Combining Ability of Potato Genotypes for Cool and Warm Seasons in Brazil

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ABSTRACT

This study was carried out to identify potato cultivars with high combining abilities for heat tolerance and to get information about the individual performance of clones originated from crosses between heat-tolerant and heat-sensitive parents. Twenty six clonal families and more than 600 clones were assessed in warm and cool seasons in Brazil. High temperatures decreased tuber number and weight , resulting in 46% reduction in tuber yield. Furthermore, there was an eight-fold increase in tuber physiological disorders and a remarkable reduction in tuber specific gravity. General combining ability (GCA) x seasons and specific combining ability (SCA) x seasons interactions were significant for most traits, indicating that the best parents and families for the warm season were not the same for the cool season. However, as these interactions represented the average behavior of a large number of parents and families , it was possible to identify some outstanding parents and families for both seasons. Genetic variances among and within families showed that it is possible to obtain superior clones.

INTRODUCTION

The potato crop has spread widely in the tropical and subtropical regions of the world. However, due to its adaptation to temperate climates, it has faced many problems in warmer environments. The optimum average temperature for potato growth and production is between 10°C and 20°C (Antunes and Fortes, 1981), and the best temperature for tuber formation for most commercial cultivars is just over 15.5°C (FAO, 1991). Fontes and Finger (1999) recommended an environment which provides a large number of light hours, day temperatures between 18 and 23°C, cool nights and a minimum of day hours with temperatures above 25° as ideal for potato cultivation.

High temperatures can affect potato production in several ways: i) general reduction in plant development, mainly by reducing the photosynthesis ability and increasing respiration losses (Wolf et al., 1990; Prange et al., 1990; Reynolds et al., 1990); ii) increase in the partitioning of biomass to the aerial plant parts in detriment of roots, stolons and tubers (Sarquís et al., 1996; Van Dam et al., 1996); iii) delay in tuberization, reducing tuber growth rate by shortening the period of photosynthates accumulation (Manrique et al., 1989; Prange et at., 1990; Menezes et al., 1999). Besides these factors, there is also an increase in the percentage of tubers' physiological disorders (cracking and second growth) which affects tubers appearance and reduces their commercial acceptance (Menezes et al., 1999).

In Brazil, more than 50% of the potato crop is carried out in the warm season (September – January), about 30% in the dry season (February – April) and approximately 20% in the cool season (May – August) (Camargo Filho and Mazzei, 1996). Although cropping in these periods is concentrated in the cooler southern states and in high altitude regions of the southeastern states, temperatures above 25°C frequently occur, resulting in low yields and poor tuber quality.

Potato breeding for heat tolerance is relatively new throughout the world and in Brazil very few studies have been done (Neves et al., 1998;

Flori and Resende, 2000). Menezes et al. (1999) have studied the adverse effects of high temperatures on potato development in Brazil, including genotypes DTO 28, LT 7, LT 8 and LT 9 released as heat tolerant by CIP (Centro Internacional de la Papa). The authors detected that even in the heat tolerant genotypes, high temperatures reduced tuber yield by 25.5%, mainly due to delay in the tuberization and to a smaller partitioning of photo-assimilates to the tubers. They also observed a reduction in tuber dry matter content and an increase in tuber cracking and second any growth.

Although the understanding of the genetic control of heat tolerance is limited, genetic variability for this trait in potato has been reported and investigated by various authors (Sekioka et al., 1974; Levy, 1984; Susnoschi et al., 1987, 1988).

The present study was carried out to identify potato cultivars with high combining ability for heat tolerance, obtain data on the genetic control of this trait and study the performance of clones derived from crosses between heat tolerant and susceptible parents.

MATERIALS AND METHODS

Twenty hybrid combinations (families) between heat tolerant (group 1) and susceptible (group 2) genotypes, three combinations within group 1 and three combinations within group 2, were assessed in four experiments. Each family was represented by about thirty randomly chosen clones. The experiments in the warm season (November to February) were set up in Lavras and Maria da Fé, State of Minas Gerais, in 1996/97 and 1997/98, respectively, while in the cool season (May to August) experiments were carried out in Lavras and Alfenas, Minas Gerais, in 1996/97 and 1997/98, respectively. A randomized complete block design with three replications was used. Cultivars Achat and Baraka were used as controls. In the experiment of Maria da Fé, cv. Monalisa was used as control instead of Baraka. Treatments were distributed in three-row plots with ten plants spaced at 0.30m x 0.80m between plants within rows and between rows, respectively. Each plant was derived from a different clone.

Two other experiments, one in the cool (May to August 1998) and the other in the warm (November 1998 to March 1999) season, were carried out in Lavras to assess the clone individual performances. An augmented block design (Federer, 1956) with 698 clones (regular treatments), consisting on average of 26 clones from each family and two controls (common treatments: Achat and Baraka) was used for the cool season experiment. Treatments were distributed in 48 blocks, each one containing on average 15 regular treatments and the two controls.

In the warm season 603 clones were assessed together with Achat and Baraka as controls, using a randomized complete block design with two replications. The plots consisted of a single row, with five plants spaced at 0.35m x 0.80m between plants within rows and between rows, respectively.

Considering the set of six experiments using the clonal families, diallel analyses were performed to estimate the general combining abilities (GCA) of the parents and specific combining abilities (SCA) of the hybrid combinations. GCA and SCA effects were estimated using least squares according to Ramalho et al. (2000). Clones were classified and selected according to the sum of ranks index proposed by Mulamba and Mok (1978).

RESULTS

Cool season

The cool season experiments were carried out under mild temperatures which varied from 12.1°C to 26.6°C. In Lavras, about 35% of the growing season had temperatures below 15°C, 35% with temperatures between 15°C and 20°C, 23% with temperatures between 20°C and 25°C and only 7% with temperatures above 25°C.

Significance among family means were detected for all traits, and a wide diversity was observed within families. However, significance for all traits was only observed among clones within the CBM 3 family (DTO 28 x Itararé). Broad sense heritabilities were high (>0,50) for all traits and were always greater among families than among clones.

The family sum of squares in the diallel analysis was partitioned into GCA and SCA. In the family experiments, SCA effects predominated for all traits in Alfenas-98, and for tuber yield and percentage of large tubers (diameter > 45 mm) in Lavras-97. GCA effects predominated in all other cases.

