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Resistance of popcorn hybrid (*Zea mays*) to multiple diseases and correlation between leaf disease intensity and agronomic traits

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Abstract

Grain yield and popcorn quality losses have become more common due to attacks by pathogens responsible for leaf diseases. Genetic resistance is the main control measure, as it is applicable in large areas and uses reduced costs and less environmental impact, compared to chemical control. In this context, the purpose was to select popcorn hybrids that meet resistance to *Exserohilum turcicum*, *Bipolaris maydis*, and *Puccinia polysora* and to have high levels of popping expansion and grain yield. We took into account two growing seasons (summer harvest - October 2014 to January 2015 - and winter harvest- April to July 2015). Twenty-eight hybrids from the complete diallel cross scheme were evaluated, among eight inbred lines (P8, P1, L55, L61, L70, L76, L77 and L88). For this purpose, we used a randomized block design with four replicates in two growing seasons. The traits investigated were the incidence of *P. polysora* (IPP), *B. maydis* (IBM), and *E. turcicum* (IET); severity of *P. polysora* (SPP), *B. maydis* (SBM), and *E. turcicum* (SET); grain yield (GY); and popping expansion (PE). Data from the experiments were submitted to the principal component analysis (PCA) through the R software. Results showed that the traits IET and IPP in the summer harvest, and IET and SET, in the winter harvest, were the most significant in the select of hybrids. The P8 x L76 and L70 x P8 hybrids were selected for summer harvest and the L77 x L61 hybrid, for winter harvest.

Keywords: genetic resistance; hybrids; leaf diseases; multivariate analysis; *Zea mays* L.
Abbreviations: IPP_incidence *Puccinia polysora;* IBM_incidence *Bipolaris maydis;* IET_incidence *Exserohilum turcicum;* SPP_severity *Puccinia polysora;* SBM_severity *Bipolaris maydis;* SET_severity *Exserohilum turcicum;* GY_grain yield; PE_popping expansion; PCA_principal component analysis; PC_principal component; CN_condition number.

Introduction

Popcorn (*Zea mays* L. var. everta (Starter.) L. H. Bailey), classified as special maize, is widely disseminated in Brazil and presents high economic importance due to a large demand and consumption of the product. Despite this, little official information is available regarding its production and marketing, particularly in Brazil. This is mainly related to the preference of packaging companies for imported seeds (Freitas Júnior et al., 2009) and to the lack of cultivars adapted to the different regions of Brazilian cultivation (Moterle et al., 2012; Carvalho et al., 2013; Gonçalves et al., 2014). The number of cultivars available under the public initiative is also small. In this regard, according to the National Registry of Cultivars (Mapa 2018), only 26% out of 105 registered cultivars come from public institutions and are available for free commercial use.

Obtaining genotypes that present high agronomic potential for grain yield – a trait of greater interest to the producer – together with high popping expansion – a trait of quality of interest to the consumer – is a great challenge in the search for new cultivars in popcorn breeding programs (Amaral Junior et al., 2010; Silva et al., 2013). Nevertheless, the superior genotype generation for resistance to disease is of great importance for the crop, as it is a more susceptible species than common maize (Arnhold, 2008; Vieira et al., 2009; Vieira et al., 2011; Kurosawa et al., 2017; Kurosawa et al., 2018).

In the common maize, the occurrence of leaf diseases crop causes damage to the quality and production of grains. However, in popcorn, these diseases become even more harmful. Among leaf diseases, the most prominent are the northern leaf blight [*Exserohilum turcicum* (Pass) Leonard & Suggs; teleomorph Setosphaeria turcica (Pass) Leonard & Suggs]; southern leaf blight [*Bipolaris maydis* (Nisik and Myiake) Shoemaker (1959); teleomorph Cochliobolus heterostrophus (Drechsler) Drechsler (1934)]; and Polysora rust caused by *Puccinia polysora* Underw (1897). Losses in crops resulting from diseases vary depending on the year and location. Many factors influence their incidence, including environmental conditions, host genotype and time (crop growth stage) of infection, management practices of different crops, and previous disease history (Munkvold and White, 2016). Chemical control can reduce the incidence of these diseases, but these methods are not economically and environmentally viable for grain yield. Conversely, the use of genetic resistance is an approach that favors cost-benefit from an economic and environmental point of view, reducing income losses caused by these diseases.

