



Agronomic performance of popcorn genotypes in Northern and Northwestern Rio de Janeiro State

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ABSTRACT. Three populations of popcorn from the Universidade Estadual do Norte Fluminense Darcy Ribeiro recurrent selection program (cycles C3, C4 and C5 from UNB2U), five simple hybrids provided by the Universidade Estadual de Maringá breeding program, five varieties (BRS Angela, UFVM-2 Barão de Viçosa, Viçosa, Beija-Flor and SAM) and three commercial hybrids (Zelia, Jade and IAC 112) were evaluated in five environments for their potential to be registered by the MAPA and recommended to producers in Northern and Northwestern Rio de Janeiro State. The experiment was arranged in a randomized block design, with three replications. The two main economic traits of the crops, grain yield (GY) and popping expansion (PE), were assessed. In the joint analysis of variance, significant differences were observed using the *F* test for the GY and PE traits. Regarding the genotype x environment interaction, only the GY was significant, thus revealing that the cultivar behavior varies according to the environment. The P_i statistics and the results for those traits showed that UNB2U-C5 and hybrid $P_1 \times P_7$ have the potential to be recommended as new alternatives for producers in the region.

Keywords: *Zea mays* L., adaptability, value for cultivation and use, grain yield, popping expansion.

Desempenho agrônomo de genótipos de milho pipoca no Norte e Noroeste do Estado do Rio de Janeiro

RESUMO. Com o objetivo de investigar a potencialidade de registro no MAPA para indicação aos produtores do Norte e Noroeste Fluminense, três populações de milho pipoca oriundas do programa de seleção recorrente da Universidade Estadual do Norte Fluminense Darcy Ribeiro (ciclos C3, C4 e C5 de UNB2U), cinco híbridos simples cedidos pelo programa de melhoramento da Universidade Estadual de Maringá, bem como cinco variedades (BRS Angela, UFVM-2 Barão de Viçosa, Viçosa, Beija-Flor e SAM) e três híbridos comerciais (Zelia, Jade e IAC 112) foram avaliados em cinco ambientes. O delineamento experimental adotado foi blocos ao acaso, com três repetições, tendo sido avaliadas as duas principais características da cultura de importância econômica: produtividade de grãos (GY) e capacidade de expansão (PE). Na análise de variância conjunta, observaram-se diferenças significativas pelo teste *F* para as características GY e PE. Em relação à interação genótipos x ambientes, apenas GY foi significativa, evidenciando comportamento diferenciado das cultivares nos ambientes. Pela estatística P_i e os resultados para estas características demonstram que a população UNB2U-C5 e o híbrido $P_1 \times P_7$ têm potencial para recomendação como nova opção de cultivo para os produtores da região.

Palavras-chave: *Zea mays* L., adaptabilidade, valor de cultivo e uso, produtividade de grãos, capacidade de expansão.

Introduction

Previously, coffee and sugar cane cultivation were responsible for much of the market economy in the northern and northwestern regions of Rio de Janeiro, but agribusiness has recently decreased in these areas. Currently, sugar cane is the major crop in these geographic areas of Rio de Janeiro State but achieves a low yield when compared with other Brazilian regions, such as São Paulo State (SOUZA et al., 2008).

Agricultural diversification is an important strategy to minimize the socio-economic problems arising from low-yielding monocultures of sugar cane, and popcorn cultivation is considered an excellent alternative due to its high yield and wide popular acceptance (AGUIAR et al., 2009; MENDES DE PAULA et al., 2010; RANGEL et al., 2011; MOTERLE et al., 2012). However, the reduced number of cultivars available in the market is a major constraint to the expansion of popcorn cultivation (MIRANDA et al., 2003; FREITAS

JÚNIOR et al., 2009; SILVA et al., 2011). According to Cruz et al. (2011), the 2010/2011 harvest made 498 corn cultivars available, of which only five were popcorn varieties (RS 20, IAC 112, IAC 125, Zélia and UFVM2-Barão de Viçosa).

