996, Van Dam et al. 1996). High temperatures also affect the internal tuber quality with a reduction of the dry matter content (Haynes and Haynes 1983, Prange et al. 1990). This is extremely important, since the greater the dry matter content, the better is the tuber frying quality. High temperatures also promote the increase of the number of tubers with physiological disorders, such as tuber cracking, secondary growth and internal spots (Menezes et al. 1999), which depreciate the appearance and reduce the commercial acceptance of the product. Besides these direct factors, high temperatures cause an indirect effect by favoring higher pest and disease incidences.

Most cultivars planted in the country nowadays had been developed for temperate conditions and, in spite of presenting good tuber appearance as tablestock, yields are low and the tuber quality poor under tropical climate conditions (elevated temperatures and short photoperiod). On this background, the establishment of locally adapted cultivars is very important for the country and improvement programs need to aim at the

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selection of genotypes with higher stability and adaptability.

The potato breeding program of the UFLA identified clones with good performance under higher temperature conditions in the rainy summer season of the south of Minas Gerais (Menezes et al. 2001). The objective of our study was to evaluate the stability of these clones in relation to tuber yield, percentage of large tubers and tuber specific gravity in different locations, years and planting seasons in the south of Minas Gerais.

## MATERIAL AND METHODS

Clones derived from crossings of Brazilian cultivars with heat-tolerant clones from the CIP (Centro Internacional de La Papa) based on 36 bi-parental crossings, described by Menezes et al. (2001), were evaluated. Nine trials were performed in different years and locations (Table 1). The planting periods were chosen to cover heat stress (rainy summer season) and ideal temperature conditions (winter season). Joint analysis of variance was carried out based on the clone means in the trials, using the mean error of the trials in the model according to Oliveira et al. (2005).

To support the identification of the best clones, the stability analysis was performed with the methods of Lin and Binns (1988) and Annicchiarico (1992), based on the adjusted means of 51 clones evaluated in all environments and in the joint analysis. The method of Lin and Binns (1988) seeks a measure of superiority, the mean square of the distance between the response of genotype *i* and the maximum mean response for all locations. The following parameter is estimated:

$$P_i = \sum_{j=1}^{n} (Y_{ij} - M_j)^2 / 2n$$

where
$P_i$ is the superiority measure of clone *i*
$Y_{ij}$ is the mean of clone *i* in environment *j*
$M_j$ is the mean of the clone with maximum response of all clones in environment *j*
*n* is the number of environments

The method proposed by Annicchiarico (1992) estimates the reliability index for each genotype in relation to its performance on the mean of a particular environment. Firstly, the mean of each genotype is expressed in percentage of the mean of each environment ($Y_i$). After this transformation, the standard deviation ($s_i$) is estimated through the underlying mean $Y_i$ value for each genotype ($\overline{Y}_i$), taking all environments into account. Thus:

$$\overline{Y}_i = \left( \sum_{j=1}^{n} \frac{Y_{ij}}{m_j} * 100 \right) / n$$

where
$\overline{Y}_i$ is the mean value of the proportional means of the overall mean in each environment for genotype *i*
$Y_{ij}$ is the mean of genotype *i* in environment *j*
$m_j$ is the mean of all genotypes for the trait considered in environment *j*

The expression

$$I_i = \overline{Y} - Z_{(1-\alpha)} \cdot S_i$$

can be applied, where:
$I_i$ is the reliability index for genotype *i*
$\overline{Y}_i$ is the mean value of the proportional means of the overall mean in each environment for genotype *i*

**Table 1**. Trials of clone evaluation over nine generations, with location, planting period and experimental design

| Clonal generations | Nr. of evaluated clones | Location | Planting period | Experimental Design | Nr. of replications |
|---|---|---|---|---|---|
| 1 | 698 | Lavras | May to Sept.1998 | Augmented blocks | 1 |
| 2 | 605 | Lavras | Nov. 1998 to Feb. 1999 | Randomized blocks | 2 |
| 3 | 1009 | Lavras | May to Sept. 1999 | Augmented blocks | 1 |
| 4 | 256 | Lavras | Jan. to April 2000 | Lattice 16 x 16 | 2 |
| 5 | 256 | Três Corações | March to July 2000 | Lattice 16 x 16 | 2 |
| 6 | 256 | Lavras | May to Sept. 2000 | Lattice 16 x 16 | 2 |
| 7 | 81 | Lavras | May to Sept. 2001 | Lattice 9 x 9 | 3 |
| 8 | 81 | São João da Mata | August to Nov. 2001 | Lattice 9 x 9 | 3 |
| 9 | 81 | Lavras | Jan. to April 2002 | Lattice 9 x 9 | 3 |

$Z_{(1-a)}$ is the standard value, in which the normal distribution function reaches value 1-a; a was pre-established by Annicchiarico (1992) as a = 0.25.
$s_i$: standard deviation of $\overline{Y}_i$

## RESULTS AND DISCUSSION

The joint analyses are summarized in Table 2, which also contains the estimate of the components of variance and heritability of the traits. For tuber yield, the component of the genotype x environment interaction ($\sigma^2_{gc\,x\,i}$) was quite high compared to that of the other traits, higher in fact than the component of genetic variance of clones ($\sigma^2_{gc}$).