To have genotypes with high popcorn quality, yield, and resistance to diseases, the selected material must combine all these traits simultaneously, meeting the requirements of the producer, seed companies, and the final consumer. Despite the fact that genetic breeding programs evaluate a number of phenotypic variables, it is still difficult to select genotypes with the greatest number of traits of interest. However, the multivariate analysis technique has been employed in genetic studies, enabling the evaluation of traits taking into account a greater number of variables and their respective correlations (Ledo et al., 2003; Hair et al., 2009).

Some multivariate techniques, like the principal components, can be used to select superior genotypes and simultaneously analyze several traits and the relationships among them. One of the goals of the technique is the possibility to reduce the data set, keeping as much relevant information as possible in the lower number of components (Hongyu et al., 2016). Studies to select genotypes were conducted using the principal component analysis in different crops, including sorghum (Pedreira et al., 2008), cowpea (Campos et al., 2010), common beans (Oliveira et al., 2018), maize (Chandrashekara et al., 2014), and soybeans (Vianna et al., 2013; Dallastra et al., 2014; Leite et al., 2018). Therefore, the adoption of this technique in popcorn can help to select superior genotypes for resistance to leaf diseases and agronomic traits. It is worth emphasizing that, even though this approach has outstanding potential, it has not been used in popcorn yet, which gives this study an innovative approach.

In view of this, the purpose of the study was to select popcorn hybrids, on the basis of the principal component analysis, which combine resistance to *E. turcicum*, *B. maydis*, and *P. polysora*, as well as superiority for popping expansion and grain yield. Furthermore, the intention is to identify the most influential traits in the selection of genotypes when evaluated in two growing seasons.

Results and Discussion

Principal component analysis

The PCA revealed the first two principal components presented eigenvalues greater than one in the summer harvest, jointly explaining 72.39% of the accumulated variance in the seven original variables (Table 1). In the winter harvest, the two principal components were enough to explain 75.73% of the total variance accumulated in the six variables evaluated (Table 1). Based on Cruz et al. (2012), total variations above 80%, achieved in the first two or three principal components, enabling analysis of the genotypes by using scatter plots. On the other hand, studies with principal components in different cultures presented favorable results, with a total variation below the recommended 80% in the first two components (Pedreira et al., 2008; Costa et al., 2013; Oliveira et al., 2018).

We verified that, in the two growing seasons, only the first two PCs generated from this analysis presented eigenvalues greater than one to determine the principal component number (PCs). In line with the Kaiser criterion (1958), only the principal components that present eigenvalues greater than one are considered in the PCA (λi>1), indicating they would be the statistically significant values. Some authors related that eigenvalues above one resulting in components with significant amounts of information from the original variables (Campos et al., 2010; Dallastra et al., 2014; Leite et al., 2018). As such, the first two PCs in the two growing seasons were considered adequate to effectively represent the total sample variance, being these selected for the data set study (Table 1).

According to Hongyu et al. (2015), the discriminative power of the variables in each principal component is measured by correlation. Thus, the characterization of the variables of greatest importance and those of least contribution to the selection enables better use of resources in the breeding program, making it possible to discriminate genotypes efficiently. Hence, in the summer harvest, IET (0.88) and IPP (0.88) descriptors equally presented the highest contribution to the component generated (Figure 1a), since they had the highest magnitude for the value (either positive or negative). Conversely, GY (0.80) and PE (- 0.71) were the most significant in the second principal component (PC2). These traits contribute significantly to the variability of hybrids, with greater influence regarding the accumulated variance. At this growing season, these variables would be the most responsive for selecting popcorn hybrids.

In the winter harvest, the principal component analysis enabled the reduction of six descriptors to two principal components. The descriptors of greater weight were IET (0.93) and SET (0.90) at PC1, and the descriptors of greater contribution in absolute value at PC2 were SBM (0.85), IBM (0.74), and GY (- 0.67) (Figure 1b). It should be noted that, for PC1 in the two growing seasons (Figure 1a and 1b), it was evident the contrast of the contribution between GY (negative contribution) and leaf diseases (positive contribution). The difference between the negative and positive values found in the variables results in different responses in hybrids. In other words, the value of one variable contributes to increasing; while the value of the other contributes to decreasing. In this way, the diseases under evaluation contribute to reducing the grain yield of popcorn crops in different harvests. An inverse relationship between GY and PE is also noted in the two harvests when the two principal components are considered, which confirms the negative correlation between these traits (Carpentieri-Pípolo et al., 2002; Rangel et al., 2011; Freitas et al. al., 2013; Cabral et al., 2015).