Thus, the development of varieties and/or hybrids possessing favorable agronomic traits and high levels of popping expansion is essential to promote popcorn cultivation. Since 1998, the Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF) has sponsored a corn breeding program with two targets: the use of recurrent selection in the UNB-2U population to obtain improved varieties and the implementation of diallels to identify superior hybrids and parents for the formation of composite genotypes (PEREIRA; AMARAL JÚNIOR, 2001; FREITAS JÚNIOR et al., 2006; RANGEL et al., 2008; SILVA et al., 2011).

The UENF recurrent selection program is in its fifth cycle and has obtained satisfactory results for both yield (an increase from 1250.00 to 3020.00 kg ha⁻¹) and popping expansion (an increase from 19.25 to 32.00 mL g⁻¹). The breeding program aimed to obtain hybrids (SILVA et al., 2010) to assess the diallel crosses from ten inbred lines of popcorn under the partnership between the UENF and the State University of Maringá (UEM) and identified hybrids that were promising for the northern and northwestern regions of the State of Rio de Janeiro.

Therefore, the present work was developed to assess the agronomic potential of the UNB2U-C5 variety and five hybrids obtained by the UENF/UEM program to verify the feasibility of registering these materials for cultivation in Northern and Northwestern Rio de Janeiro State.

Material and methods

The experiments were conducted during the 2009/2010 (Campos dos Goytacazes and Cambuci) and 2010/2011 (Campos dos Goytacazes, Cambuci and Itaocara) seasons, comprising five environments of Northern and Northwestern Rio de Janeiro.

Sixteen genotypes of popcorn formed by eight open-pollinated varieties and eight hybrids (Table 1) were assessed. The experiment was arranged in a randomized block design, with three replications. The plots comprised two rows of 12 m, with 0.9 m spacing between rows and 0.2 m spacing between plants, totaling 120 plants per plot. Three seeds were used per hole at a depth of 0.05 m. Thinning was performed 21 days after emergence. Topdressing and other cultural practices were performed as recommended (SAWAZAKI, 2001).

Table 1. Characterization of the genotypes evaluated in five environments in Northern and Northwestern State of Rio de Janeiro.

Genotypes	Type	Origin
BRS Angela	Open-pollinated variety	Embrapa
UFVM2 - Barão de Viçosa	Open-pollinated variety	UFV
Viçosa	Open-pollinated variety	UFV
Beija-Flor	Open-pollinated variety	UFV
SAM	Open-pollinated variety	-
UNB2U-C3	Open-pollinated variety	UENF
UNB2U-C4	Open-pollinated variety	UENF
UNB2U-C5	Open-pollinated variety	UENF
Zelia	Three-way hybrid	Pionner
Jade	Three-way hybrid	Pionner
IAC 112	Modified one-way hybrid	IAC
P ₁ x P ₃	One-way hybrid	UEM/UENF
P ₁ x P ₇	One-way hybrid	UEM/UENF
P ₂ x P ₄	One-way hybrid	UEM/UENF
P ₂ x P ₅	One-way hybrid	UEM/UENF
P ₃ x P ₇	One-way hybrid	UEM/UENF

The two principal traits of popcorn, grain yield (GY) and popping expansion (PE), were assessed. The GY was determined based on the average of the plot, through the weighing of the grains after the removal of the cob, which was expressed in kg ha⁻¹. The PE was determined in the laboratory: 30 g of seeds in a special plastic container were popped in a microwave oven at 1000 W for 2 min and 20 s, with three replicates per treatment. The expanded volume was measured in a graduated cylinder, and PE was calculated using the ratio of the expanded final volume (mL) and the initial weight of the grains (30 g).

The data were submitted to analyses of variance, according to the environment, and the selective accuracy (AS) was estimated by the expression:

$$AS = (1 - [1/F])^{0.5},$$

where:

F is the value of the F test for the source of genotype variation (RESENDE; DUARTE, 2007). Homogeneity between the residual variances (MSRs) was verified by the ratio between the highest and lowest MSR (GOMES, 1990). The following model was adopted for the joint analysis:

$$Y_{ijk} = \mu + R/E_{k(j)} + G_i + E_j + GE_{ij} + \xi_{ijk},$$

where:

Y_{ijk} is the average phenotypic value of the plot, μ is the average, $R/E_{k(j)}$ is the effect of the k^{th} replication in the j^{th} environment, G_i is the fixed effect of the i^{th} genotype, E_j is the effect of the j^{th} environment, GE_{ij} is the effect of the interaction of the i^{th} genotype in the j^{th} environment and ξ_{ijk} is the experimental error.