The GCA estimates for the three cool season experiments were not consistent, since there were parents showing positive GCA estimates in one experiment and negative in others (Table 1). For example, LT 7 and EPAMIG 76-0580 parents showed high and positive effects for tuber yield in Lavras-98 and high negative values in Alfenas-98. For tuber yield, DTO 28 clone and cv. Aracy showed significant and positive effects on Alfenas-98, and non-significant on the other two experiments. However, clone DTO 28 contributed to the increase in the percentage of tuber cracking in its hybrids.

The parents with the best GCA estimates for tuber specific gravity were LT 7 and cv. Baronesa, which had high and positive estimates in two experiments. Clone LT 7 also contributed favorably to the increase in the percentage of large tubers (Table 1). Cultivar Desirée, considered heat tolerant (Levy, 1984), contributed to the reduction in the percentage of large tubers and tuber specific gravity (Table 1).

The families with greater SCA estimates for tuber yield were CBM 7 (LT 7 x EPAMIG 76-0580)), CBM 3 (DTO 28 x Itararé) and CBM 1 (LT 8 x Aracy). It should be pointed out also that parents LT 7 and DTO 28 and cv. Aracy had high GCA estimates for this trait. Family CBM 3 had the disadvantage of presenting a high percentage of tuber cracking (Table 2).

In spite of the reasonable magnitude of the determination coefficients SCA for the percentage of large tubers, only family CBM 17 (LT 7 x Itararé) showed positive estimates in all three cool season experiments.

Table 2 shows the means of the clonal families in the three cool season experiments. The Scott and Knott test (1974) was applied to compare the means in each experiment separately. Several families were superior to the control cultivar (Achat) for tuber yield and tuber specific gravity. The control cultivar Baraka had low tuber yield in Lavras-97, showing better performance in the other two experiments.

Family means were not consistent over the three experiments. The CBM 7 (LT 7 x EPAMIG 76-0580) and CBM 4 (Baronesa x LT 7) families showed good tuber yields in Lavras, but did not repeat the good performance in Alfenas, where several other families showed greater tuber yield. Similarly, the CBM 1 (LT 8 x Aracy), CBM 11 (Itararé x Aracy), CBM 21 (EPAMIG 76-0526 x Desirée) and CBM 24 (DTO 28 x LT 9) families, which were among the highest yielding in Lavras-97 and Alfenas-98, did not repeat the good performance in Lavras-98. The CBM 3 (DTO 28 x Itararé), CBM 5 (DTO 28 x Desirée), CBM 6 (Baraka x LT 7), CBM 7 (LT 7 x EPAMIG 76-580) and CBM 16 (LT 7 x EPAMIG 76-526) families were among the highest yielding in all three experiments. Also, the CBM 6 (Baraka x LT 7) and CBM 7 (LT 7 x EPAMIG 76-580) along with CBM 4 (Baronesa x LT 7) and CBM 24 (DTO 28 x LT 9) families presented a high percentage of large tubers.

Table 1 - Estimates of general combining abilities (GCA) for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, in three experiments carried out in the cool season.

	Parents	Tuber yield/plant (g)			Large tubers (%)			Tuber specific gravity ($x 10^{-4}$)			Tuber second growth/1 (%)			Tuber cracking/1 (%)		
		Lavras97	Alfenas98	Lavras98	Lavras97	Alfenas98	Lavras98	Lavras97	Alfenas98	Lavras98	Lavras97	Alfenas98	Lavras98	Lavras97	Alfenas98	Lavras98
Group 1	LT 7	67,150	-61,384**	98,828**	2,112	4,851**	7,199**	0,739**	-0,118	0,694**	-0,223	0,385**	-0,002**	-0,368*	0,061	-0,007**
	LT 8	-69,755	23,301	-103,762**	-0,068	4,384	-7,702*	-0,243	-0,208	-0,081**	-0,371	-0,352*	0,008**	0,217	0,480**	-0,001
	LT 9	-137,803*	-6,544	-24,507	-0,967	3,132	-5,403	-0,104	-0,276*	-1,052**	-0,259	-0,328*	-0,012**	-0,451	0,237*	-0,003**
	DTO 28	84,492	56,327*	30,647	2,896	-2,994	13,042**	-0,081	0,531**	0,010**	-0,251	-0,234	0,001	1,223**	-0,283**	0,017**
	Desireé	-29,549	23,181	-82,687**	-5,289*	-9,920**	-14,012**	-0,769**	0,008	-0,202**	1,059**	0,166	0,005**	-0,495*	-0,345**	-0,004**
Group 2	Aracy	-28,570	54,964*	10,802	-1,171	2,099	-4,019	0,099	-0,026	-0,040**	-0,396*	0,162	-0,009**	-0,595**	0,012	-0,013**
	Baraka	9,520	26,320	18,408	2,870	-1,771	5,392	-0,412	0,195	0,206**	0,162	0,125	0,001	0,034	-0,317**	-0,004**
	Baronesa	-61,676	-9,510	-30,201	0,205	7,197**	-6,334	0,740**	-0,192	0,531**	-0,279	-0,250	0,007**	-0,933**	0,266*	-0,001
	EP 526	71,118	-3,185	3,868	0,457	-0,616	-2,530	-0,343	-0,180	-0,530**	0,095	-0,225	0,001	0,434	0,107	-0,002
	EP 580	58,442	-63,876*	58,566**	-0,076	-6,790**	3,976	0,013	0,345**	-0,044**	0,512**	0,137	0,004**	0,277	-0,158	0,012**
	Itararé	-58,791	-1,742	-84,565**	-1,870	1,445	3,529	-0,136	-0,249*	-0,094**	-0,132	-0,049	-0,001	0,890**	0,139	0,009**

**,* Significant at the 1 and 5% level of probability by the teste F, respectively.
/1 Data transformed to $\sqrt{x + 1}$

In general, families had low tuber specific gravity means, indicating that tubers are not suitable for processing as fried products. Tubers with a minimum dry matter content of 20.5%, which corresponds to a density of 1.075, are recommended for the potato processing industry in Brazil (Melo, 1999). The CBM 2 (LT 7 x Aracy), CBM 4 (Baronesa x LT 7), CBM 6 (Baraka x LT 7) and CBM 8 (Baronesa x DTO 28) families were among the highest for tuber specific gravity, in Lavras, but did not show similar performance in Alfenas.

