Evaluation of potato clones for heat tolerance in the southern region of Minas Gerais, Brazil

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ABSTRACT

The purpose of this study was to evaluate potato clones previously selected for heat tolerance as to choose the most adapted and stable ones for use as parent varieties in future breeding programs or as new cultivars for the market. Ninety-one clones and eight controls were evaluated, among them three cultivars widely planted in the state of Minas Gerais and three cultivars considered to be heat tolerant. Six trials were carried out in different growing seasons in the southern region of Minas Gerais State (Brazil), in both mild and high temperatures. It was possible to identify genotypes which are highly stable when subjected to high temperatures and responsive under mild temperature conditions, especially the clones CBM 7-78 and SR2 50-04. The rank summation index allowed the greatest genetic gain for all traits together. The clones SR2 35-05 and CBM 4-48 have ideal traits for the fresh market. Clone SR2 53-02 has long shaped tubers and high tuber specific gravity, ideal traits for the frozen pre-fried products industry. For the chip industry, the clones CBM 7-12 and CBM 7-78 are most recommended, due to their rounded shape and high dry matter content.

Key words: Heat stress, *Solanum tuberosum* L., stability

Avaliação de clones de batata tolerantes ao calor na região sul de Minas Gerais

RESUMO

O objetivo do estudo foi avaliar um grupo de genótipos previamente identificados como tolerantes ao calor, a fim de selecionar aqueles mais adaptados e estáveis para que sejam utilizados como genitores em programas de melhoramento ou como novas cultivares para o mercado. Foram avaliados 91 clones e 8 testemunhas, dentre estas, três cultivares amplamente utilizadas pelos produtores e três consideradas tolerantes ao calor. Conduziu-se seis ensaios em diferentes épocas na região sul de Minas Gerais, sendo alguns sob condições de temperaturas amenas e outros sob altas temperaturas. Foi possível identificar genótipos altamente estáveis quando submetidos à temperaturas elevadas e responsivos em condições de temperaturas amenas, com destaque para os clones CBM 7-78 e SR2 50-04. A seleção pelo índice da soma de postos foi a que proporcionou o maior ganho, quando considerados todos os caracteres em conjunto. Os clones SR2 35-05 e CBM 4-48 possuem características ideais para o mercado *in natura*. Já o clone SR2 53-02 possui formato alongado e alto peso específico, características ideais para a indústria de pré-fritas. Para a indústria de *chips*, os clones CBM 7-12 e CBM 7-78 são os mais indicados, com formato arredondado e alto teor de matéria seca.

Palavras-chave: Temperaturas elevadas, *Solanum tuberosum* L., estabilidade

Introduction

In the 2013 crop year, Brazil attained record production of 3.53 million tons of potatoes, occupying the position of second largest producer of potatoes in Latin America, near the leader Peru, whose production was 4.07 million tons. Minas Gerais State is responsible for 36 percent of total production of the country (Conab, 2013).

Stress conditions like drought, salinity and high or very low temperatures have caused extensive losses in food production in Brazil and worldwide. The predominant climate in most of Brazilian territory is tropical, with high temperatures nearly the entire year. Nevertheless, it is known that in the environment, plants are frequently subjected to combinations of these different types of stresses. This reality has been the focus of innumerable studies that aim at selection of plants tolerant to abiotic stresses (Gao et al., 2007; Wahid et al., 2007).

The potato is a plant that requires mild climates, especially at night. On average, temperatures from 5 to 21 ºC are ideal for development and production of the Solanaceae. With mean temperatures below 5 ºC, the risk of death through frosts is very high. In addition, plant development is very slow at relatively low temperatures. Mean daily temperatures (day and night) greater than 21 ºC are presumed to be too hot for potato growth. It is assumed that in many producing regions, the day/night temperature range is 27/15 °C (Haverkort et al., 2008).

In the rainy and dry crop seasons, mean temperatures are higher, which makes producers seek higher altitude regions to offset the adverse effects of heat. Nevertheless, temperatures above the ideal range frequently occur, especially in the rainy crop season (planting from September to December). In addition, most of the cultivars currently planted in the country were developed specifically for temperate conditions and, although they exhibit good qualities for commerce and industry, when subjected to the climatic conditions of Brazil, they do not reach their potential in tuber productivity and quality. Therefore, obtaining cultivars adapted to these conditions is important for the country.