The partition of the complex interaction was performed for the GY in pairs of environments

using the algorithm proposed by Cruz and Castoldi (1991) in which the complex part was expressed by:

$$C = \sqrt{(1-r)^3} \sqrt{Q_1 \cdot Q_2}$$

such that Q_1 and Q_2 were the average squares of genotypes in the environments 1 and 2, respectively, and r referred to the correlation between the averages of the genotypes in the two environments. The method used to estimate adaptability and stability was that proposed by Lin and Binns (1988):

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

where:

P_i is the superiority index of the i^{th} cultivar, X_{ij} is the yield of the i^{th} cultivar planted in the j^{th} location, M is the maximum response achieved among all of the cultivars in the j^{th} location, and n is the number of environments. This expression was partitioned into the following:

$$P_i = \left[\frac{n(X_i - \bar{M})^2 - \sum_{j=1}^n (X_{ij} - \bar{X} - M_j - \bar{M})^2}{2n} \right]$$

where:

X_i is the average of the cultivar i achieved in n environments, and M is the average of the maximum response of all of the cultivars in all of the environments. The first term of the equation refers to the sum of the squares related to the genetic effect, and the second is the sum of the squares of the GE interaction.

Results and discussion

The individual analyses of variance showed significant differences for the source of genotype variation for GY and PE in all of the environments, indicating large variations in the genotypes assessed (Table 2). The estimates of accuracy were high ($\geq 70 < 90$) or very high (≥ 90) in all cases, indicating high experimental precision. The use of accuracy as a measure of experimental precision, as proposed by Resende and Duarte (2007), has the advantage of being independent of the assay average, making accuracy an adequate measure of experimental precision. According to Cargnelutti Filho and Storck (2009), statistical analyses of selective accuracy are considered more appropriate than the coefficient of

variation and least significant difference by the *Tukey* test, as the average percentage, to evaluate the experimental precision in competition assays of corn cultivars.

To make the mean square residual (MSR) of the joint analysis representative of an unbiased estimate of the average residual variance, the homogeneity of the MSRs was assessed by the relationship between the highest and lowest MSR. A ratio of 4.06 and 1.55 was achieved for GY and PE, respectively (Table 2). According to Gomes (1990), the variances are considered homogeneous, i.e., a joint analysis can be performed without any restriction when the ratio between the highest and lowest MSR is less than 7.0.

Table 2. Mean squares, averages and coefficients of variation of two experimental traits evaluated in five environments and in sixteen popcorn genotypes.

SV	DF	Mean squares ^{1/}	
		GY	PE
Block/environ.	10	1188258.06	12.50
Genotype (G)	15	3308784.39**	316.44**
Environment (E)	4	1714511.75**	54.53**
G x E	60	775175.81**	7.66 ^{NS}
Residue	150	333652.90	6.18
Average	-	2692.27	30.84
QMr ⁺ /QMr ⁻	-	4.06	1.55

^{1/}GY = grain yield and PE = popping expansion. ** = Significant at 1% probability.

Considering the sources of variation genotype and environment, the joint analysis of variance revealed significant differences using the *F* test for the GY and PE traits, which indicates the existence of variation among the genotypes and among the environments tested (Table 2). Regarding the genotype x environment interaction (GE), only the GY was significant ($p < 0.01$), which evidenced differences in the behavior of the cultivars due to environmental variations. No significant effects in GE were observed for PE, which agrees with the findings of Von Pinho et al. (2003), in their assessment of eight popcorn varieties (five varieties and three hybrids) in different locations and crop years in the state of Minas Gerais. However, several authors reported the presence of a GE interaction for the popping expansion trait (VENDRUSCOLO et al., 2001; NUNES et al., 2002; SCAPIM et al., 2010). Studies on PE inheritance indicate that the trait is quantitatively inherited and is mainly of an additive nature but that its genetic control is dependent on a smaller number of genes when compared to the output (ROBBINS JUNIOR; ASHMAN, 1984; DOFING et al., 1991; LU et al., 2003; BABU et al., 2006; LI et al., 2007).