The performances of the thirty best clones in the cool season are shown in Table 3. All clones were superior to the control cultivars Achat and Baraka in tuber yield and tuber specific gravity. The CBM 6 (Baraka x LT 7) and CBM 7 (LT 7 x EPAMIG 76-0580) families had the greatest number of high yielding clones (five clones). The LT 7 clone was among the 66.7% superior materials. Some clones were superior in tuber yield and also in tuber specific gravity. The CBM 16.16, CBM 6.25 and CBM 2.16 clones attained yields over 900.0 g per plant, more than 76% of large tubers and tuber specific gravity as high as 1.0880. All clones presented negligible percentage of tuber physiological disorders (Table 3).

Warm season

The warm season experiments were carried out under higher temperatures, which varied from 17.3ºC to 28°C. In Lavras, no below 15ºC temperature was recorded during the growing period. In 38% of the time ,temperatures were between 15°C and 20°C, in 39% between 20°C and 25°C, and in 23% above 25°C.

Significant differences were detected among families means and among clones for all the assessed traits, indicating the possibility of selecting superior clones. High heritability estimates were obtained at the family level for tuber yield, percentage of large tubers and tuber specific gravity. Partitioning of family sum of squares showed the presence of wide variability, mainly for tuber yield, percentage of tuber cracking, percentage of tuber second growth and tuber specific gravity.

GCA effects for group 1 were significant for all traits in all diallel analyses, while the GCA for group 2 and SCA variance estimates were

Table 2 - Family means for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders in experiments carried out in the cool season.

Families	Tuber yield/plant (g)[/1]				Large tubers (%)[/1]				Tuber specific gravity[/1]				Tuber second growth (%)[/1]				Tuber cracking (%)[/1]			
	Lav97*	Alf98	Lav98	Mean	Lav97	Alf98	Lav98	Mean	Lav97	Alf98	Lav98	Mean	Lav97	Alf98	Lav98	Mean	Lav97	Alf98	Lav98	Mean
CBM 1	813a	862a	524d	733	82a	78a	36c	65	1,073b	1,066c	1,074c	1,071	1,73b	1,01c	0,02a	0,92	0,95c	5,00a	0,11a	2,02
CBM 2	651b	638b	647c	645	84a	54b	57b	65	1,077b	1,065c	1,082a	1,075	3,04b	7,29a	0,01a	3,45	1,93c	0,23c	0,01a	0,72
CBM 3	829a	801a	614c	748	85a	50b	71a	69	1,071c	1,071b	1,063e	1,068	4,73b	0,37c	0,00a	1,70	33,66a	0,00c	0,00a	11,22
CBM 4	804a	607b	657c	689	92a	65a	65a	74	1,091a	1,064c	1,079b	1,078	1,62b	1,76c	0,02a	1,13	1,00c	2,18b	0,01a	1,06
CBM 5	730a	811a	598c	713	87a	55b	51b	64	1,070c	1,070b	1,065e	1,068	5,16b	1,42c	0,04a	2,21	12,49b	0,48c	0,02a	4,33
CBM 6	789a	735a	704b	743	82a	64a	64a	70	1,078b	1,065c	1,075c	1,072	4,33b	6,53a	0,07a	3,64	3,58c	0,49c	0,07a	1,38
CBM 7	1037a	597b	816a	817	84a	69a	67a	73	1,081b	1,069b	1,070d	1,073	6,24a	2,45b	0,02a	2,90	3,78c	0,95c	0,01a	1,58
CBM 8	760a	653b	588c	667	85a	55b	53b	64	1,077b	1,069b	1,075c	1,074	2,38b	2,88b	0,02a	1,76	0,76c	1,02c	0,00a	0,59
CBM 9	632b	753a	525d	637	87a	71a	52b	70	1,063c	1,060d	1,064e	1,063	3,76b	0,93c	0,00a	1,56	1,99c	1,90b	0,06a	1,32
CBM 10	631b	675b	483d	596	70b	47c	47b	55	1,063c	1,063c	1,069d	1,065	7,70a	4,44a	0,02a	4,05	0,78c	0,15c	0,02a	0,32
CBM 11	811a	901a	535d	749	73b	70a	63a	68	1,078b	1,069b	1,071d	1,073	7,46a	0,17c	0,01a	2,55	3,71c	2,27b	0,00a	1,99
CBM 12	685b	570b	503d	586	82a	34c	48b	55	1,065c	1,075a	1,061f	1,067	12,44a	2,28b	0,02a	4,91	3,10c	0,00c	0,00a	1,03
CBM 13	631b	875a	587c	698	80b	62a	69a	70	1,070c	1,077a	1,069d	1,072	10,42a	0,83c	0,00a	3,75	6,81b	0,15c	0,00a	2,32
CBM14	552b	818a	330e	567	71b	58b	42c	57	1,065c	1,064c	1,062f	1,064	1,93b	4,17a	0,02a	2,04	4,77c	0,00c	0,00a	1,59
CBM 15	572b	991a	553d	705	83a	69a	70a	74	1,071c	1,076a	1,066e	1,071	1,46b	1,74c	0,01a	1,07	14,81b	0,26c	0,01a	5,03
CBM 16	708a	635b	710b	684	77b	52b	63a	64	1,073b	1,065c	1,070d	1,069	2,08b	1,48c	0,01a	1,19	2,47c	0,68c	0,00a	1,05
CBM 17	567b	651b	356e	525	85a	72a	69a	75	1,077b	1,063c	1,072d	1,071	3,20b	2,45b	0,00a	1,88	7,89b	2,50b	0,05a	3,48
CBM 18	633b	887a	498d	673	81a	57b	75a	71	1,072b	1,069b	1,069d	1,070	0,55b	0,22c	0,00a	0,26	7,09b	0,00c	0,00a	2,36
CBM 19	548b	659b	457d	555	86a	44c	65a	65	1,067c	1,075a	1,065e	1,069	4,09b	0,14c	0,00a	1,41	7,35b	0,00c	0,00a	2,45
CBM 20	508b	663b	588c	586	80b	59b	51b	63	1,074b	1,064c	1,039g	1,059	1,64b	1,60c	0,05a	1,10	2,21c	1,29c	0,04a	1,18
CBM 21	896a	745a	473d	704	85a	44c	35c	55	1,064c	1,061d	1,060f	1,062	14,55a	2,55b	0,02a	5,71	7,02b	0,25c	0,01a	2,43
CBM 22	567b	695b	561d	608	77b	46c	57b	60	1,073b	1,072b	1,069d	1,071	6,95a	1,57c	0,00a	2,84	3,79c	0,54c	0,12a	1,48
CBM 23	455b	844a	371e	556	68b	67a	40c	58	1,069c	1,065c	1,070d	1,068	9,26a	0,46c	0,00a	3,24	2,77c	0,48c	0,00a	1,08
CBM 24	704a	816a	505d	675	91a	62a	73a	75	1,075b	1,073b	1,069d	1,072	0,69b	0,45c	0,00a	0,38	12,26b	0,30c	0,00a	4,19
CBM 25	813a	743a	536d	697	85a	67a	72a	75	1,069c	1,072b	1,062f	1,067	2,98b	0,76c	0,00a	1,25	16,85b	1,04c	0,02a	5,97
CBM 26	550b	680b	455d	561	79b	57b	52b	63	1,067c	1,057d	1,062f	1,062	4,34b	3,07b	0,01a	2,47	8,36b	1,74b	0,04a	3,38
Achat	645b	583b	491d	573	78b	54b	55b	62	1,063c	1,060d	1,064e	1,062	0,54b	0,18c	0,00a	0,24	1,11c	2,88b	0,00a	1,33
Baraka	348b	746a	650c	582	76b	76a	83a	78	1,066c	1,062d	1,068d	1,065	0,48b	0,51c	0,00a	0,33	2,13c	0,62c	0,01a	0,92
Grand mean	674	737	547	653	81	59	59	66	1,072	1,067	1,067	1,069	4,49	1,92	0,01	2,14	6,27	0,98	0,02	2,42
CV (%)	26,01	13,51	32,64		8,67	11,61	32,7		0,55	0,30	0,49		30,01	24,71	0,77		30,40	22,75	3,19	