In tropical climates, excess solar radiation and high temperatures are often the most restrictive factors which affect development and yield. Lambert et al. (2006) observed that growing under high temperatures reduces the number and weight of the tubers, resulting in decreases of up to 58% in yield and 25% in percentage of large tubers. Under stress conditions, various processes that affect tuber yield are inhibited, such as the photosynthetic rate, induction of tuberization and tuber development (Veilleux et al., 1997; Hall, 2003; Wahid et al., 2007).

Potato selection with a view toward heat tolerance has been undertaken for many years in many countries. However, in Brazil, which is a predominantly tropical country, selection for this trait began only recently (Menezes et al., 2001; Lambert et al., 2006; Benites & Pinto, 2011). Through intense debates among breeders discussing "what to breed for" in the potato crop, they cite resistance to abiotic stresses, more specifically heat tolerance, as one of the main goals in genetic breeding (Bonnel, 2008).

The purpose of this study was to evaluate a group of potato genotypes, previously selected for heat tolerance, in different environments in the southern region of Minas Gerais State, Brazil.

Materials and Methods

Six experiments were conducted in three locations in the southern region of the state of Minas Gerais (municipalities of Lavras, Camanducaia and Ipuiúna – Table 1).

Lavras is located at 21°14' latitude South, 45°59' longitude West and altitude of 918.8 m. The climate in the region is characterized by a mean annual temperature of 19.4 °C, mean annual rainfall of 1529.7 mm and mean relative air humidity of 76.2%. Camanducaia is located in the Serra da Mantiqueira (Mantiqueira mountains) at 22°45' latitude South and 46°08' longitude West. The experiment was conducted at 1600 m altitude. Climate in the location is cool/dry and characterized by mean annual temperature of 17 °C and mean annual rainfall

Table 1. Average temperature six environments in the south of Minas Gerais State during 19 months (vegetative and reproductive development), Minas Gerais State, Brazil

Monthly	Average temperature of each environment					
	Lavras (Jun/07)	Lavras (Mar/08)	Camanducaia (Apr/08)	Lavras (Nov/08)	Ipuiúna (Jan/09)	Lavras (Feb/09)
1	22.22	21.00	16.15	15.48	22.5	22.20
2	23.48	22.13	16.91	14.26	19.2	22.08
3	22.77	22.59	18.46	15.17	17.7	21.60
4	22.63	21.70	16.57	17.19	17.4	20.46
5	23.46	19.96	18.32	17.17	15.8	18.33
6	21.31	23.72	19.26	19.09	15.6	20.49
7	21.36	23.09	17.60	19.18	17.2	21.21
8	20.46	21.54	17.51	18.45	17.8	20.47
9	19.89	20.96	15.48	18.03	15.9	19.19
10	18.25	18.70	16.54	21.13	16.6	20.28
11	17.51	20.80	17.12	21.14	17.4	20.50
12	19.70	21.22	18.12	15.93	17.1	22.12
13	14.63	22.98	16.83	16.04	18.0	21.67
14	15.28	20.87	16.81	21.11	17.9	20.77
15	16.04	21.23	17.65	18.46	16.7	21.56
16	harvest	22.22	16.24	21.28	harvest	22.38
17		19.81	15.65	22.20		harvest
18		21.48	16.38	22.08		
19		harvest	harvest	harvest		

of 1700 mm. The municipality of Ipuiúna is located in the Serra da Tronqueira (Tronqueira mountains), an extension of the Serra da Mantiqueira, at 22°05' latitude South, 46°11' longitude West and 1500 m altitude. Mean annual temperature is 18.1 °C and mean annual rainfall is 1740 mm.

Camanducaia and Ipuiúna were environments that had milder temperatures. In both locations, more than 80% of the cycle remained under conditions near 20 °C. At Lavras, however, the temperatures were higher and were around the optimum value (up to 20 °C) between 50% and 60% of the crop cycle. In the same location, periods were also registered with temperatures considered to be extreme (≥25 °C), affecting 10% of the period of crop development (Figure 1).

Ninety-one clones previously identified as heat tolerant by Menezes et al. (2001) and Benites & Pinto (2011) were evaluated, denominated CBM, SR1 and SR2. In addition to heat tolerance, these clones showed better agronomic performance, combining high dry matter content of the tubers and percentage of large tubers (Lambert et al., 2006).