The Cruz and Castoldi (1991) algorithm revealed the predominance of a complex type of interaction between the pairs of environments evaluated for GY (Table 3). This result indicates a low correlation

between the performance of the genotypes and environments evaluated, leading to changes in the ranking of the genotypes due to their different responses to environmental variations (ROBERTSON, 1959). Therefore, it is necessary to search for measures to reduce the effects of the GE interaction, including studies on the stability and adaptability of different genotypes, seeking to discriminate the responses of each genotype to environmental variations to identify those with broad or specific adaptability and those with predictable behavior (NUNES et al., 2002; GARBUGLIO et al., 2007).

Table 3. Estimates of the complex interactions for grain yield evaluated in sixteen popcorn genotypes in five environments.

Environments	Interactions (%)
Cambuci (09/10) x Campos dos Goytacazes (09/10)	64.68
Cambuci (09/10) x Cambuci (10/11)	94.96
Cambuci (09/10) x Campos dos Goytacazes (10/11)	57.20
Cambuci (09/10) x Itaocara (10/11)	66.94
Campos dos Goytacazes (09/10) x Cambuci (10/11)	90.13
Campos dos Goytacazes (09/10) x Campos dos Goytacazes (10/11)	32.01
Campos dos Goytacazes (09/10) x Itaocara (10/11)	52.29
Cambuci (10/11) x Campos dos Goytacazes (10/11)	80.03
Cambuci (10/11) x Itaocara (10/11)	91.79
Campos dos Goytacazes (10/11) x Itaocara (10/11)	45.16

The overall averages ranged from 1790.56 to 3485.71 kg ha⁻¹ for the GY and from 24.41 to 37.87 mL g⁻¹ (Table 4) for the PE, demonstrating the high potential of certain genotypes in the environments studied. The UNB2U-C5 population was the most productive (3047.56 kg ha⁻¹) and presented the highest PE (35.69 mL g⁻¹) among the open-pollinated varieties. The variety Viçosa presented the second highest GY average (2863.55 kg ha⁻¹) among the open-pollinated varieties, but it presented the lowest value for PE (24.41 mL g⁻¹). In contrast, the BRS Angela and UFVM2 - Barão de Viçosa varieties presented good PE values (34.52 and 33.31 mL g⁻¹

respectively) but both achieved low yields (2192.11 and 2314.50 kg ha⁻¹, respectively) in the evaluated environments. Hybrids P₂ x P₄ and P₂ x P₉ achieved the highest average GY (3262.13 and 3485.71 kg ha⁻¹) (Table 3); however, these materials presented PE values below 30 mL g⁻¹. The hybrid P₁ x P₇ achieved GY and PE values (2875.46 kg ha⁻¹ and 36.82 mL g⁻¹, respectively) close to the best commercial hybrid, IAC 112 (2724.40 kg ha⁻¹ and 37.87 mL g⁻¹, respectively). It should be emphasized that the IAC 112 hybrid is highly productive in the State of São Paulo and is responsible for the reduced importation of popcorn grains in Brazil (MENDES DE PAULA et al., 2010). The other commercial hybrids, Zélia and Jade, revealed GY of 2509.81 and 2423.52 kg ha⁻¹, respectively, and PE of 33.36 and 33.53 mL g⁻¹, respectively.

Pi Lin and Binns (1988) statistics showed that genotypes P₂ x P₉, P₂ x P₄, UNB2U-C4, P₁ x P₃, UNB2U-C5 and P₁ x P₇ presented the lowest P_i values for GY. Therefore, these genotypes tend to be more adaptable and stable (Table 5) and can be considered superior, as they exhibited the highest average GY and a small contribution to interaction. This high correlation between average and stability is a feature of the method of Lin and Binns (1988) because it relates stability to genotype ability to present the smallest deviation in relation to the maximum in the environments under study. As observed by other authors, this is the most important advantage of this method because it allows the identification of the most stable genotypes among the most productive genotypes (DAROS; AMARAL JÚNIOR, 2000; SCAPIM et al., 2000; CARBONELL et al., 2001; FERREIRA et al., 2004; CARGNELUTTI FILHO et al., 2007; MENDES DE PAULA et al., 2010; SCAPIM et al., 2010).