/1 In each column, values followed by the same letter are not significantly different at the 5% probability level (Scott and Knott, 1974)

/2 Lav97: Lavras 1997; Alf98: Alfenas 1998; Lav98: Lavras 1998.

variable. Unlike the cool season performance, GCA effects prevailed over SCA for all traits, indicating that selection of high GCA parents should be worth to obtain a population for extraction of heat-tolerant clones. However, the SCA effects accounted for at least 30% of the variation among the family means for tuber yield and should not be disregarded. For the other traits, choice of parents is easier because the SCA estimates were lower.

Parents DTO 28, LT 9, Aracy and EPAMIG 76-0526 had significant and positive GCA estimates for tuber yield in one experiment and significant but negative in another (Table 4). The only exception was clone LT 7, which contributed favorably to increase tuber yield in Lavras-98, and showed positive but non significant estimates in the other two. This parent, together with LT 9, DTO 28 and Itararé contributed to increase the percentage of large tubers in their crosses.

Contrary to the cool season, the GCA estimates for tuber specific gravity were more consistent (Table 4). Parents LT 7, Aracy and Baronesa contributed significantly to increase tuber specific gravity and reduce the percentage of tuber cracking of their hybrids. LT 7 and Aracy contributed further to the reduction in the percentage of tuber second any growth.

The CBM 2 (LT 7 x Aracy), CBM 3 (DTO 28 x Itararé), CBM 4 (Baronesa x LT 7) and CBM 7 (LT 7 x EPAMIG 76-0580) families presented tuber yield either equal or superior to the control cultivars in all three experiments (Table 5). In general, tuber specific gravity was very low, and the CBM 2 (LT 7 x Aracy) and CBM 4 (Baronesa x LT 7) families performed better than the others. A very high percentage of tuber physiological disorders was obseved at this planting time. Control cultivars Achat and Baraka had a high proportion of tuber cracking and secundary growth in Lavras-98. In the other two experiments, no family was better than the controls. Among the highest yielding, the CBM 1 (LT 8 x Aracy), CBM 2 (LT 7 x Aracy) and

Table 3 - Means for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, of the best cool season clones. Lavras - Mg, jun/1998.

Clones	Tuber yield/ plant (g)	Large tubers (%)	Tuber specific gravity	Tuber second growth (%)	Tuber cracking (%)
CBM 6.19	1666,51	76,57	1,0767	0,03	0,00
CBM 7.16	1383,17	91,02	1,0755	0,00	0,02
CBM 6.26	1373,38	87,15	1,0748	0,00	0,00
CBM 16.16	1369,01	76,59	1,0887	0,00	0,00
CBM 6.25	1350,01	88,38	1,0896	0,00	0,00
CBM 7.27	1206,51	79,30	1,0749	0,00	0,00
CBM 8.3	1177,71	88,02	1,0754	0,00	0,00
CBM 13.7	1153,81	78,62	1,0790	0,00	0,00
CBM 14.16	1073,81	93,18	1,0743	0,00	0,00
CBM 7.12	1051,51	100,00	1,0773	0,00	0,00
CBM 16.4	1030,67	93,10	1,0794	0,03	0,00
CBM 11.26	994,84	70,63	1,0778	0,07	0,00
CBM 11.12	983,81	87,40	1,0744	0,00	0,00
CBM 2.16	963,81	90,55	1,0952	0,00	0,00
CBM 7.5	899,01	96,45	1,0706	0,00	0,00
CBM 17.26	894,63	95,73	1,0775	0,00	0,08
CBM 1.13	871,51	96,26	1,0746	0,00	0,00
CBM 3.16	871,51	91,29	1,0705	0,00	0,50
CBM 4.23	869,01	100,00	1,0836	0,04	0,00
CBM 2.15	839,01	68,23	1,0841	0,00	0,00
CBM 22.7	837,56	86,03	1,0831	0,00	0,00
CBM 7.20	828,18	98,38	1,0741	0,00	0,00
CBM 4.8	824,01	82,25	1,0749	0,00	0,00
CBM 2.6	815,26	96,20	1,0838	0,00	0,00
CBM 23.30	811,51	90,34	1,0772	0,09	0,00
CBM 6.6	805,88	92,02	1,0714	0,00	0,00
CBM 6.4	790,26	90,42	1,0822	0,00	0,00
CBM 17.11	779,01	84,38	1,0914	0,00	0,00
CBM 8.5	771,51	92,17	1,0838	0,00	0,00
CBM 4.12	764,01	100,00	1,0843	0,00	0,00
Achat	490,71	54,63	1,0635	0,00	0,00
Baraka	650,20	82,89	1,0679	0,00	0,01
Overall mean	545,14	57,90	1,0673	1,00	1,00

CBM 4 (Baronesa x LT 7) families had the lowest incidence of tuber cracking.