Eight cultivars were used as controls, two of Brazilian origin (Epamig 0580 and Aracy), three imported cultivars (Asterix, Atlantic and Ágata) and another three considered in the literature as heat tolerant (LT-7, LT-9 and Desireé). The LT clones were introduced from the International Potato Center (CIP) and the Desirée cultivar is of Dutch origin. The experimental design was randomized blocks with three blocks, spacing of 0.30 x 0.80 m and plots of one row with five plants. The soil was prepared by plowing, disking and trenching, to which were applied 3000 kg ha^{-1} of the commercial fertilizer formula 4-14-08 (N, P$_2$O$_5$, K$_2$O). Around thirty or forty days after planting, top dress fertilization was made with ammonium sulfate, using 300 kg ha^{-1}, and the crop was earthed up. Control of weeds, insect pests, diseases and other crop treatments were performed according to traditional management practices for commercial potato production in the region.

At Lavras, irrigations followed a weekly schedule from the time of planting, being suspended fifteen days before harvest of the experiment. Desiccation of the vines was also performed at that time. At Camanducaia and Ipuiúna, irrigation was not performed. The characteristics of greatest importance for production and industrialization of the tubers were considered for analysis: production of marketable tubers; production of large tubers (transverse Ø ≥ 45 mm); average weight of tubers; tuber specific gravity (TSG), estimated by: TSG = weight in the air/(weight in the air – weight in the water); percentage of physiological disorders; general tuber appearance (1 = bad to 5 = excellent); shape of the tubers: according to the length/greatest diameter ratio (lenght gd^{-1}) and classified as long, oval or round.

Individual and joint analyses of variance of the experiments were performed by means of the GLM procedure of SAS (Statistical Analysis System) statistical package. In analyses of stability and adaptability, the Lin & Binns (1988) method was used, by Genes software.

Selection of superior clones was performed by the rank summation index (Mulamba & Mock, 1978). The goal was classification of the genotypes using various traits simultaneously. Three characteristics were used for estimation of the indexes, namely: production of large tubers, specific gravity of the tubers and general tuber appearance. Distinct criteria were used for the purpose of selecting clones suitable for the fresh market or for use in the frozen pre-fried or chip industry. The index methodology proposed by Mulamba & Mock (1978) is characterized by classifying the genotypes in relation to each one of the traits, individually, in the most favorable order for the objectives of the breeder. After that, the classification values for each trait are added up. In constructing the index for the fresh potato market, weight 2 was used for production of large tubers and overall appearance of the tubers and weight 1 for specific gravity of the tubers. For the index for industrial use, weight 2 was used for production of large tubers and specific gravity of the tubers, and weight 1 for general tuber appearance. Selection intensity of 12.5% was applied.

Based on the mean data of the six characteristics evaluated in the six environments, for the clones and the controls, a nonparametric selection index called the graphic method was applied. To apply this methodology, the variables were initially standardized, since they have different units and magnitudes. For this purpose, the Z estimate was obtained by the following expression:

$$Z = \frac{(X-m)}{s}$$

in which:

X   - phenotypic observation of the characteristic at issue
m   - overall mean of the characteristic
s   - standard deviation

After that, with standardized data, a chart was made with six semi-axes for each clone evaluated, in which each one of the semi-axes represents one of the characteristics evaluated.
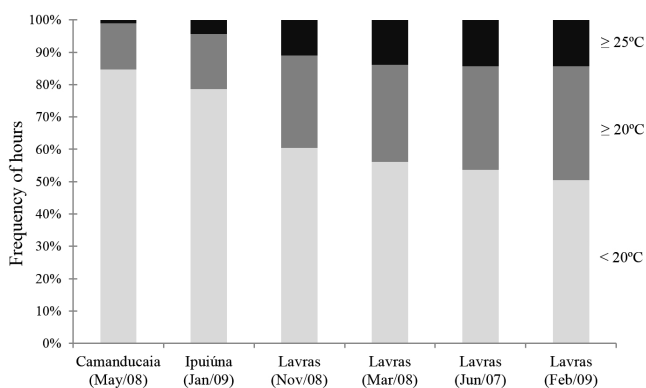

Figure 1. Representation of the six crop environments associated with frequency of hours with the temperature throughout the entire crop cycle. The frequency of hours is divided up into below 20 °C, greater than or equal to 20 °C and greater than or equal to 25 °C, respectively, Minas Gerais State, Brazil

Results and Discussion

The environments that proved to be more productive were Lavras (Nov/08), with mean production of 731.53 g plant^{-1} and Lavras (Feb/09), with 655.12 g plant^{-1} (Figure 2) (p<0,05).