In general, when selection is carried out under diverse environmental conditions that include stressful environments, the genotype x environment interaction is of key importance. According to Cecarelli et al. (1991), low-yield environments are highly unpredictable, owing to the variation in frequency, duration and intensity of the stress-causing factors.

To get reliable estimates of statistical stability parameters these must be obtained from a large number of environments (>10), usually from experiments in late stages of the breeding program (Kang 1998). However, initial data of improvement programs may be used, considering that when one uses nonparametric methods, it is not necessary to assume any hypothesis regarding the phenotypic value distribution. In the case of potato, an adequate number of tubers per clone is generally not available in early stages of the program and, in view of the virus contamination that occurs during successive multiplications of the material of vegetative propagation, planting of trials in several environments becomes unfeasible. In some programs stability studies in early stages were realized to identify superior clones (Brown et al. 1996, Sharma et al. 2001) as well as to study the interaction to identify the best families (Ortiz and Golmirzaie 2004).

Table 3 shows the means and respective indices of stability for 15 clones that presented good stability for all three traits. The index proposed by Annicchiarico (1992) is fairly simple to estimate and of easy interpretation. The higher this index, the greater is the probability of success of the genotype in the environments (reability index). In the method of Lin and Binns (1988), the ideal genotype is the one with the lowest estimate of *Pi* that is, with the best performance in the highest possible number of environments.

Some clones, such as CBM 7-15, CBM 8-03, CBM 16-16, and CBM 22-19 presented high stability for all traits, simultaneously. Interestingly the means of these clones for all traits were fairly high (Table 3). One example is clone CBM 16-16, with a mean of 991 g plant$^{-1}$, 71% large tubers and tuber specific gravity of 1.0759. These values exceeded the overall trial mean and, what is more important, the control means in most trials. In the trial of Três Corações, in a highly favorable environment, this clone presented a mean yield of 1999

**Table 2**. Summary of the joint analyses of variance of nine trials for tuber yield, percentage of large tubers and tuber specific gravity

| Source of variation | df | Mean square<br>Tuber yield (g plant$^{-1}$) | Percentage of large tubers (%) | Tuber specific gravity (x $10^{-4}$) |
|---|---|---|---|---|
| Clones (C) | 50 | 133133.27** | 1657.04** | 7.200** |
| Environments ( E) | 81 | 4437988.83** | 24169.03** | 67.500** |
| C x E | 400 | 85309.09** | 328.68* | 0.900** |
| Mean error | 1784 | 33216.64 | 279.71 | 0.577 |
| Overall mean | | 832.04 | 64.20 | 1.072 |
| CV (%) | | 21.85 | 25.90 | 30.70 |
| $\sigma^2_{gc}$ | | 2952.10 | 81.99 | 0.388 |
| $\sigma^2_{gc\,x\,a}$ | | 28940.25 | 27.20 | 0.179 |
| $h^2$ | | 0.35 | 0.80 | 0.87 |

** and * significant by the F test at 1 and 5% probability, respectively

**Table 3**. Means of tuber yield, percentage of large tubers and tuber specific gravity with respective values of the indices of stability for the 15 most stable clones, according to the methods of Annicchiaricho (1992) and Lin and Bins (1988)