All selected clones based on the Mulamba and Mok (1978) index had a better performance than cv. Achat, which is very sensitive to high temperatures, and cultivar Baraka, which is a less sensitive cultivar (Table 6). In spite of the very high temperatures recorded during the warm season, tuber yields of some clones were good. Some of them produced a high percentage of large tubers (Table 6). However, the tuber specific gravity means were very low, showing the difficulties in selecting high yielding clones with adequate specific gravity in the warm season.

Among the highest yielding clones, those with the highest specific gravity were CBM 3.26, CBM 4.23 and CBM 2.9 which performed considerably better than the control cultivars (Table 6). LT 7 was parent of 53.3% of the best clones and DTO 28 in the 36.7% .

Table 4 - Estimates of general combining abilities (GCA) for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, in three experiments carried out in the warm season.

	Parents	Tuber yield/plant (g)			Large tubers (%)			Tuber specific gravity (x 10^{-4})			Tuber second growth (%)[1/]			Tuber cracking (%)[/1]		
		Lav 96[2/]	MF 97	Lav 98	Lav 96	MF 97	Lav 98	Lav 96	MF 97	Lav 98	Lav 96	MF 97	Lav 98	Lav 96	MF 97	Lav 98
Group 1	LT 7	14,980	17,840	33,808**	0,312	1,785	3,563*	0,670**	0,388**	0,314**	-0,382**	-0,226*	-0,306*	-0,687**	-0,370	-0,296**
	LT 8	-13,977	29,598	-1,719	-1,116	-0,138	-5,882*	-0,134	0,059	0,136	-0,192	-0,027	0,183	0,014	-0,116	-0,013
	LT 9	-51,120**	113,500**	7,777	-3,591	7,007**	2,658	-0,300*	0,394**	-0,127	-0,553*	0,178	-0,077	-0,211	-0,021	-0,105
	DTO 28	40,714**	-91,655**	25,463*	5,784*	5,826**	4,432*	-0,291*	-0,543**	-0,297**	0,042	-0,168	-0,227	1,729**	1,332**	1,161**
	Desireé	-14,362	-42,429	-80,719**	-2,722	-13,654**	-7,358**	-0,388**	-0,378**	-0,180**	1,089**	0,394**	0,606**	-0,552	-0,674*	-0,628**
Group 2	Aracy	46,687**	23,559	-25,193*	0,229	-0,435	-1,276	0,406**	0,380**	0,296**	-0,616**	-0,155	-0,143	-0,553*	-0,652*	-0,456**
	Baraka	-41,424*	6,811	10,749	1,756	3,971	4,031	-0,478**	-0,426**	-0,364**	0,382	-0,195	0,114	0,902*	0,442	0,388*
	Baronesa	-32,934	24,530	8,147	-0,699	0,292	-0,282	0,434**	0,668**	0,479**	0,275	0,193	-0,003	-0,710*	-0,807*	-0,636**
	EP 526	22,591	-67,964*	45,123**	-7,068	-13,951**	-2,518	-0,383	-0,643**	-0,176*	0,133	-0,098	0,118	-0,783*	-0,120	0,043
	EP 580	-25,120	-31,550	-21,955	-2,966	-0,434	-1,826	0,011	-0,221**	-0,137*	0,123	0,158	0,066	0,244	0,267	0,221
	Itararé	23,010	47,278	-1,154	9,659	10,847**	2,905	-0,129	0,189	-0,151*	-0,132	0,096	-0,125	1,004**	0,988**	0,519**

* *, * Significant at the 1 and 5% for the test F, respectively.
[1/] Data transformed to $\sqrt{x+1}$
[2/] Lav96: Lavras 1996; MF97: Maria da Fé 1997; Lav98: Lavras 1998.

Table 5 - Family means for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, in three experiments carried out in the warm season.

