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Yield and popping expansion components in local popcorn varieties from Southern Brazil

Componentes de rendimiento y capacidad de expansión de variedades locales de maíz pira en el sur de Brasil

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Resumen

En el presente trabajo se evaluaron la productividad de granos (GY), la capacidad de expansión (PE), la capacidad de expansión sin el peso de los granos no reventados (PEW), además de otras 11 características agronómicas y morfológicas de 14 variedades locales de maíz (*Zea mays* L.) 'pira' (LPV) provenientes del extremo oeste de Santa Catarina, en el sur de Brasil. Utilizando un delineamiento experimental de bloques completos al azar con tres repeticiones se realizaron dos experimentos, en dos regiones diferentes del estado de Santa Catarina; un primer ensayo en Florianopolis (litoral este) y un segundo ensayo en el municipio de Anchieta (extremo oeste). La mayor correlación positiva se observó entre productividad y prolificidad (PRL) (r = 0.72) seguida de la productividad vs. el número de granos por fila (NGR) (r = 0.71), mientras que con el índice de circularidad de la cariópside (CCI) la correlación fue negativa (r = -0.67). La variable (PEW) mostro correlación positiva con CCI (r = 0.70) y con la relación espesor/largo (TWR) (r = 0.70). La variedad de maíz pira 574A se destacó por sus altos valores de PE y PRL. El mejoramiento de poblaciones compuestas y de poblaciones per se es una estrategia de selección potencial para LPV, basada en la complementariedad y correlación entre las variables y los valores de GY, PE, PEW, TWR CCI – HEP – relación entre altura de la primera mazorca/altura de la planta; PH – altura de la planta; PRL – WHG – peso de 100 gramos; VHG - volumen de 100 gramos; EL – longitud de la mazorca; NRE – numero de filas por mazorca; NGR – ED – diámetro de la mazorca.

Palabras clave: Agrobiodiversidad; correlación fenotípica; potencial genético; premejoramiento; variedades criollas; *Zea mays* L.

Abstract

The aim of this study was to evaluate grain yield (GY), popping expansion (PE), popping expansion disregarding the weight of unpopped kernels (PEW), and eleven other agronomic and morphological traits of 14 local popcorn varieties (LPV) from far west of the state of Santa Catarina, Southern Brazil. Two experiments were carried out, in a completely randomized block design with three replications, in different regions of Santa Catarina: one in the municipality of Florianópolis (east coast) and the other in Anchieta (western). Grain yield had the highest positive correlation with prolificacy (PRL) (r = 0.72) and number of grains per row (NGR) (r = 0.71), and a negative correlation with caryopsis circularity index (CCI) (r = −0.67). Variable PEW showed a positive correlation with CCI (r = 0.70) and with thickness/width ratio (TWR) (r = 0.70). Variety 574A stood out for high PE and PRL. The improvement of composite populations and of populations *per se* is a potential breeding strategy for LPV, based on the complementarity and correlation among variables and the GY, PE, and PEW values, CCI – HEP – first ear height/plant height relation, PH – plant height; PRL – WHG – weight of 100 grains; VHG - volume of 100 grains; EL – ear length; NRE – number of rows per ear; NGR – number of grains per row of ear; ED – ear diameter.

Key words: Agrobiodiversity; Genetic potential; Landrace; Phenotypic correlation; Pre-breeding; *Zea mays* L.

Introduction

In recent years, Brazil has stood out as one of the biggest popcorn producers in the world. Although this crop has achieved high national relevance, official information is still inexistent in terms of growing area, production, and grain yield.

One of the weak points of the popcorn production chain in Brazil is the low market availability of national cultivars, that are qualitatively superior and adapted to different regions of the country. This lack of options has been responsible for the dependency of the national production system on the packing companies, which own the seed registrations (Cruz, Filho and Queiroz, 2014).

Because of its use for human consumption, popcorn must primarily possess good popping expansion (PE). However, PE is related to various other factors, such as genetics, production, harvest, processing, drying, pericarp and endosperm conditions, and grain size, shape, and moisture content (Lyerly, 1942; Miranda, Souza, Galvão, Guimarães, Melo and Santos, 2008). Besides these attributes, popcorn must have a good grain yield (GY), which in turn is commonly correlated with prolificacy (PRL), number of rows per ear (NRE), number of grains per row (NGR), ear length (EL), and ear diameter (ED) and negatively correlated with PE (Broccoli and Burak, 2004, Miranda, Souza, Galvão, Guimarães, Melo and Santos, 2008, Vidal-Martínez, Clegg, Johnson and Valdivia-Bernal, 2001).