In the two harvests, the attributes associated with resistance to diseases showed greater relevance for the hybrid discrimination in the first two principal components, followed by GY and PE. As already known and evidenced by the results, the genotype selection of popcorn in breeding programs is mainly based on the traits of interest, such as GY and PE. The variables associated with biotic stresses, such as leaf diseases, can directly or indirectly influence the reduction of the values of these traits. This is why the addition of characters associated with resistance to disease is required in the selection process of superior genotypes.

Biplot analysis

According to Figure 2a, the variables related to IET, SET, IBM, IPP, and SPP leaf diseases had similar contributions to the PC1 in the summer harvest. This was confirmed by the variables that have a longer vector and were closer to the PC1 axis. This indicates that traits related to the diseases have a positive correlation and a negative correlation with

GY, which can also be observed in the winter harvest (Figure 2b). These results confirm the findings of Chandrashekara et al. (2014), who evaluated southern leaf blight and northern leaf blight in maize and found positive associations among the diseases and negative associations with grain yield. Evidence on losses in grain productivity, resulting from increasing attacks of *E. turcicum* pathogens (Ferguson and Carson, 2007; Muiru et al., 2010; Wang et al., 2010; Ding et al., 2015), *B. maydis* (Hussain et al., 2016; Mubeen et al., 2017), and *P. polysora* (Costa et al., 2012; Teixeira et al., 2017), are described in the literature, reiterating the negative relationship among the diseases caused by these pathogens and the grain yield.

In the summer harvest, analysis of the vector projections, and the graph position verified the existence of highly positive correlations among the IPP, IBM, and SPP traits, taking into account their projections are in the same quadrant (Figure 2a). During a study of genotypic correlations among leaf diseases in S_1 families of popcorn, Arnhold (2008) also noticed a positive correlation between the severity of Polysora rust (*Puccinia* sp.) and the severity of *B. maydis*. Different positively correlated diseases help to obtain greater genetic gains in resistance of popcorn, given that the selection will bring gains for both variables, which will make it easier for breeders to obtain genotypes resistant to *B. maydis* and *P. polysora*. In the same harvest, this situation can also be considered regarding the IET and SET traits. However, there was less correlation between SET and the occurrence of IBM or IPP and SPP, which hinders the use of indirect selection to choose hybrids for these variables at this growing season.

In the winter harvest, there was a strong correlation between incidence and severity of evaluated diseases, between IET and SET and between IBM and SBM (Figure 2b). The positive correlation between these variables shows that, there is the possibility of evaluating only the easiest character to measure because the selection is being carried out indirectly for the other variable. A greater emphasis can be placed on the evaluation of a single trait, disregarding the evaluation of other variables that contribute less to the distinction among hybrids. We observed the correlation of the traits associated with the resistance to *E. turcicum* with the popping expansion, which showed to be small and positive in both harvests. This suggests that PE can be influenced by the selection of hybrids with higher resistance to *E. turcicum*. However, in the winter harvest, the correlation was higher, which shows this season was better to maximize the PE potential and resistance to *E. turcicum* in the hybrids under evaluation, as can be seen in the results from this study (Figure 4).

A two-dimensional graph formed by PC1 and PC2 was plotted with the scores of each hybrid on the incidence and severity percentages of leaf diseases, grain yield, and popping expansion (Figures 2a and 2b) to ease the selection and better visualization of the hybrid dispersion. In these cases, hybrids are influenced by the proximity of each trait to the axis of each principal component. Accordingly, when the selection is based on the reduction of leaf diseases, the focus is on obtaining hybrids with lower scores. In contrast, if the selection for the most important trait is related to the grain yield and the popping expansion, the chosen hybrids should be those with the highest scores.

In the summer harvest, the PC1 was responsible for aggregating the L61 x L76 (3) and P1 x L70 (25) hybrids. It found further to the left of the PC1 axis, as they showed the lowest scores for IET and IPP (Figure 2a). This allows affirming these hybrids will help reduction in the levels of these diseases, which corroborates with the mean values of these hybrids for these traits (Figure 3). In the second principal component (PC2), the L77 x L88 (11) and P1 x L88 (13) hybrids were highlighted for presenting a high score, which resulted in their position on the PC2 upper axis (Figure 2a). The superiority of these hybrids for GY, the main trait that explains the data variability in the PC2 axis, can also be verified by the mean test (Figure 3). For the other traits, however, the hybrids did not show high means (Figure 3).