| Clone | Tuber yield | | | Percentage of large tubers | | | Specific weight of tubers | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (g plant$^{-1}$) | $I_i$ [1] (%) | $P_i$ [2] | Mean (%) | $I_i$ (%) | $P_i$ | Mean | $I_i$ (%) | $P_i$ |
| CBM 7-15 | 1053 | 133 | 143849.7 | 76 | 122 | 302.3 | 1.0678 | 100 | 0.000752 |
| CBM 8-03 | 991 | 122 | 109972.0 | 79 | 129 | 138.5 | 1.0727 | 100 | 0.000493 |
| CBM 22-19 | 1015 | 121 | 114165.4 | 68 | 104 | 498.8 | 1.0700 | 100 | 0.000656 |
| CBM 16-16 | 991 | 120 | 122558.2 | 71 | 111 | 394.4 | 1.0759 | 100 | 0.000423 |
| CBM 24-06 | 910 | 116 | 231460.9 | 73 | 115 | 380.6 | 1.0705 | 100 | 0.000628 |
| CBM 16-15 | 941 | 115 | 170595.7 | 68 | 104 | 509.5 | 1.0683 | 100 | 0.000703 |
| CBM 15-10 | 995 | 115 | 137890.7 | 71 | 104 | 669.8 | 1.0623 | 99 | 0.001085 |
| CBM 4-15 | 833 | 112 | 287254.0 | 64 | 99 | 712.1 | 1.0738 | 100 | 0.000465 |
| CBM 2-21 | 815 | 111 | 341476.7 | 60 | 100 | 1077.4 | 1.0824 | 101 | 0.000220 |
| CBM 26-22 | 903 | 109 | 244373.0 | 68 | 106 | 511.7 | 1.0658 | 99 | 0.000844 |
| CBM 22-17 | 898 | 108 | 213675.2 | 61 | 92 | 843.4 | 1.0676 | 100 | 0.000723 |
| CBM 15-25 | 852 | 107 | 302566.9 | 79 | 129 | 133.8 | 1.0645 | 99 | 0.000973 |
| CBM 24-27 | 864 | 106 | 270705.8 | 78 | 123 | 147.9 | 1.0655 | 99 | 0.000857 |
| CBM 7-12 | 848 | 105 | 254001.2 | 74 | 112 | 409.8 | 1.0730 | 100 | 0.000547 |
| CBM 6-02 | 872 | 100 | 241334.4 | 68 | 105 | 583.8 | 1.0680 | 100 | 0.000714 |

[1] $I_i$: reliability index of Annicchiarico in percentage: values over 100 indicate the most stable genotypes
[2] $P_i$: Lin and Binns' superiority measure: low $P_i$ values indicate high stability

g plant$^{-1}$, 90% large tubers and a specific gravity of 1.0800. The latter trait is important, as it is highly correlated with tuber dry matter content, responsible for the frying quality, where values equal to or higher than 1.0800 are desirable. In the trial mean under stress conditions (Table 4) this clone performed satisfactorily for tuber yield, although with a high percentage of tubers with secondary growth.

There was agreement between the two methods of stability, demonstrated by the high correlation coefficients between the indices for the traits (–0.80 for tuber yield,–0.94 for percentage of large tubers and –0.98 for tuber specific gravity). The values are negative, since for the index of Lin and Binns (Pi) smaller values indicate higher clone stability, opposite to the index of Annicchiarico (Ii). The clones with lowest Pi values presented highest Ii values (Table 3).

The correlation coefficients between the indices of Annicchiarico and of Lin and Binns of the clones with the mean of the respective clones in the environments were also estimated (Table 5). In general, the correlation coefficients were high between indices and mean in the absence of stress and the overall mean of the environments. The Pi index presented low correlation (-0.11) with the mean under stress for tuber yield. This was to be expected for this index, since the Pi value is the mean of all environments, representing superiority in the sense of a general adaptability. In the selection with Pi only, a genotype with little general adaptation but with specific adaptation could be discarded. In this last aspect, in the selection specifically for stress conditions, the Pi did not present a high value. The stress-adapted clone CBM 2-21 for instance presents a high Pi value for tuber yield in relation to other clones displayed in Table 3. However, when targeting broad adaptation, which is generally the case, the Pi should be used since it makes the selection of clones with stability and with good performance in both conditions possible. Examples are clones CBM 22-19, CBM 8-03, CBM 7-15, and CBM 16-16, with low Pi values (Table 3) and with good performance under favorable as well as unfavorable conditions. Clarke et al. (1992), who evaluated selection methods for wheat drought tolerance also found a high correlation of Pi with the overall genotype mean across the environments. They claim, however, that Pi is somewhat