The far west region of Santa Catarina State features a broad genetic diversity of *Zea mays* L. local varieties and wild relatives, and it has thus been indicated as a microcenter of diversity for the genus *Zea* (Costa, Silva and Ogliari, 2016; Silva, Vidal, Costa, Vaio and Ogliari, 2015). However, information is still scarce regarding its genetic potential as a gene source for popcorn breeding programs, neglecting this valuable source of diversity with adaptive potential (Dwivedi, Ceccarelli, Blair, Upadhyaya, Are and Ortiz, 2015).

This study aimed to evaluate the genetic potential of local popcorn varieties (LPV) from the municipalities of Anchieta (ANC) and Guaraciaba (GBA), in far western Santa Catarina, Southern Brazil, and set which traits have a positive influence on the grains yield and popping expansion.

Materials and methods

Study area

The experiments were carried out in two distinct regions of Santa Catarina, evaluating 13 LPV from GBA, one from ANC, plus one open-pollinated check (RS 20), developed by the State Federation for Agriculture and Livestock Research (Federação Estadual de Pesquisa Agropecuária, FEPAGRO/RS). All treatments had a predominantly white pericarp, except for the check, whose pericarp was yellow (Table 1). The LPV with white pericarp color were chosen due to its major presence in the region according to Costa et al (2016).

Table 1. Identification, origin, cultivation time and shape of local popcorn varieties with predominantly white grains evaluated in experiments conducted in Florianópolis and Anchieta, Santa Catarina – Brazil, 2014/2015 crop year.

IDV[1]	Community/City[2]	Shape
574A	Liso Baixo/ GBA	Pointed
648C	Olímpio/ GBA	Round
283A	Guataparalto/ GBA	Round
319E	Guataparema/ GBA	Pointed
66A	Barra da Traíra/ GBA	Pointed
2360A	Cordilheira/ ANC	Pointed
884B	São João/ GBA	Pointed
977A	São Vicente/ GBA	Round
244A	Flores da Cunha/ GBA	Pointed
793B	Perondi/ GBA	Round
857C	São Cristovão/ GBA	Round
612A	Mirim/ GBA	Round
48A	Barra da Guaraciaba/ GBA	Round
880A	São Domingos/ GBA	Pointed
RS 20	Rio Grande do Sul	Round

[1]Identification code of local varieties from the Federal University of Santa Catarina's genebank; [2]Anchieta (ANC) and Guaraciaba (GBA); NA – No answer. Source: date obtained from Census of Diversidy's database

The first experiment was carried out from Sep 2014 to Feb 2015 in Florianópolis (FLN), located on the east coast (27.41° S lat, 48.32° W long, 2.0 m asl) of the state of Santa Catarina. The second experiment was conducted from Dec 2014 to May 2015 in ANC (26.59° S lat, 53.38° W long, 700 m asl), far west part of the state, 745 km from FLN.

Experimental design and evaluated traits

A completely randomized block design with three replications was adopted. The plot consisted of two 5.0-m-long rows spaced 0.8 m apart; the usable plot area was 2.4 m^2 and plant density was 62,500 plants ha^{-1} after thinning.

Fertilizers were applied in the FLN experiment according to the results of soil analysis (Table 2) and as recommend for the state of Santa Catarina (50 kg ha^{-1} N, 35 kg ha^{-1} P_2O_5, and 25 kg ha^{-1} K_2O). In ANC, the experimental area was not fertilized (Table 2), since this is the common practice among the popcorn maintainers in the region.

Table 2. Soil analysis of the experimental areas at Anchieta and Florianópolis, Santa Catarina, Aug 2014.

Analysis	ANC	FLN
Clay content (%)	20.0	10.0
pH-Water 1:1	6.3	5.4
Phosphor (mg dm^{-3})	19.7	40.6
Potassium (mg dm^{-3})	176.0	70.0
Organic matter (%)	2.1	4.2
Calcium (cmolc dm^{-3})	18.4	2.3
Magnesium (cmolc dm^{-3})	3.6	1.0
CEC pH 7.0 (cmolc dm^{-3})	24.7	8.3

Report emitted by EPAGRI's laboratory, part of the Official Network of Soil Analysis Labs of Santa Catarina and Rio Grande do Sul - ROLAS. Report digital signature: FLN (6B2176E1-FCB1-410E-99CE-B6B4A1BCDBE7) and ANC (C17CCEF5-2476-4FAA-8AA1-37768838373E) available on: http://solosch.epagri.sc.gov.br/.