Families	Tuber yield/plant (g)[1]				Large tubers (%)[1]				Tuber specific gravity[1]				Tuber secundary growth (%)[1]				Tuber cracking (%)[1]			
	Lav96[2]	MF97	Lav98	Mean	Lav96	MF97	Lav98	Mean	Lav96	MF97	Lav98	Mean	Lav96	MF97	Lav98	Mean	Lav96	MF97	Lav98	Mean
CBM 1	414^{a}	452^{b}	295^{b}	387	58^{a}	54^{b}	42^{b}	52	1,055^{b}	1,058^{a}	1,053^{a}	1,055	11,17^{c}	2,23^{b}	29,14^{c}	14,18	11,85^{b}	0,00^{c}	15,65^{e}	9,17
CBM 2	336^{a}	469^{b}	435^{a}	413	64^{a}	59^{b}	65^{a}	63	1,060^{a}	1,060^{a}	1,057^{a}	1,059	7,84^{c}	1,13^{b}	23,27^{c}	10,75	9,68^{b}	1,37^{c}	17,10^{e}	9,38
CBM 3	448^{a}	367^{b}	416^{a}	410	74^{a}	69^{a}	62^{a}	68	1,046^{c}	1,048^{d}	1,043^{c}	1,046	53,48^{a}	3,59^{b}	16,26^{c}	24,44	16,87^{b}	22,97^{a}	52,51^{b}	30,78
CBM 4	349^{a}	447^{b}	401^{a}	399	60^{a}	55^{b}	59^{a}	58	1,066^{a}	1,063^{a}	1,054^{a}	1,061	9,05^{c}	2,42^{b}	21,54^{c}	11,00	15,16^{b}	1,61^{c}	18,37^{e}	11,71
CBM 5	360^{a}	319^{c}	422^{a}	367	65^{a}	47^{c}	55^{a}	56	1,042^{c}	1,043^{e}	1,039^{c}	1,042	26,28^{b}	2,38^{b}	25,38^{c}	18,01	16,35^{b}	3,75^{c}	42,15^{c}	20,75
CBM 6	311^{b}	249^{c}	334^{b}	298	64^{a}	53^{b}	55^{a}	57	1,056^{b}	1,052^{b}	1,049^{b}	1,052	17,52^{b}	1,51^{b}	26,46^{c}	15,16	25,77^{a}	4,20^{c}	29,36^{d}	19,78
CBM 7	335^{a}	440^{b}	372^{a}	383	58^{a}	49^{c}	57^{a}	54	1,059^{a}	1,053^{b}	1,048^{b}	1,053	10,43^{c}	2,25^{b}	22,35^{c}	11,68	14,88^{b}	2,22^{c}	18,61^{e}	11,90
CBM 8	313^{b}	290^{c}	359^{a}	320	66^{a}	65^{a}	60^{a}	64	1,052^{b}	1,055^{b}	1,056^{a}	1,055	19,60^{b}	3,12^{b}	32,55^{c}	18,42	25,43^{a}	0,72^{c}	14,41^{e}	13,52
CBM 9	207^{b}	666^{a}	422^{a}	432	58^{a}	68^{a}	67^{a}	64	1,041^{c}	1,051^{c}	1,042^{c}	1,045	20,92^{b}	3,86^{a}	25,67^{c}	16,82	12,75^{b}	5,54^{b}	35,39^{c}	17,89
CBM 10	279^{b}	385^{b}	267^{c}	310	66^{a}	50^{c}	51^{b}	56	1,050^{c}	1,051^{c}	1,049^{b}	1,050	15,16^{c}	5,99^{a}	38,10^{b}	19,75	33,53^{a}	4,31^{c}	31,56^{d}	23,13
CBM 11	392^{a}	352^{c}	269^{c}	338	58^{a}	59^{c}	43^{b}	53	1,059^{a}	1,051^{c}	1,042^{c}	1,051	19,29^{b}	5,86^{a}	24,12^{c}	16,42	23,60^{a}	11,99^{b}	43,55^{c}	26,38
CBM 12	344^{a}	307^{c}	243^{c}	298	60^{a}	48^{c}	44^{b}	51	1,046^{c}	1,046^{d}	1,044^{c}	1,045	18,53^{b}	6,88^{a}	40,38^{b}	21,93	30,56^{a}	1,53^{c}	29,22^{d}	20,44
CBM 13	232^{b}	341^{c}	337^{b}	304	58^{a}	71^{a}	51^{b}	60	1,049^{c}	1,047^{d}	1,043^{c}	1,046	23,53^{b}	5,64^{a}	39,14^{b}	22,77	17,46^{b}	18,96^{a}	50,30^{b}	28,91
CBM 14	437^{a}	235^{c}	364^{a}	345	60^{a}	36^{d}	47^{b}	48	1,057^{b}	1,048^{d}	1,045^{c}	1,050	6,79^{c}	5,12^{a}	27,95^{c}	13,29	19,72^{a}	5,86^{b}	40,15^{c}	21,91
CBM 15	268^{b}	258^{c}	431^{a}	319	56^{a}	59^{c}	65^{a}	60	1,048^{c}	1,045^{e}	1,040^{c}	1,044	33,15^{a}	2,20^{b}	14,67^{c}	16,67	4,79^{b}	10,17^{b}	59,54^{b}	24,83
CBM 16	366^{a}	346^{c}	443^{a}	385	49^{a}	48^{c}	54^{a}	50	1,053^{b}	1,049^{d}	1,051^{b}	1,051	5,06^{c}	5,73^{a}	24,92^{c}	11,90	18,84^{a}	0,89^{c}	12,24^{e}	10,66
CBM 17	383^{a}	389^{b}	351^{b}	374	76^{a}	67^{a}	60^{a}	68	1,055^{b}	1,056^{a}	1,045^{c}	1,052	20,57^{b}	1,75^{b}	26,16^{c}	16,16	11,47^{b}	8,36^{b}	39,60^{c}	19,81
CBM 18	411^{a}	304^{c}	344^{b}	353	60^{a}	57^{c}	58^{a}	59	1,054^{b}	1,048^{d}	1,044^{c}	1,049	25,65^{b}	3,12^{b}	19,80^{c}	16,19	11,22^{b}	11,31^{b}	46,70^{c}	23,08
CBM 19	306^{b}	382^{b}	376^{a}	355	62^{a}	59^{c}	55^{a}	59	1,046^{c}	1,048^{d}	1,044^{c}	1,046	27,20^{b}	2,19^{b}	31,40^{c}	20,26	18,62^{a}	7,14^{b}	32,07^{d}	19,28
CBM 20	348^{a}	427^{b}	303^{b}	359	64^{a}	55^{c}	53^{b}	57	1,054^{b}	1,058^{a}	1,048^{b}	1,053	12,07^{c}	3,29^{b}	26,99^{c}	14,12	14,66^{b}	0,67^{c}	19,85^{e}	11,73
CBM 21	359^{a}	262^{c}	307^{b}	310	47^{a}	23^{e}	48^{b}	39	1,045^{c}	1,043^{e}	1,044^{c}	1,044	6,53^{c}	2,28^{b}	30,10^{c}	12,97	26,57^{a}	0,38^{c}	19,17^{e}	15,37
CBM 22	271^{b}	362^{b}	321^{b}	318	49^{a}	60^{c}	54^{b}	54	1,050^{c}	1,055^{b}	1,047^{c}	1,051	15,67^{c}	4,00^{a}	26,72^{c}	15,46	14,43^{b}	7,91^{b}	35,82^{c}	19,39
CBM 23	279^{b}	336^{c}	302^{b}	306	59^{a}	34^{d}	45^{b}	46	1,050^{c}	1,051^{c}	1,046^{c}	1,049	9,42^{c}	7,53^{a}	28,85^{c}	15,27	32,18^{a}	2,72^{c}	23,51^{d}	19,47
CBM 24	326^{a}	331^{c}	437^{a}	364	72^{a}	68^{a}	62^{a}	67	1,047^{c}	1,047^{d}	1,041^{c}	1,045	33,58^{a}	3,52^{b}	12,95^{c}	16,68	7,54^{b}	9,41^{b}	62,65^{a}	26,53
CBM 25	382^{a}	187^{c}	422^{a}	331	70^{a}	41^{c}	55^{a}	55	1,045^{c}	1,039^{f}	1,040^{c}	1,041	26,42^{b}	1,63^{b}	31,72^{c}	19,92	21,82^{a}	17,65^{a}	50,72^{b}	30,06
CBM 26	216^{b}	370^{b}	347^{b}	311	59^{a}	48^{c}	50^{b}	52	1,050^{c}	1,048^{d}	1,047^{b}	1,048	17,06^{b}	4,63^{a}	27,96^{c}	16,55	20,82^{a}	6,37^{b}	40,37^{c}	22,52
Achat	203^{b}	429^{b}	219^{c}	284	33^{a}	40^{c}	0^{c}	24	1,056^{b}	1,048^{d}	1,027^{e}	1,044	8,73^{c}	2,52^{b}	75,00^{a}	28,75	9,36^{b}	0,51^{c}	75,00^{a}	28,29
Baraka	398^{a}	-	338^{b}	368	52^{a}	-	70^{a}	61	1,050^{c}	-	1,033^{d}	1,042	9,56^{c}	-	24,43^{c}	17,00	9,13^{b}	-	55,68^{b}	32,40
Monalisa	-	364^{b}	-	364	-	62^{c}	-	62	-	1,048^{d}	-	1,048	-	0,95^{b}	-	0,95	-	5,49^{b}	-	5,49
Grand mean	331	360	359	350	60	54	55	56	1,051	1,050	1,046	1,049	18,22	3,48	28,36	16,68	17,68	6,13	36,12	19,98
CV (%)	17.32	21.79	38.43		15.41	11.70	38.36		0.37	0.24	0.84		16.41	26.65	45.54		22.65	22.04	37.55	