**Table 4**. Means of tuber yield, percentage of large tubers, tuber specific gravity, tuber appearance, percentage of cracked tubers, percentage of tubers with secondary growth, plant vigor and growth cycle (DAE: days after emergence) of the 10 best clones under heat stress for the traits. Lavras, rainy summer seasons of 1998, 2000 and 2001

| Clones | Tuber yield (g plant$^{-1}$) | % of large tubers | Tuber specific gravity | Tuber appearance[1] | Cracked tubers (%) | Tubers with secondary growth (%) | Plant vigor[2] | Growth cycle[3] (days) |
|---|---|---|---|---|---|---|---|---|
| CBM 2-21 | 773 | 74 | 1.0788 | 2.8 | 4.6 | 9.7 | 2.9 | 83 |
| CBM 26-22 | 667 | 56 | 1.0613 | 1.5 | 0.0 | 17.0 | 3.0 | 104 |
| CBM 8-11 | 652 | 62 | 1.0671 | 1.6 | 7.6 | 20.4 | 3.0 | 84 |
| CBM 4-15 | 627 | 54 | 1.0666 | 1.7 | 13.1 | 19.9 | 3.4 | 92 |
| CBM 2-01 | 621 | 50 | 1.0716 | 1.8 | 12.6 | 12.6 | 3.4 | 80 |
| CBM 16-16 | 613 | 65 | 1.0695 | 2.2 | 4.3 | 23.9 | 4.0 | 90 |
| CBM 7-12 | 584 | 62 | 1.0687 | 2.2 | 1.3 | 12.2 | 3.2 | 109 |
| CBM 2-27 | 579 | 61 | 1.0576 | 1.4 | 4.6 | 7.8 | 3.5 | 101 |
| CBM 16-08 | 576 | 52 | 1.0614 | 1.8 | 0.7 | 17.9 | 3.0 | 85 |
| CBM 8-03 | 557 | 69 | 1.0679 | 1.6 | 2.0 | 17.6 | 4.4 | 114 |
| ACHAT | 305 | 14 | 1.0410 | 2.0 | 25.0 | 31.1 | 3.0 | 84 |
| BARAKA[4] | 548 | 62 | 1.0451 | 2.0 | 30.2 | 12.2 | - | -0 |

[1] tuber appearance was evaluated on a score scale, from 1 (poor appearance) and 5 (ideal appearance)
[2, 3] vigor and cycle were evaluated only in Lavras, 2002; vigor was evaluated on a score scale of 1 (low plant vigor) to 5 (good vigor)
[4] means of control Baraka of the harvests of 1998 and 2000

**Table 5**. Correlation coefficients between the stability indices of Annichiarico ($I_i$) and Lin and Bins ($P_i$) with each clone mean in the environments for tuber yield (TY), percentage of large tubers (PLT) and tuber specific gravity (TSG)

| Stability index | Trait | Mean under stress | Mean in the absence of stress | Environment mean |
|---|---|---|---|---|
| $I_i$ | TY | 0.58** | 0.61** | 0.91** |
| | PLT | 0.69** | 0.77** | 0.99** |
| | TSG | 0.87** | 0.89** | 1.00** |
| $P_i$ | TY | -0.11 | -0.83** | -0.96** |
| | PLT | -0.52** | -0.78** | -0.98** |
| | TSG | -0.86** | -0.85** | -0.98** |

** significant at 1% probability by the t test

influenced by the most productive environments. In spite of the agreement between the indices, the index of Annichiarico (Ii) was more correlated with tuber yield mean under stress than that of Lin and Binns (Pi). It was verified that the Ii for clone CBM 2-21 is superior to that of the others, and is therefore considered stable by this method.

Table 4 presents the means of the 10 best selected clones based on the means of tuber yield, percentage of large tubers, tuber specific gravity, tuber appearance, and percentage of tubers with cracks and secondary growth, under stress conditions (rainy summer season). Clone CBM 2-21 attained a 40% higher yield than the most productive control, outmatching the controls by a higher percentage of large tubers and tuber specific gravity. However, despite the good score of tuber appearance, the percentage of tubers with secondary growth in this clone was high. More attention should be paid to the traits large tuber appearance and percentage of tubers with cracks or secondary growth when selecting for heat tolerance, aiming at the mean of the selected clones (Table 4). The variability for resistance to physiological disorders has been cited (Mackay et al. 1998) and is a quite important criterion for the selection of cultivars for warm climates (Levy et al. 2001). Menezes et al. (2001) observed clones with a general combining ability for reduction of the incidence of physiological disorders. The importance of this trait is noteworthy, since clones released by the CIP (Centro Internacional of the Potatao) as heat-tolerant presented a high incidence of tuber cracking under the rainy summer seasons conditions in the south of Minas Gerais, disqualifying them as parents in improvement program (Menezes et al. 2001). Based on the best clones selected under stress conditions (Table 4), crossings between those with low crack incidence and with little secondary growth are recommended, since most clones presented a high mean for either one or the other of these traits.