In both locations, the evaluated traits were GY, PE, and popping expansion disregarding the weight of the unpopped kernels (PEW). Popping expansion was estimated as the ratio between the final volume of popcorn popped in a microwave oven (1 min 30 s) and the initial grain weight (30 g), based on Normative Instruction no. 61 from the Ministry of Agriculture, Livestock and Supply (Ministério da Agricultura, Pecuária e Abastecimento, MAPA) (Brazil, 2011). For PEW, the weight of the unpopped kernels was subtracted from the PE, and so the maximum expansion potential was estimated. Additionally, another 11 traits were evaluated, all commonly correlated with GY, PE, and PEW, namely: plant height (PH), height of first ear/plant height ratio (HEP), PRL, EL, NGR, NRE, ED, weight of 100 grains (WHG), volume of 100 grains (VHG), thickness/width ratio (TWR = T/W), with *T* corresponding to grain thickness and *W* to grain width), and caryopsis circularity index (CCI) *(CCI = T / (W+L)*, with *T* corresponding to grain thickness, *W* to grain width, and *L* to grain length).

Data analysis

Analysis of variance was performed for each environment and followed the fixed model, except for block and experimental error, considering the following equation: $Y_{ij} = \mu + t_i + b_j + e_{ij}$, where: Y_{ij} is the observation of *i* th and *j* th block; μ is the overall mean of the experiment; t_i is the additive effect of treatments; b_j is the additive effect of random blocks; and e_{ij} is the random experimental error. A Scott-Knott grouping test was performed at the 5% probability error, for each variable and experiment, in the analyses whose F test was significant (P < 0.05).

Analysis of variance was also performed for the two environments and followed the joint analysis (CA) fixed model, except for block and experimental error, as follows: $Y_{ijk} = \mu + t_i + l_j + tl_{ij} + b_{k(j)} + e_{ijk}$, where Y_{ijk} is the observation of *i* th treatment (*i* = 1, 2, ...15), *j* th environment (*j* = 1, 2), and *k* th block (*k* = 1, 2, 3); μ is the overall mean of the experiment; t_i is the effect of *i* th treatment (popcorn varieties); l_j is the effect of *j* th environment; tl_{ij} is the effect of the interaction between location and treatment; $b_{k(j)}$ is the effect of random blocks within environment and; e_{ijk} is the experimental error.

For the analyses of variance per location, the coefficient of experimental variation (*EVc*) was estimated for each environment as $EVc\%=100^* \sqrt{RMS} / \mu$, where μ is the overall mean of the analyzed variable and *RMS* is the residual mean square. The genetic quadratic component was estimated as $Ø\_g = ((MST-RMS)) / J$, where MST is the mean square of treatments and j is the number of replications. The coefficient of genetic variation (*GVc*) was calculated as $GVc\%=100^* \sqrt{(Ø\_g)} / \mu$.

In order to understand how each trait influences the yield and popping expansion, the Pearson's linear correlations based on phenotypic variances of CA was performed among GY, PE, PEW, and the other 11 traits.

Using the PE, PEW, and GY means, it was used the index selection based on classical rank summation without economic weight (Mulamba and Mock, 1978), and a pressure selection of 20% to select promising varieties for the recurrent selection or formation of intervarietal hybrids. Analysis was performed using the software GENES (Cruz, 2006).

Results

Varieties RS 20 (check) and 612A had similar means for HEP in both environments and for PH in FLN. nBoth varieties showed significantly lower means for HEP and PH than the other varieties in both experiments. For both variables, the treatment means showed to be consistent between the two environments and were ≈47% (PH) and ≈35% (HEP) greater than the means of check variety based on the combined analysis with both environments (Table 3).

Higher means for WHG and VHG were estimated for 857C, 793B, 884B, and 2360A in FLN and, in both experiments, the means of these varieties were significantly higher than the means of check for both variables. The treatment means were also significantly higher in FLN for WHG and VHG and were ≈35% (WHG) and 32% (VHG) greater than check means in this environment (FLN) and ≈14% (WHG) and ≈5% (VHG) higher than check means in ANC (Table 3). Ear measurements, expressed by ED and EL, showed

Table 3. Analysis of variance and Skott-Knott test for plant height (PH), first ear heigth / plant heigth relation (HEP), weight of 100 grains (WHG), volume of 100 grains (VHG) and ear diameter (ED) from the evaluation of local and commercial varieties of popcorn, in experiments conducted in Florianópolis (FLN) and Anchieta (ANC), Santa Catarina – Brazil, 2014/2015 crop year.