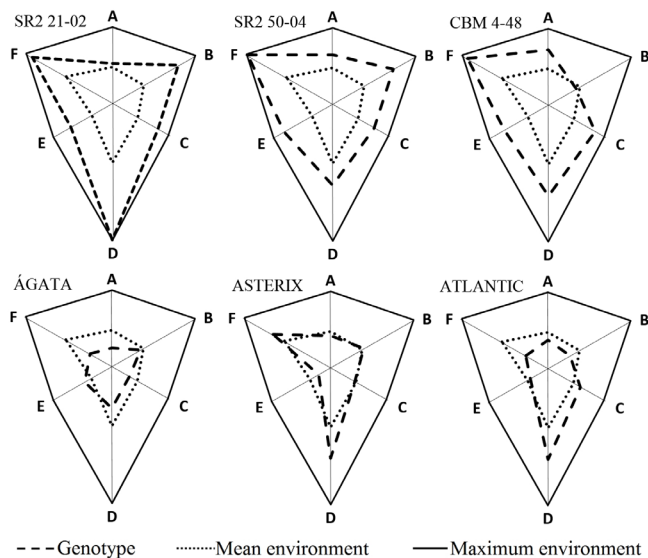- - - Genotype   ········ Mean environment   —— Maximum environment

Figure 2. Mean behavior of the best clones and of three controls for tuber yield in six experiments conducted in Lavras-June/07 (A), Lavras-Mar/08 (B), Camanducaia-Apr/08 (C), Lavras-Nov/08 (D), Ipuiúna-Jan/09 (E), and Lavras-Feb/09 (F), in Minas Gerais State, Brazil

This last environment was conducted in the rainy crop season, a time considered not to be suitable for planting in the region because of the high temperatures registered in that period. Nevertheless, it was an atypical year and the temperatures remained mild during the period of tuber bulking, favoring crop performance. In relation to yield, Silva et al. (2009) showed that late maturing clones tend to be more productive than early ones, with more vigorous growth, greater duration of the photosynthetically active leaf area, with a greater tuberization rate and longer period for tuber bulking.

The environments that exhibited worse performance were Ipuiúna and Camanducaia, with mean values of 292.33 g plant^{-1} and 359.97 g plant^{-1}, respectively (p<0.05). In Ipuiúna and Camanducaia, low performance may be explained by the occurrence of a strong hail, causing loss of plots and general leaf stripping in the experiment.

Similar behavior to that of yield was observed for the percentage of large tubers and average weight of the tubers. The greatest mean value was at Lavras (Nov/08), with 77% of large tubers and 106.72 g plant^{-1} of average tuber weight. The lowest percentage of large tubers was observed in Ipuiúna (39.7 %), which also obtained the worst mean value for average tuber weight (65.87 g plant^{-1}).

The mean value for specific gravity remained near 1.0750 in all environments, a value considered as ideal for the fresh potato market, both for use in cooking or frying. The specific gravity of the tubers was highly correlated with the dry matter content (Schippers, 1976). Only at Lavras (Mar/08) was the mean value below the other environments, with specific gravity of 1.0652. A similar result was observed by Menezes et al. (2001), in the rainy crop season at Lavras (1994/95). This occurs due to the more frequent occurrence of high temperatures during the crop cycle, affecting a range of aspects from formation of stolons to translocation of photoassimilates to the tubers. In this environment, a high percentage of physiological disorders was also observed (13.48%). In contrast, at Camanducaia (Apr/08),

Lavras (Nov/08) and Ipuiúna (Jan/09) physiological disorders on tubers were practically not seen. In these locations, there was a lower frequency of temperatures above 20 °C and 25 °C throughout the crop cycle (Figure 1). According to Menezes et al. (2001), with an increase in temperature (>25 °C), the occurrence of cracking and knobby potatoes becomes more frequent. Camanducaia and Ipuiúna also showed the greatest mean values for general tuber appearance, with mean values near 2.70. The type of soil found in these two locations is sandy, causing less damage to the tuber surface, which favors their visual appearance.