Table 4. Means of two experimental traits (grain yield - GY and popping expansion - PE) evaluated in sixteen genotypes.

Genotypes	GY					Mean	PE Mean
	Env1 ¹	Env2	Env3	Env4	Env5		
BRS Angela	2075.67	2500.00	2363.27	2171.30	1850.31	2192.11	34.52
UFVM2- Barão de Viçosa	1658.67	2770.00	2494.29	2602.47	2047.07	2314.50	33.31
Viçosa	2878.00	2561.67	3701.39	2656.64	2520.06	2863.55	24.41
Beija-Flor	2114.00	1497.00	3028.94	2663.12	1757.87	2212.18	27.47
SAM	1915.00	1743.67	2200.00	1850.31	1243.83	1790.56	27.59
UNB2U-C3	2515.67	1018.67	2353.70	2641.20	2596.45	2225.14	29.77
UNB2U-C4	3032.33	3240.67	3184.03	2989.97	2487.65	2986.93	31.38
UNB2U-C5	2577.33	3163.67	3530.09	3358.80	2608.02	3047.58	35.69
Zelia	2523.33	2716.00	2819.44	2362.96	2127.31	2509.81	33.36
Jade	2731.33	2577.00	2514.81	2899.38	1395.06	2423.52	33.53
IAC 112	3534.00	2135.67	3274.69	2598.15	2079.48	2724.40	37.87
P ₁ x P ₃	2646.33	3889.00	2930.56	3188.27	2534.72	3037.78	29.11
P ₁ x P ₇	2400.00	3125.00	3085.65	2720.37	3046.30	2875.46	36.82
P ₂ x P ₄	2679.00	3533.67	3446.76	3405.86	3245.37	3262.13	20.93
P ₂ x P ₉	3858.00	3835.00	3357.87	3322.92	3054.78	3485.71	29.54
P ₃ x P ₇	3742.33	4051.00	1288.43	3287.04	3355.71	3144.90	28.20

¹Env1 = Cambuci (2009/2010); Env2 = Campos dos Goytacazes (2009/2010); Env3 = Cambuci (2010/2011); Env4 = Campos dos Goytacazes (2010/2011) and Env5 = Itaocara (2010/2011).

The P_i estimation can be divided into two parts: the first is attributed to genetic drift in relation to the maximum; and the second refers to the interaction between the genotype and environment (LIN; BINNS, 1988). Because the second part can change the classification of genotypes, the ideal material should present the lowest P_i , with most of this value being attributable to genetic drift (MENDES DE PAULA et al., 2010). Thus, the six genotypes that expressed the lowest P_i estimates revealed percentage values of the GA interaction ranging from 6.69 to 51.01%. Among these genotypes, UNB2U-C4, $P_1 \times P_7$ and UNB2U-C5 presented the lowest values, with magnitudes of 6.69, 17.71 and 24.91%, respectively (Table 5)

According to the P_i statistics, the favorable environments for GY were Campos dos Goytacazes for the 2009/2010 and 2010/2011 harvests and Cambuci for the 2010/2011 harvest, which exhibited the highest averages in comparison to the other environments. The environments of Cambuci for the 2009/2010 harvest and Itaocara for the 2010/2011 harvest were considered unfavorable.

Although in different ranking, the six genotypes with the lowest general P_i values were also the ones that exhibited the lowest P_{if} value for the favorable environments. The following genotypes were notable for general P_i in descending order of magnitude: $P_1 \times P_7$; UNB2U-C5; $P_1 \times P_3$; UNB2U-C4; $P_2 \times P_4$ and $P_2 \times P_9$. For the favorable environments, $P_1 \times P_7$, UNB2U-C4, UNB2U-C5, $P_1 \times P_3$, $P_2 \times P_4$ and $P_2 \times P_9$, in that order, presented the lowest P_{if} values (Tables 5 and 6).

Table 5. Estimates of the stability parameters of Lin and Binns (1988) for the trait grain yield (kg ha^{-1}), of 16 popcorn genotypes evaluated at five locations.