Treatment	PH (m)		HEP		WHG (g)		VHG (mL)		ED (mm)	
	FLN	ANC	FLN	ANC	FLN	ANC	FLN	ANC	FLN	ANC
574A	1.48c	1.43a	0.57b	0.56a	16.0b	14.9a	19.8c	14.8b	30.8b	27.5
648C	1.43c	1.64a	0.5c	0.58a	11.8c	11.4b	14.7c	14.8b	27.9b	26.6
283A	1.59b	1.55a	0.52b	0.58a	13.5c	9.7b	16.2c	12.3b	31.8a	26.9
319E	1.42c	1.58a	0.54b	0.55a	13.2c	11.5b	16.2c	15.3b	32.1a	27.4
66A	1.41c	1.58a	0.57b	0.57a	13.8c	10.2b	17.8c	14.3b	29.7b	27.8
2360A	1.57b	1.67a	0.57b	0.57a	18.3a	12.1b	23.0b	17.3a	32.5a	30.0
884B	1.89a	1.83a	0.64a	0.61a	21.5a	12.8a	28.3a	17.2a	33.4a	27.9
RS20	1.12d	0.99c	0.39d	0.43b	11.7c	10.8b	15.0c	15.3b	29.9b	25.6
244A	1.55b	1.53a	0.55b	0.58a	15.6b	12.8a	18.5c	17.5a	28.9b	28.5
793B	1.68b	1.63a	0.59b	0.61a	21.6a	13.0a	27.7a	18.0a	33.7a	30.6
857C	1.83a	1.84a	0.61a	0.62a	21.6a	14.7a	27.2a	18.5a	33.8a	28.3
612A	1.26d	1.33b	0.42d	0.48b	11.9c	11.8b	15.0c	15.3b	29.8b	27.1
48A	1.59b	1.57a	0.55b	0.54a	14.4b	11.9b	17.7c	16.0b	32.4a	28.2
880A	1.76[a]	1.63a	0.66a	0.59a	15.6b	14.5a	19.0c	18.8a	30.7b	29.8
977A	1.58b	1.63a	0.55b	0.59a	16.2b	11.9b	20.7c	16.3a	29.7b	27.7
Mean[1]	1.544	1.562	0.548	0.564	15.8	12.3	19.8	16.1	31.1	28.0
GVc (%)[2]	12.49	11.83	12.42	7.12	20.69	10.31	22.17	8.92	4.80	2.56
EVc(%)[3]	7.05	9.72	7.69	8.63	12.43	12.84	13.26	10.91	5.86	6.96
Genotype[4]	0.000	0.000	0.000	0.006	0.000	0.008	0.000	0.007	0.005	0.221
GxEI[5]	0.506		0.273		0.000		0.000		0.307	
Location[6]	0.725		0.222		0.001		0.000		0.004	

[1]Mean of three replications in each site; [2]Genotipic variation coefficient; [3]Experimental variation coefficient; [4]Significance of the difference between treatments extracted from the variance analysis; [5]Significance of the genotype x environment interaction extracted from the variance analysis of the joint analysis; [6]Significance of the difference between sites; [ns]Not significant at 5% error probability in F test. *Means followed by the same letters are not statistically different in Skott-Knott test at 5% error probability.

significant differences between treatments only in FLN, and treatment means were significantly higher in FLN. When considering the treatment means estimated in FLN for variables ED and EL (Table 3 and Table 4), the values were ≈4% higher (ED) and ≈6% lower (EL) than check means. Seven local varieties (283A, 319E, 2360A, 884B, 793B, 857C, and 48A) showed ED means higher than check in FLN, while in ANC, the six outstanding varieties (283A, 2360A, 884B, RS20, 793B, and 880A) included check.

Treatments means for PRL in ANC were not significantly different than those estimated in FLN. The more prolific varieties (574A, 648C, 283A, 319E, 66A, and 2360A) evaluated in FLN differed significantly from the check. In ANC, despite the significant F test, the Scott-Knott grouping test did not detect differences between treatments because of the high EVc% and low GVc% (Table 4).

Significant differences among varieties were detected for variables *NRE* and *NGR* only in FLN. In that location, there was a larger mean range for NRE and a higher GVc% for *NGR* compared with *ANC* (Table 4).