All the characteristics, with the exception of the percentage of physiological disorders, exhibited significant differences among treatments (p<0.05). The same was observed among clones and among controls, showing that there is great genetic variability among the genotypes evaluated. Fernandes et al. (2011) noted that even in cultivars commonly planted, the index is still variation among genotypes for high yield and protein.

The clone vs. control contrast was significant (p<0.05) for production of marketable tubers, percentage of large tubers, average weight of the tubers and specific gravity, indicating that they exhibited different behaviors for these characteristics.

Based on sum of squares decomposition of source of variation clone x environment, the significance (p<0.05) was observed for all the traits, showing that the behavior of the clones did not coincide in all the environments. For the contrast clones vs. controls x environments significant for most of the traits (except for physiological disorders) indicates that the performance of the clones was different from that of the controls, in all the environments. The clones (Table 2) proved to be superior to the controls for production of marketable tubers, percentage of large tubers, average weight of the tubers, specific gravity and general tuber appearance.

The coefficients of variation (CV) fit within the limits normally observed for each trait, with the exception of physiological disorders, which was 373.76% (Table 2). This high value observed was also found by Menezes et al. (2001) and Lambert et al. (2006) in which they discuss the difficulty of evaluation for this characteristic.

By the method of Lin & Binns (1988), it was possible to visualize the interaction (%) of the genotypes with the environment. Observing all clones, 12% of clones had a mean interaction below 70%; the clone CBM 7-78 obtained only 47% of interaction, proving to be highly stable. The clones considered to be more stable and adapted to all the environments were CBM 7-78, SR2 50-04, CBM 4-48, SR2 21-02, SR2 35-05. The interesting point is that the best clones were the most productive, both in the environments with mild temperatures as well as under high temperatures, showing that it is possible to select clones which are adapted to stressful environments caused by high temperatures and, at the same time, responsive to environments with mild temperatures. Lambert et al. (2006) identified that for high temperature conditions, in general, the genotypes with best performance are specifically adapted; however, genotypes with good performance in both conditions may also be selected.

Table 2. Mean values of joint analysis of the 14 best ranked clones (15%) and controls for production of marketable tubers, percentage of large tubers, average weight of tubers, specific gravity, percentage of physiological disorders, overall appearance of tubers and shape of the tubers in six environments in the south of Minas Gerais State, Brazil

Superior clones	Characteristics (overall mean)						Shape
	Production (g plant[-1])	Large Tubers (%)	Average weight of tubers (g)	Specific gravity	Physiological disorders (%)	Tuber appearance	
CBM 2-18	656.74	63.62	94.72	1.0883	2.60	2.39	Oval
CBM 4-16	614.49	78.28	103.07	1.0779	1.08	2.69	Round
CBM 4-48	772.71	80.40	108.21	1.0688	4.35	2.60	Long
CBM 7-12	695.28	77.25	95.24	1.0740	0.41	2.54	Round
CBM 7-78	797.66	72.34	98.03	1.0741	1.61	2.47	Round
CBM 8-20	532.92	64.03	90.20	1.0749	0.14	2.94	Oval
SR1 4-03	471.53	76.25	86.23	1.0778	1.48	2.93	Round
SR1 7-42	641.88	72.49	98.05	1.0850	8.12	2.61	Round
SR2 6-09	636.44	70.97	83.77	1.0796	4.81	2.29	Round
SR2 21-02	915.63	67.85	84.14	1.0724	6.41	2.49	Oval
SR2 30-03	505.00	71.37	88.96	1.0764	1.01	2.60	Round
SR2 35-05	687.43	59.32	86.16	1.0654	0.72	2.97	Long
SR2 50-04	828.75	77.64	101.21	1.0719	6.64	2.77	Oval
SR2 53-02	574.05	57.60	88.01	1.0738	3.32	3.13	Long
Ágata	348.96	39.38	67.09	1.0531	1.10	3.36	Oval
Aracy	475.60	66.94	81.02	1.0732	3.70	2.52	Round
Asterix	553.74	44.07	84.39	1.0677	3.96	2.31	Long
Atlantic	470.90	46.83	58.07	1.0703	3.13	2.14	Round
Desireé	279.65	43.04	66.74	1.0592	2.39	2.19	Oval
Epamig 0580	516.02	62.89	75.78	1.0603	6.58	1.81	Round
LT-7	304.03	47.63	61.22	1.0669	2.50	2.17	Round
LT-9	232.85	71.28	83.74	1.0652	1.95	2.71	Round
Mean Selec.	666.46	70.67	93.29	1.0757	3.05	2.67	
Mean controls	397.72	52.76	72.26	1.0645	3.16	2.40	
Overall mean	503.73	59.19	83.58	1.0737	4.11	2.41	
CV (%)	33.67	25.42	19.85	0.53	373.66	23.07	