[1/] In each column, values followed by the same letter are not significantly different at the 5% level of probability (Scott and Knott, 1974).
[2/] Lav96: Lavras 1996; MF97: Maria da Fé 1997; Lav98: Lavras 1998.

Table 6 - Means for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, of the best warm season clones. Lavras, 1998.

Clones	Tuber yield/ plant (g)	Large tuber (%)	Specific gravity	Tuber second growth (%)	Tuber cracking (%)
CBM 16.15	950,00	67,11	1,0522	11,74	17,14
CBM 15.6	812,50	78,54	1,0495	6,16	12,51
CBM 8.11	806,25	78,97	1,0594	22,11	22,87
CBM 5.26	765,63	84,62	1,0453	11,30	17,79
CBM 24.13	758,34	83,62	1,0442	3,34	36,67
CBM 2.1	750,00	83,55	1,0577	10,90	36,52
CBM 24.6	743,75	81,31	1,0567	5,26	50,00
CBM 13.25	737,50	91,67	1,0530	17,42	55,43
CBM 15.25	703,13	87,14	1,0455	4,76	28,03
CBM 2.20	700,00	80,95	1,0528	2,50	27,50
CBM 2.21	693,75	83,80	1,0665	12,13	13,70
CBM 16.16	675,00	75,19	1,0545	37,78	7,69
CBM 9.18	662,50	95,08	1,0487	6,25	50,00
CBM 7.12	659,38	82,41	1,0562	5,57	3,57
CBM 8.3	643,75	75,05	1,0596	19,57	4,35
CBM 3.26	643,75	68,42	1,0709	5,62	1,62
CBM 16.8	641,67	59,95	1,0573	3,57	2,18
CBM 8.20	609,38	77,65	1,0590	4,00	13,50
CBM 4.28	609,38	75,42	1,0663	22,42	11,55
CBM 4.23	608,34	56,45	1,0679	18,26	0,00
CBM 19.11	606,25	74,43	1,0537	2,78	13,89
CBM 8.27	587,50	81,98	1,0527	22,42	18,42
CBM 17.19	562,50	75,93	1,0523	0,00	18,75
CBM 2.29	556,25	76,20	1,0581	8,34	20,84
CBM 2.19	554,17	83,27	1,0507	11,27	15,61
CBM 2.27	528,13	77,31	1,0559	6,93	13,64
CBM 8.13	509,38	88,13	1,0550	30,62	0,00
CBM 6.21	506,25	77,84	1,0621	3,13	34,38
CBM 2.9	493,75	87,97	1,0676	5,88	11,77
CBM 7.18	465,63	77,52	1,0583	2,78	2,78
Achat	218,75	0,00	1,0269	75,00	75,00
Baraka	337,50	69,55	1,0333	24,43	55,68
Overall mean	358,50	54,55	1,0461	28,36	36,12

Joint analysis

The joint analyses of variance included all four experiments with the clonal families but not the experiments with individual clones. There were significant differences, due to seasons, families and families x seasons interaction. Significant differences among the experimental means were observed (Tables 2 and 5), especially when the cool season and warm season experiments were compared. Generally in the warm season there were reductions in tuber yield, percentage of large tubers and tuber specific gravity, and significant increases in tuber physiological disorders.

The families x seasons interaction showed that the family behavior was not consistent in all seasons, that is, the best families in the cool season were not the best under warm conditions. SCA effects were predominant for tuber yield, while GCA effects were larger for the other traits. The families x seasons interaction was partitioned into three components, General Combining Ability of Group 1 (GCA 1) x seasons, General Combining Ability of Group 2 (GCA 2) x seasons and SCA x seasons, and most of them were significant. The exception was GCA 2 x seasons for tuber yield, indicating that crosses involving heat-sensitive parents (Group 2) had similar performance for tuber yield in both seasons. The significance of the GCA 1 x seasons component indicated that the heat-tolerant parents which most contributed to the progeny mean for a given trait were not the same in both seasons. These results corroborate with the GCA and SCA individual analyses estimates, which show fairly inconsistency of magnitude among the experiments, even in a single season.

GCA estimates for tuber yield were non significant for all parents (Table 7). Within group 1, parent DTO 28 contributed to the percentile increase of large tubers and their average weight (not shown), but its families presented high tendency for tuber cracking.

Table 7 - Estimates of general combining abilities (GCA) for tuber yield, percentage of large tubers, tuber specific gravity and physiological disorders, in experiments performed in the warm and cool seasons.