Estimates for TWR and CCI showed differences between treatments by the Scott-Knott test only in FLN (both with $P \leq 0,01$), although the F value was significant for *CCI* in *ANC* ($P \leq 0,05$) (Table 5). In FLN, treatments were separated by the Scott-Knott test into two groups, both for TWR and CCI. Furthermore, ANC showed higher

Table 4. Analysis of variance and Skott-Knott test for ear length (EL), prolificacy (PRL) number of rows per ear (NRE) and number of grains per row (NGR) from the evaluation of local and commercial varieties of popcorn, in experiments conducted in Florianópolis (FLN) and Anchieta (ANC), Santa Catarina – Brazil, 2014/2015 crop year.

Treatment	EL (cm)		PRL		NRE		NGR	
	FLN	ANC	FLN	ANC	FLN	ANC	FLN	ANC
574A	12.67b	10.73	1.00a	0.58a	13.7a	13.6	25.9b	20.5
648C	11.59b	11.81	1.01a	0.84a	12.8b	12.7	27.9a	23.7
283A	14.08a	11.67	1.03a	0.82a	15.3a	14.0	35.7a	24.0
319E	12.78b	11.45	0.86a	0.60a	15.6a	13.3	30.7a	23.3
66A	12.61b	13.15	0.81a	0.72a	12.7b	13.8	25.1b	25.4
2360A	14.24a	11.12	0.88a	0.69a	13.2b	13.6	26.3b	20.1
884B	14.69a	10.81	0.70b	0.54a	13.4b	12.6	20.3b	21.6
RS20	14.02a	10.77	0.40b	0.65a	13.7a	13.6	30.8a	19.9
244A	11.31b	11.75	0.60b	0.68a	11.4b	12.8	21.3b	23.9
793B	13.90a	11.44	0.67b	0.47a	12.5b	13.8	28.7a	23.5
857C	11.71b	11.38	0.66b	0.51a	12.3b	13.7	21.2b	19.9
612A	12.21b	9.93	0.59b	0.75a	13.9a	13.8	25.7b	17.0
48A	12.92b	11.69	0.75b	0.70a	14.4a	14.0	30.0a	23.9
880A	15.99a	13.65	0.96a	0.95a	14.0a	14.1	29.1a	25.7
977A	12.55b	11.21	0.77b	0.52a	12.6b	12.7	20.7b	20.5
Mean[1]	13.15	11.5	0.78	0.67	13.4	13.5	26.6	22.2
GVc (%)[2]	7.58	-	19.08	15.59	7.1	-	14.06	2.83
EVc(%)[3]	10.64	15.85	20.83	22.07	7.84	8.33	14.37	17.63
Genotype[4]	0.019	0.7906^{ns}	0.0025	0.020	0.0023	0.7961^{ns}	0.0012	0.4189^{ns}
GxEI[5]	0.4688		0.0619		0.2383		0.0767	
Location[6]	0.0227		0.1371		0.7957		0.041	

[1]Mean of three replications in each site; [2]Genotipic variation coefficient; [3]Experimental variation coefficient; [4]Significance of the difference between treatments extracted from the variance analysis; [5]Significance of the genotype x environment interaction extracted from the variance analysis of the joint analysis; [6]Significance of the difference between sites; ^{ns}Not significant at 5% error probability in F test. Means followed by the same letters are not statistically different in Skott-Knott test at 5% error probability.

rates, on average, for both variables; i.e., rounder grains, possibly because of the larger available space for grains that grow in thickness, in less productive ears.

Local popcorn variety 574A exhibited a higher mean PE in both experiments, and the mean value estimated for the two environments was 21% higher than the minimum value of 30 mL g^{-1} established by MAPA for marketing (Brazil, 2011) and 43% higher than the check mean estimated in both FLN and ANC. Local popcorn variety 880A also stood out for this same variable for showing higher means than check in both locations.

For PEW evaluated in ANC, LPV 574A also obtained a significantly higher mean and was 47% higher than that established by MAPA. In FLN, the same LPV (574A) did not differ from check (RS 20) or LPV 977A. The means for PEW were around 25% larger than those estimated for PE. Check means were higher than the treatment means in both experiments.