The best clones exhibited yields greater than overall mean in most of the environments (Figure 2). Those that proved to be highly productive may be called "filled ball" clones since the line of the graph which corresponds to the genotype in question is above the mean value, in all the environments.

The rank summation indexes for 'fresh' and 'industrial' potatoes allowed similar selection gains for production of large potatoes (43%). Barbosa & Pinto (1998) showed that the selection index proposed by Mulamba & Mock (1978) is recommended for use in potato breeding programs, allowing excellent gains from selection. The 'fresh' index proved to be efficient for selection of clones for use in the fresh market. In addition to the significant gain for production of large tubers, this index obtained the greatest gain for general tuber appearance (9%).

For the 'industry' index, in addition to the significant gain for production of large potatoes, the specific gravity varies from 1.0736 to 1.0784. This result is interesting, mainly for selection in environments with high temperatures. It is important that all the traits be improved together so that the new population is nearer to that which is desired.

In general, the rank summation index (fresh and industry potatoes) was efficient in selecting genotypes. There were satisfactory gains for all the characteristics, including production of large tubers, specific gravity and general tuber appearance, characteristics which are of great importance for the market. The different weights stipulated in the method of the rank summation index allowed the selection of clones suitable for both culinary use (cooking or frying) and in the pre-fried and chip industry.

The recommendation of clones for these different types of market depends a great deal on the shape of the tubers.

Long and oval tubers are generally recommended for the fresh market and for use in the frozen pre-fried industry. For the chip industry, it is necessary that the tubers have a round shape (Table 2).

The performance of some genotypes for all the agronomical important characteristics is shows in Figure 3. Each extremity of the graph corresponds to a characteristic and those clones that show best performance have a place above the mean value of the treatments. They may be called "filled ball" clones because they went beyond the mean value in all the characteristics. It is also possible to visualize the performance of the controls and compare them with the mean value of the treatments.

Thus, it was possible to identify clones to be used as parents in the potato breeding, and formation of a new population for the purpose of accumulating favorable alleles and, in the future, extract superior genotypes with heat tolerance.

In order for these clones to be recommended for the fresh market, it is necessary that they have characteristics that classify them as multiuse potatoes, therefore, they must be suitable for use for both cooking and frying. Another market requirement is that clones for this purpose must have a long or oval shape and general tuber appearance, such as smooth skin and shallow eyes. The clones SR2 35-05 and CBM 4-48 fit within these requirements because they are clones with a long shape, have specific gravity near 1.0660, have yields well above those of the controls, are highly stable and have good general tuber appearance (Table 2).