Observing the two main components, PC1 and PC2, the L88 x L76 (1), P1 x L76 (7), L61 x L88 (9), L70 x L88 (10), L77 x L61 (20), and L77 x L70 (23) hybrids stand out for presenting their lower scores for the traits represented by PC1 and their higher scores for the traits represented by PC2 (Figure 2a). However, it can be seen that all hybrids pointed out presented, for popping expansion, a mean estimate below the recommended one (30 mL g^{-1}) for popcorn marketing (Figure 3), when the means for the characters evaluated in these hybrids are considered. Even though hybrids are a source of resistance, they are not suitable to be recommended. however, it was possible to distinguish the P8 x L76 (2) and L70 x P8 (15) hybrids, once these pairs displayed satisfactory scores and means for traits related to leaf diseases, grain yield, and popping expansion.

In the winter harvest, the biplot analysis with the main components characterized the hybrids in two different dimensions associated with resistance to *E*. *turcicum* and *B*. *maydis* (Figure 2b). In relation to PC1, the hybrids with the lowest scores were: P8 x L88 (8), L77 x L88 (11), and L77 x P8 (16), to the left of the PC1 axis, all of which can be distinguished as promising for resistance to IBM and SBM. In contrast, the L61 x L76 (3) and L70 x L76 (4) hybrids, plotted below the PC2 axis, are the most interest for selection concerning the lowest scores for IET and SET. All the aforementioned hybrids of popcorn are the most resistant to the *B. maydis* and *E. turcicum* pathogens, for having the lowest means for the attributes of resistance to these diseases (Figure 4). Nevertheless, the L77 x L61 (20) hybrid was highlighted because of the superiority of the phenotypic values for the six traits that compose the two main axes. In both growing seasons, the wide dispersion of genotypes in the two principal components, proved that there is high variability in the responses of hybrids to diseases. During the two growing seasons, it could be identified both clusters of hybrids with higher levels of resistance to at least one of the leaf diseases studied and clusters of hybrids with higher levels of resistance to all these diseases.

In the summer harvest, the L61 x L76 (3), P1 x L76 (7), L61 x P8 (14), L77 x L61 (20), P1 x L61 (22), L77 x L70 (23), and P1 x L70 (25) hybrids were clustered opposite to the incidence and severity of diseases, pointing to higher levels of resistance to multiple diseases from these genotypes. From the parents of these hybrids, a higher frequency of L61, L70, and P1 lines is observed. Similarly, in the winter harvest, the L61 x L76 (3), L70 x L76 (4), L77 x L76 (5), L61 x L88 (9), L70 x L88 (10), L77 x L61 (20), and L55 x L77 (26) hybrids were clustered opposite to the characters related to the diseases. These hybrids have the L61, L70, and L76 lines as their most frequent parents. These lines had already been mentioned, in the work of Kurosawa et al. (2017), as sources of resistance to at least one or two of these leaf diseases.

Table 1. Estimates of the eigenvalues associated with the main components, jointly with their relative and accumulated importance, for eight traits of popcorn in two growing seasons (summer and winter harvests). Campos dos Goytacazes - RJ, Brazil.

Components	Eigenvalue (λ_i)		Variance Explained (%)		Variance Accumulated (%) Accumulated (%)	
	Summer Harvest	Winter Harvest	Summer Harvest	Winter Harvest	Summer Harvest	Winter Harvest
1	3.28	2.72	46.87	45.31	46.87	45.31
2	1.79	1.83	25.52	30.42	72.39	75.73
3	0.78	0.92	11.17	15.32	83.56	91.05
4	0.58	0.36	8.36	6.02	91.92	97.07
5	0.27	0.14	3.85	2.26	95.77	99.33
6	0.17	0.04	2.40	0.67	98.17	100.00
7	0.13	-	1.83	-	100.00	-