The GY means showed a significant variation between the experiments. In ANC, the treatments mean corresponded to ≈41% of that obtained in FLN. Varieties 880A, 48A, 283A, 319E, and 2360A showed the highest means in FLN, where the experimental area was fertilized. Local varieties 880A, 48A, 283A, and 319E displayed the highest means in both environments. The *GVc*% varied across experiments and variables. The average GVc% in FLN of all variables was 13%, and in *ANC* it was 10%. The largest

Table 5. Analysis of variance and Skott-Knott test for grain thickness / width relation (TWR), caryopsis circularity index (*CCI*), popping expansion (PE), popping expansion without the weight of unpopped grains (PEW) and grain yield (GY) from the evaluation of local and commercial varieties of popcorn, in experiments conducted in Florianópolis (FLN) and Anchieta (ANC), Santa Catarina – Brazil, 2014/2015 crop year.

Treatment	TWR		CCI		PE (mL g^{-1})		PEW (mL g^{-1})		GY (t ha^{-1})	
	FLN	ANC	FLN	ANC	FLN	ANC	FLN	ANC	FLN	ANC
574A	0.73a	0.79	0.28a	0.31a	34.1a	38.6a	40.0a	44.2a	2.176b	0.657b
648C	0.60b	0.67	0.25b	0.29a	27.0c	24.9c	35.8b	28.3c	1.704b	0.97a
283A	0.60b	0.70	0.24b	0.29a	19.3e	22.9d	23.4e	27.5c	2.824a	0.987a
319E	0.70a	0.73	0.28a	0.30a	21.1e	20.9d	29.9d	29.1c	2.417a	0.921a
66A	0.66b	0.72	0.26b	0.29a	24.4d	24.2c	30.0d	29.6c	1.652b	1.259a
2360A	0.66b	0.67	0.28a	0.29a	26.9c	23.6d	33.3c	29.6c	2.386a	0.783b
884B	0.82a	0.74	0.32a	0.3a	29.6b	27.4c	36.0b	32.6b	1.813b	0.720b
RS20	0.70a	0.77	0.31a	0.35a	26.9c	23.3d	38.6a	34.0b	-	0.760b
244A	0.74a	0.71	0.29a	0.30a	23.2d	21.8d	28.2d	25.7d	1.394b	0.913a
793B	0.61b	0.69	0.25b	0.29a	23.9d	18.8d	29.3d	24.4d	2.01b	0.639b
857C	0.75a	0.76	0.29a	0.31a	29.8b	26.9c	32.5c	35.3b	1.737b	0.671b
612A	0.66b	0.76	0.29a	0.33a	26.0c	26.1c	33.8c	35.2b	1.743b	0.532b
48A	0.60b	0.65	0.25b	0.27a	21.9e	25.0c	25.2e	28.8c	2.925a	1.122a
880A	0.75a	0.77	0.29a	0.31a	31.1b	30.3b	36.7b	36.5b	2.901a	1.215a
977A	0.77a	0.79	0.30a	0.32a	29.4b	27.1c	39.3a	37.1b	1.588b	0.655b
Mean[1]	0.69	0.73	0.28	0.3	26.3	25.5	32.8	31.9	2.091	0.854
GVc (%)[2]	8.95	3.7	7.71	4.28	15.11	17.25	15.17	16.04	19.15	18.57
EVc(%)[3]	8.38	8.12	6.98	6.76	5.88	9.99	4.79	5.98	22.74	27.37
Genotype[4]	0.001	0.138[ns]	0.000	0.039	0.000	0.000	0.000	0.000	0.021	0.028
GxEI[5]	0.508[ns]		0.349[ns]		0.005		0.000		0.039	
Location[6]	0.006		0.000		0.058		0.020		0.000	

[1]Mean of three replications in each site; [2]Genotipic variation coefficient; [3]Experimental variation coefficient; [4]Significance of the difference between treatments extracted from the variance analysis; [5]Significance of the genotype x environment interaction extracted from the variance analysis of the joint analysis; [6]Significance of the difference between sites; [ns]Not significant at 5% error probability in F test. Means followed by the same letters are not statistically different in Skott-Knott test at 5% error probability.

differences among environments were found for the traits WHG, VHG, NGR, and TWR. In both environments, PRL and GY had the highest GVc%. In ANC, variables EL and *NRE* had higher *RMS* than they did MST, making it impossible to estimate the GVc%.

Significant genotype × environment (G×E) interactions were detected for WHG, VHG, PE, PEW, and GY. For these variables, some varieties were less influenced by environment change. Variety 612A, for example, maintained a stable mean in FLN and ANC for variables WHG, VHG, and PE; 880A was constant between environments for variables VHG and PEW; and 66A was more stable for PE, besides showing the lowest reduction in GY (24%) from FLN to ANC. Popcorn varieties 244A, 283A, and 48A had an increase in PEW in ANC, contrary to the general downward trend observed in that environment for the other varieties.