Although the controls had not been included in the stability analysis, since different cultivars used with this purpose participated only in some experiments, it was verified that in all environments several clone means were statistically equal or superior to the control means for the evaluated traits (data not shown). Figure 1 shows the performance of the 10 most stable clones according to the index of Annicchiarico. The control means and overall mean of the experiments are represented in the diagram as well. It was verified that the selected clones performed as well under favorable as under stress conditions.

By the identification of the most stable clones and taking additional traits of the plant (growth habit and plant type) and tuber (shape, skin type and eye depth) into account, adapted genotypes will be selected that can be used intensively in the program as parents and/ or as new cultivar. Some of these clones were intercrossed and became the starting population in a recurrent selection program for population improvement for heat tolerance in the potato breeding program at UFLA.

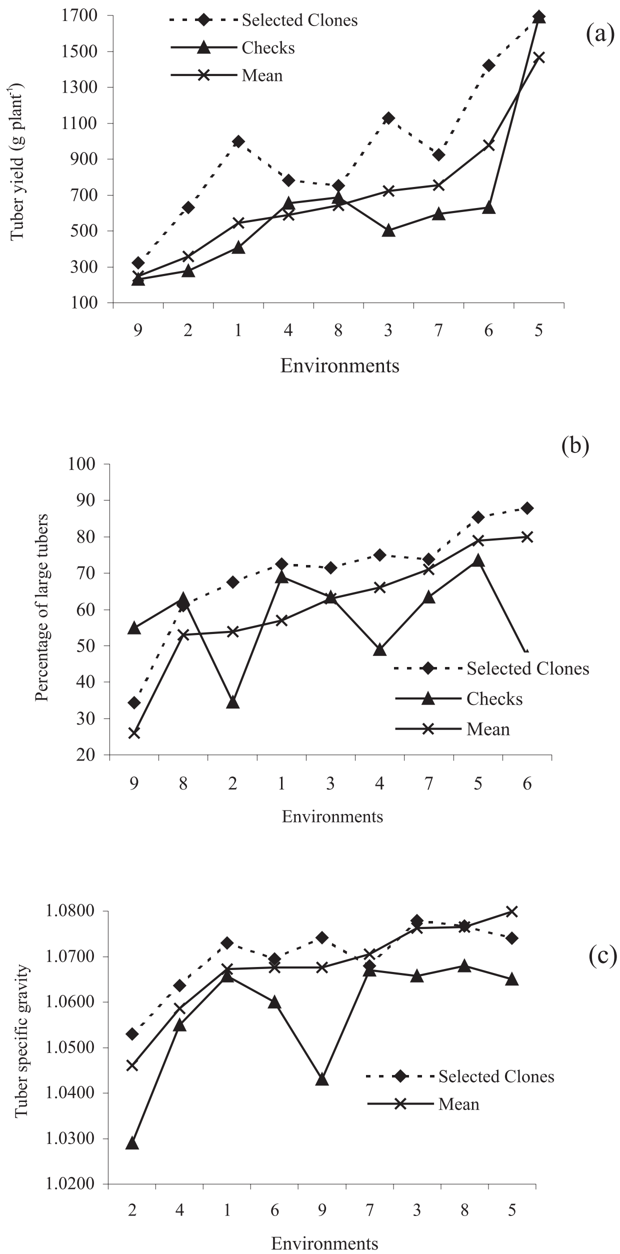


**Figure 1.** Performance of the 10 most stable clones according to the index of Annicchiarico and of the controls for tuber yield (a), percentage of large tubers (b) and tuber specific gravity (c). Values on axis X represent the environmental mean. (♦selected clones, ▲controls, **x** average)

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# Melhoramento da batata para condições tropicais: I. Análise de estabilidade

**RESUMO -** *A obtenção de cultivares adaptadas à condições de altas temperaturas é um dos objetivos do melhoramento da* *batata nos trópicos. Para tal finalidade, é necessário que os programas procurem selecionar genótipos com maior estabilidade e adaptabilidade em vários ambientes. O objetivo do presente trabalho foi estudar a estabilidade de 51 clones para produção de tubérculos, porcentagem de tubérculos graúdos e peso específico de tubérculos em diferentes localidades, anos e épocas de plantio no sul de Minas Gerais. Foi possível identificar clones com boa estabilidade e, simultaneamente, alta performance para produção de tubérculos, porcentagem de tubérculos graúdos e peso específico de tubérculos. Maiores esforços devem ser feitos para seleção específica para condições de estresse, considerando-se vários caracteres simultaneamente, com ênfase na resistência a defeitos fisiológicos de tubérculos, além dos caracteres mencionados.*

**Palavras-chave**: *Solanum tuberosum* L., tolerância a calor, melhoramento genético.

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