Genotypes	General $P_i/10000$	Deviation		% of genetic derivation	Contribution to the interaction (%)
		Genetic	Interaction		
BRS Angela	111.63 (13)	109.86	1.77	98.41	1.59
UFVM2*	102.93 (12)	92.47	10.47	89.83	10.17
Viçosa	44.38 (7)	32.87	11.51	74.07	25.93
Beija-Flor	131.21 (14)	106.90	24.31	81.47	18.53
SAM	182.33 (16)	177.44	4.89	97.32	2.68
UNB2U-C3	139.74 (15)	105.02	34.73	75.15	24.85
UNB2U-C4	25.33 (3)	23.63	1.69	93.31	6.69
UNB2U-C5	30.18 (5)	22.66	7.52	75.09	24.91
Zelia	69.38 (10)	67.81	1.57	97.74	2.26
Jade	89.51 (11)	78.23	11.27	87.41	12.59
IAC 112	62.37 (9)	45.12	17.24	72.35	27.65
$P_1 \times P_3$	28.10 (4)	20.26	7.84	72.12	27.88
$P_1 \times P_7$	40.75 (6)	33.53	7.22	82.29	17.71
$P_2 \times P_4$	17.35 (2)	8.50	8.85	48.99	51.01
$P_2 \times P_9$	2.62 (1)	1.78	0.84	67.91	32.09
$P_3 \times P_7$	58.50 (8)	14.02	44.48	23.96	76.04

*Barão de Viçosa.

With respect to the unfavorable environments, the genotypes with the lowest P_{id} values were not the

same as those that expressed the lowest overall P_i estimates. The following genotypes were notable for the unfavorable environments: $P_3 \times P_7$; $P_2 \times P_9$; $P_2 \times P_4$; UNB2U-C4; Viçosa and IAC 112 (Table 6). The UNB2U-C5 population was allocated to the fourth position in the favorable environments and occupied the eighth position in the unfavorable environments.

The hybrid $P_1 \times P_7$ was allocated in a new position in the unfavorable environments. However, it is noteworthy that the Cambuci environment for the 2009/2010 harvest, which was considered unfavorable, was strongly affected by both abiotic and biotic factors during the evaluation period. This result can be verified by the Cruz and Castoldi (1991) algorithm in a highly complex interaction (94.96) between the agricultural years of 2009/2010 and 2010/2011. In this scenario, further evaluations are necessary for the Cambuci environment to corroborate the results obtained in the present study.

Table 6. Estimates of the parameters stability and adaptability, considering favorable and unfavorable environments by the method of Lin and Binns (1988) for the trait grain yield.

Genotypes	Lin and Binns (1988)	
	Favorable ($P_i/10000$)	Unfavorable ($P_i/10000$)
BRS Angela	95.34 (12)	136.07 (13)
UFVM2*	62.39 (9)	163.74 (15)
Viçosa	46.32 (7)	41.47 (5)
Beija-Flor	125.45 (14)	139.87 (14)
SAM	166.63 (15)	205.88 (16)
UNB2U-C3	193.27 (16)	59.46 (10)
UNB2U-C4	18.29 (5)	35.88 (4)
UNB2U-C5	13.65 (4)	54.98 (8)
Zelia	60.79 (8)	82.26 (11)
Jade	63.95 (10)	127.84 (12)
IAC 112	75.05 (11)	43.34 (6)
$P_1 \times P_3$	11.13 (3)	53.55 (7)
$P_1 \times P_7$	30.89 (6)	55.54 (9)
$P_2 \times P_4$	5.54 (2)	35.06 (3)
$P_2 \times P_9$	2.86 (1)	2.26 (2)
$P_3 \times P_7$	97.28 (13)	0.33 (1)

*Barão de Viçosa.

However, by the results obtained, it is notable that the open-pollinated variety UNB2U-C5 and the hybrid $P_1 \times P_7$ presented high potential to be introduced to Northern and Northwestern Rio de Janeiro, as these materials combined high yield and good popping expansion, as was also reported by Rangel et al. (2011) and Silva et al. (2010, 2011). Therefore, these genotypes have the potential to be registered by the Ministry of Agriculture, Livestock and Supply (MAPA) and to be recommended to local producers aiming at agricultural diversification in the region.

Conclusion

The open-pollinated UNB2U-C5 variety and the hybrid $P_1 \times P_7$ can be recommend for Northern and Northwestern Rio de Janeiro State.

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