For industry use, as production of frozen pre-fried potatoes, it is necessary that the tubers have high dry matter content of the tubers (high specific gravity) for the purpose of reducing oil consumption and providing for greater crispiness. Another demand for use in the pre-fried industry is the shape of the
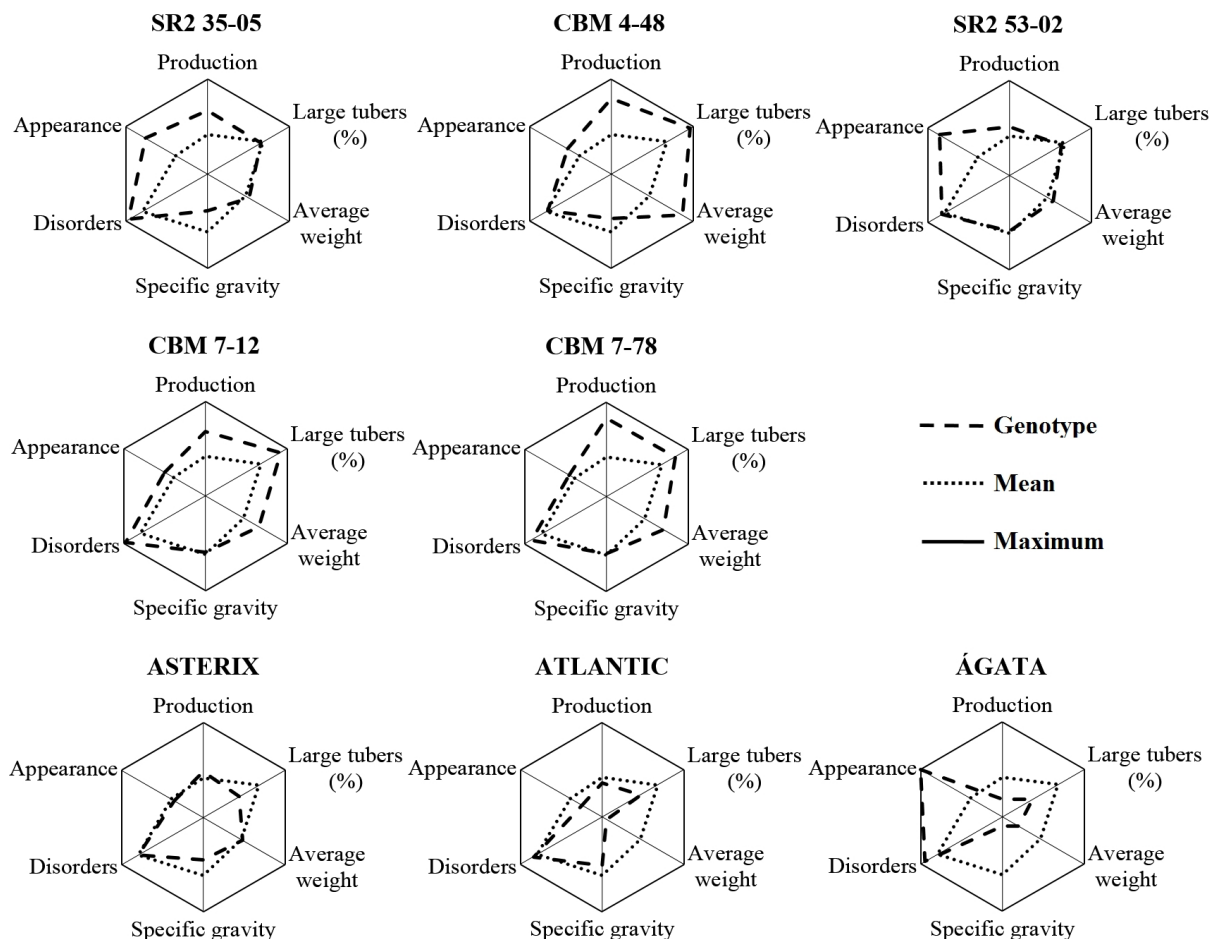
Figure 3. Mean behavior of the clones recommended for use in the fresh potato market and use in the chip and frozen pre-fried industry for the following characteristics of the tubers: production, percentage of large tubers, average weight, specific gravity, percentage of physiological disorders and appearance of the tubers in six experiments conducted in the southern region of Minas Gerais State, Brazil

tubers, which must be long, since the final product is fried sticks. A clone that fits within these requirements is SR2 53-02, with high specific gravity, average weight of the tubers near 88 g and long shape (Table 2).

For chip production, the industry requires clones that, in addition to having high dry matter content of tubers, have tubers with a rounded shape. The clones CBM 7-12 and CBM 7-78 can be recommended for this purpose because in addition to having a rounded shape and specific gravity near 1.0740, they were highly stable and productive.

Figures 2 and 3 exhibit a comparison between the performance of the clones cited and some cultivars commonly used by producers. It may be seen that all the clones selected are very promising as parent varieties for use in plant breeding and that some are suitable for introduction in value of cultivation and use (VCU) testing to be registered as new cultivars.

Conclusions

The clone x environment interaction was expressive, showing that selection for heat tolerance should be performed in the greatest number of environments possible.

Clones that are stable at high temperatures, and responsive under mild conditions, were identified, and thus they may be used as parent varieties in breeding programs targeting heat tolerance.

The clones SR2-3505 and SR2 53-02 were highly productive and stable and may, in the future, be recommended for the fresh market and pre-fried cultivars, respectively.

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