The highest estimated correlations with GY were obtained with PRL, NGR (positive), and CCI (negative) (Table 6). Popping expansion showed the highest correlations with TWR, PEW (positive), and NGR (negative), while PEW displayed the highest correlations with TWR, CCI, PE (positive), and NGR (negative) (Table 6). Correlations with PEW were higher than the correlations with PE, for the same variables.

The results of the present study highlight, for this purpose, local popcorn varieties 574A, 880A, and 884B, based on Mulamba and Mock's index.

Discussion

Results for the correlations between GY and traits PRL, NGR, and *CCI* followed the same trend as those reported in other studies; e.g., Vidal-Martínez, Clegg, Johnson and Valdivia-Bernal (2001), who correlated GY with NGR (0.90), and Broccoli and Burak (2004), who correlated GY with PRL (0.32) and CCI (−0.32).

In the correlations established with PE, Broccoli and Burak (2004) obtained a positive value (0.47) with CCI, and Lyerly (1942) with TWR (0.57), which are very close to the values observed in the present study. In the evaluation of the PEW we intended to assess PE only with poppable grains and thus determine the correlation with the maximum expansion potential of each variable. In the present study, PEW showed a high positive correlation with CCI and TWR and a moderate negative correlation with NGR and GY (Table 6).

Table 6. Correlation between popping expansion (PE), popping expansion without the weight of unpopped grains (PEW) and grain yield (GY), between themselves and with another 11 variables analyzed in experiments conducted with local popcorn varieties, in Anchieta (ANC) and Florianópolis (FLN), Santa Catarina - Brazil, 2014/2015 crop year.

Variável	PE	PEW	GY
TWR	0.569*	0.702**	-0.392
CCI	0.407	0.707**	-0.679**
HEP	0.137	-0.179	0.500
PH	0.005	-0.291	0.431
PRL	0.100	-0.069	0.726**
WHG	0.343	0.080	-0.002
VHG	0.166	-0.011	-0.076
EL	-0.035	-0.076	0.627**
NRE	-0.198	-0.167	0.569*
NGR	-0.449	-0.493	0.711*
ED	-0.124	-0.377	0.420
PE	—	0.847**	-0.193
PEW	0.857**	—	-0.434
GY	-0.193	-0.434	—

[1]Pearson's linear correlation; [2]Significance of Pearson's linear correlation; TWR - grain thickness/width relation; CCI – caryopsis circularity index; HEP – first ear height/plant height relation, PH – plant height; PRL – prolificacy; WHG – weight of 100 grains; VHG - volume of 100 grains; EL – ear length; NRE – number of rows per ear; NGR – number of grains per row of ear; ED – ear diameter.

Based on the correlations established between PE and PEW with CCI and TWR, both variables (CCI and TWR) can be considered good indirect measurements for the identification of varieties with good PE, especially TWR, which showed the strongest positive correlation with PE and PEW, and a weak negative correlation with GY. Selection based on high TWR values, as an indirect way of identifying varieties with higher PE without loss of GY, can be related to the pointed grain shape of some LPV. They are generally longer due to their morphology, and consequently contain a larger mass (Table 5 and Table 6).

The treatments mean for PH were lower than those observed by Solalinde, Scapim, Vieira, Amaral Júnior, Vivas, Pinto Mora and Viana (2014) and Miranda, Souza, Galvão, Guimarães, Melo and Santos (2008). Although these second authors also observed the lowest values for PH and HEP in variety RS 20, in the set of evaluated genotypes. Reduced PH and HEP are important traits in the popcorn crop, since varieties with low PH and HEP are less susceptible to lodging and stalk breaking (Kist, Ogliari, Miranda Filho and Alves, 2010).

For variables WHG and VHG, only the means in FLN were higher than those obtained by Pereira and Amaral (2001), whose estimated values were 12.6 g and 17.9 mL, respectively. Mean values in the present work for EL were lower than those estimated by Agele, Ayanwole and Olakojo (2008), without any of the varieties showing values close to the mean of 17.6 cm, obtained by the said authors.

Variable PRL also showed a much lower mean than those observed by Ematné, Nunes, Dias, Prado and Souza (2016) (1.33) and by Miranda, Coimbra, Godoy, Souza, Guimarães and Melo (2003) (1.2). Although PRL means are low, there is high genetic variation for the selection of superior varieties, as expressed by GVc% estimates. Prolificacy values lower than 1 express inability of some plants to produce fertile ears. This behavior may be due to inbreeding or even to the inexistence of artificial selection, directly affecting grain yield.