	Parents	Tuber yield/ plant (g)	Large tubers (%)	Tuber specific gravity (x 10^{-4})	Tubers second growth (%)[1/]	Tuber cracking (%)[/]
Group 1	LT 7	9,6468	2,2651**	0,4196**	-0,1115	-0,3410**
	LT 8	-7,7082	0,7656	-0,1313	-0,2354*	0,1488
	LT 9	-20,4916	1,3953	-0,0711	-0,2404*	-0,1115
	DTO 28	22,4695	2,8778**	-0,0960	-0,1526	1,0002**
	Desireé	-15,7898	-7,8961	-0,3815**	0,6768**	-0,5167**
Group 2	Aracy	24,1599	0,1807	0,2149**	-0,2512**	-0,4472**
	Baraka	0,3065	1,7064	-0,2803**	0,1184	0,2654**
	Baronesa	-19,8973	1,7488	0,4127**	-0,0152	-0,5462**
	EP 0526	5,6402	-5,2944**	-0,3872**	-0,0237	-0,0880
	EP 0580	-15,5260	-2,5666*	0,0370	0,2322**	0,1575
	Itararé	2,4388	5,0206**	-0,0812	-0,0542	0,7551**

* *, * Significant at the 1 and 5% level of probability by the test F, respectively.

[1/] Data transformed to $\sqrt{x+1}$

Parent LT 7 contributed significantly to the increase in the percentage of large tubers and tuber specific gravity. It also had the advantage of reducing the percentage of tuber cracking. Cultivar Desirée contributed negatively to tuber specific gravity and percentage of tuber secondary growth (Table 7). Within group 2, cultivars Aracy and Baronesa showed high positive GCA estimates for tuber specific gravity and negative effects for tuber physiological disorders (Table 7). Cultivar Itararé contributed to the increase in the percentage of large tubers but had the disadvantage of increasing tuber cracking.

There was wide variation in the SCA estimates (not shown), and none of the parents had either high or low absolute values for all traits. The families which had positive SCA for tuber specific gravity had negative estimates for tuber yield and percentage of large tubers, showing the difficulty in finding parents which complement each other for all traits.

DISCUSSION

The main environmental factors which restrict potato yield under tropical conditions are water shortage, poor soils and temperature. In conventional cropping, soil correction and water supplementation in the dry season are routine. Therefore, temperature is the only preponderant factor that, in general, is higher than the ideal for the crop both in the warm and dry seasons. In the state of Minas Gerais, where this study was performed, tuber yield of economic crops is twenty percent higher in the cool season than in the warm and dry seasons (Resende et al., 1999). The warm season temperatures recorded in this study were much higher than the commonly found temperatures during economic potato growing in Brazil. The enhanced effect of the heat stress could contribute for the identification of heat-tolerant clones, which could have a better behavior when cultivated under lower temperatures .

The family means make the differences among the cool and warm seasons evident (Tables 2 and 5). Tuber yield in the warm season was about 350 g/plant, which is only 54% of the average in the cool season. Also, there was a 15% reduction in the percentage of large tubers compared with the cool season. Averages for tuber specific gravity in the cool and the warm seasons were 1.0688 and 1.0491, respectively. When viewed under the perspective of tuber dry matter content, this results in a 19.2% to 14.8% reduction. Finally, there was an approximate eight-fold increase in the percentage of tuber cracking and tuber secondary growth in the warm season compared to the cool season. All these results show the importance of selecting heat-tolerant clones for high temperature periods.

Similar effects have been reported by many authors. Sarquís et al., (1996) showed a reduction in tuber yield in two potato cultivars under high temperatures when compared to mild temperatures due to a lower proportion of tubers larger than 3.5 cm long. Menezes et al. (1999) assessed the performance of ten potato genotypes in the cool and warm seasons in Southern Minas Gerais and reported that tuber yield was reduced under heat stress mainly due to a delay in tuber initiation, which reduced the period of tuber bulking, resulting in small tubers.

No trait alone has been an effective indicator of heat tolerance but Tai et al., (1994) considered tuber dry matter content to estimate an index of heat susceptibility. In the present study selection of families and clones was based on an index taking into account tuber yield, percentage of large tubers, specific gravity and incidence of tuber physiological disorders.

Although the cool and warm seasons are highly contrasting planting periods regarding climatic aspects, parents or clones with wide adaptation to these environments could be advantageous, especially considering seed potato production. However, due to the large families x seasons interaction, the best strategy for potato breeding in this region in Brazil would be the selection within families more adapted to each environment. It should be considered, however, that clone LT 7 was present in more than fifty percent of the selected clones in both seasons and it is the most promising parent to be used for both warm and cool seasons among all others evaluated in this study. No single parent showed high GCA estimates for all traits, indicating that selection for superior hybrid combinations should be based in the complementation of traits in the progeny as well.

Achat (control) is one the most widely grown potato cultivar in Brazil. It was developed in Germany and is fairly resistant to viruses, bacterial wilt and to common scabs. It also has minor resistance to foliar fungal diseases. However, it has low frying quality and is very sensitive to high temperatures. Filgueira (1991) studying the stability of some potato genotypes showed that Achat has a highly unstable and unpredictable performance, representing a high-risk option for the potato grower. Thus, this cultivar should be replaced gradually by more heat tolerant clones to be used in the warm and dry seasons.

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RESUMO

Capacidade de Combinação de Genótipos de Batata para as Estações Frias e Quentes no Brasil.

Este trabalho foi realizado com os objetivos de identificar cultivares de batata com altas capacidades de combinação para tolerância ao calor e avaliar o desempenho de clones de batata obtidos pelo cruzamento entre genótipos tolerantes e sensíveis ao calor. Vinte e seis famílias clonais e mais de 600 clones foram avaliados em duas safras (primavera-verão: temperaturas altas e inverno: temperaturas amenas) na região sul de Minas Gerais. As temperaturas altas reduziram o número e o peso de tubérculos resultando em decréscimo de 46% na produção. Ocorreu, ainda, aumento de oito vezes na incidência de defeitos fisiológicos dos tubérculos e acentuada redução no peso específico dos tubérculos. As interações da capacidade geral de combinação (GCA) x safras e da capacidade específica de combinação (SCA) x safras foram significativas para a maioria dos caracteres, indicando que os melhores genitores e famílias para cultivo em temperaturas altas não foram os mesmos para as condições de temperaturas amenas. Os melhores clones para a safra de inverno também não foram os melhores na safra de primavera-verão, evidenciando que a melhor estratégia de melhoramento da batata para essa região é a seleção de clones adaptados a cada safra. Entretanto, como essas interações representam o comportamento médio de um grande número de genótipos, foi possível identificar genitores e famílias superiores nas duas condições ambientais.

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