Overall, the average PE across the varieties was close to the 25 g mL^{-1} found by Freitas Júnior, Amaral Júnior, Rangel and Viana (2009) in full-sibling progenies and much higher than the average 16.5 mL g^{-1} estimated by Miranda, Souza, Galvão, Guimarães, Melo and Santos (2008) and 18.7 mL g^{-1} by Miranda, Coimbra, Godoy, Souza, Guimarães and Melo (2003).

Regarding the estimated means for PE and PEW, the values might have been underestimated in relation to other studies. The 23% difference between PE and PEW is indicative that the maximum grain popping expansion could not have been reached, either because of the occurrence of damaged grains, which cause a significant reduction in PE values, or because of insufficient grain exposure time in the microwave oven. Although the present study considered the exposure time of one and a half minutes, established by MAPA, in many cases, this time was less than that used by others researchers (Jele, Derera and Siwela, 2014; Scapim, Pacheco, Amaral Júnior, Vieira, Pinto and Conrado, 2010; Silva, Amaral Júnior, Gonçalves, Candido, Vittorazzi and Scapim, 2013), possibly because it underestimates real values.

As for GY, even in FLN, where the means were higher than in ANC, estimates were considerably lower than those obtained by Miranda, Souza, Galvão, Guimarães, Melo and Santos (2008) (2980 kg ha^{-1}) and Miranda, Souza, Guimarães, Namorato, Oliveira and Soares (2009) (2740 kg ha^{-1}). Although the EVc% estimated for GY was very high, these values are common in grain yield evaluations (Daros, Amaral Júnior and Pereira, 2002; Freitas, Amaral Júnior, Freitas Júnior, Cabral, Ribeiro and Gonçalves, 2014; Freitas Júnior, Amaral Júnior, Rangel and Viana, 2009; Silva, Amaral Júnior, Gonçalves, Candido, Vittorazzi and Scapim, 2013), because this is a trait that reflects the results of many other correlated variables.

Taking into consideration only traits common to those evaluated by Miranda, Coimbra, Godoy, Souza, Guimarães and Melo (2003) (PH, HEP, WHG, PRL, and GY), with the average *GVc*% close to 14%, and common traits evaluated by Freitas, Amaral Júnior, Freitas Júnior, Cabral, Ribeiro and Gonçalves (2014) (PH, DCO, PRL, GY and PE), with average GVc% close to 7%, FLN was superior, on average, to both studies (17%), while ANC (13%) showed an average GVc% only lower than that found by Miranda, Coimbra, Godoy, Souza, Guimarães and Melo (2003). In this case, environmental conditions in FLN exposed more markedly the variations of genetic origin in the set of evaluated varieties.

The G×E interaction observed by Broccoli and Burak (2004) and Scapim et al. (2010) for variables GY and PE reinforce the results of the present study. Among the traits that did not show significant G×E in this study, only HEP expressed a different performance in other experiments (Freitas, Amaral Júnior, Freitas Júnior, Cabral, Ribeiro and Gonçalves, 2014), while PH, ED, EL, *CCI*, NRE, and NGR agree with the works of Broccoli and Burak (2004), Freitas, Amaral Júnior, Freitas Júnior, Cabral, Ribeiro and Gonçalves (2014), and Vidal-Martínez, Clegg, Johnson and Valdivia-Bernal (2001).

Local varieties 612A, 880A, and 66A showed lower variation between environments for traits associated with PE, and LPV 66A and 244A presented lower variation between locations regarding GY. Varieties 283A and 48A showed higher PE means when cultivated in their region of origin, even when no fertilizer was applied.

Based on the genetic potential of these LPV, performance between environments, and the favorable correlations established between traits, it is possible to outline genetic improvement strategies that value the complementary combination between populations for attributes of high performance, as is done in the development of intervarietal hybrids and interpopulational improvement.

Conclusions

Among the varieties, the thickness/width ratio shows the highest correlation with popping expansion.

Local varieties 574A and 880A shows average popping expansion superior to 30 $mL.g^{-1}$ being fit for commercial use even without formal improvement.

Local varieties 574A, 880A, and 884B presented potential for breeding strategies focused on the development of composite populations, given the possibility of complementary combination among populations for high-performance attributes.

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