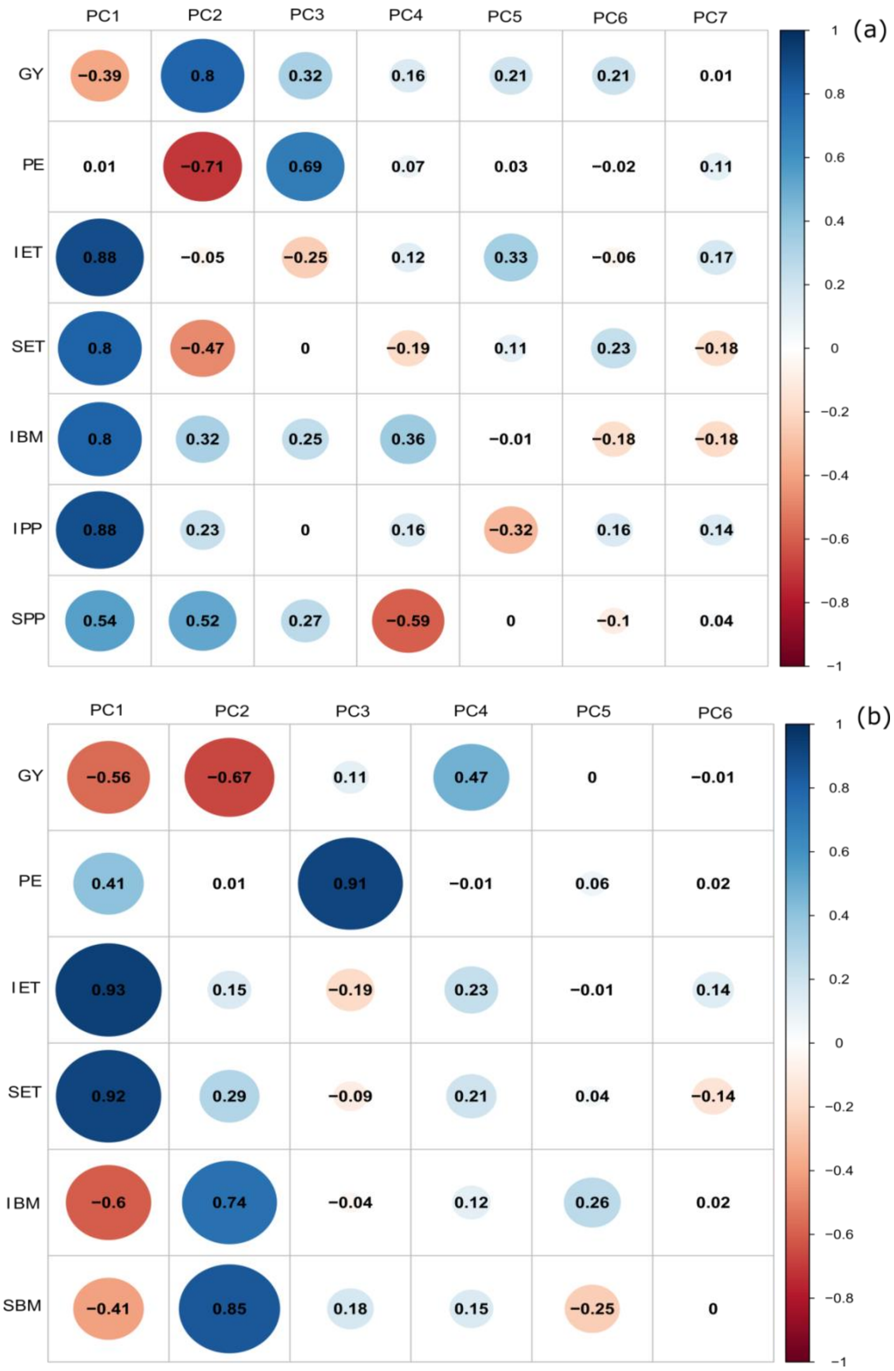

Fig 1. Correlations among the principal components and traits: grain yield (GY); popping expansion (PE); incidence of *E. turcicum* (IET); severity of *E. turcicum* (SET); incidence of *B. maydis* (IBM); severity of *B. maydis* (SBM); incidence of *P. polysora* (IPP) and severity of *P. polysora* (SPP), evaluated in two growing seasons. Campos dos Goytacazes - RJ, Brazil. (a) summer harvest; (b) winter harvest.

Table 2. Identification of 28 simple hybrids ($F_{1's}$) of popcorn. Campos dos Goytacazes - RJ, Brazil.

Identification	Hybrids	Identification	Hybrids
1	L88 x L76	15	L70 x P8
2	P8 x L76	16	L77 x P8
3	L61 x L76	17	L55 x P8
4	L70 x L76	18	P1 x P8
5	L77 x L76	19	L70 x L61
6	L55 x L76	20	L77 x L61
7	P1 x L76	21	L55 x L61
8	P8 x L88	22	P1 x L61
9	L6 1x L88	23	L77 x L70
10	L70 x L88	24	L55 x L70
11	L77 x L88	25	P1 x L70
12	L55 x L88	26	L55 x L77
13	P1 x L88	27	P1 x L77
14	L61 x P8	28	P1 x L55

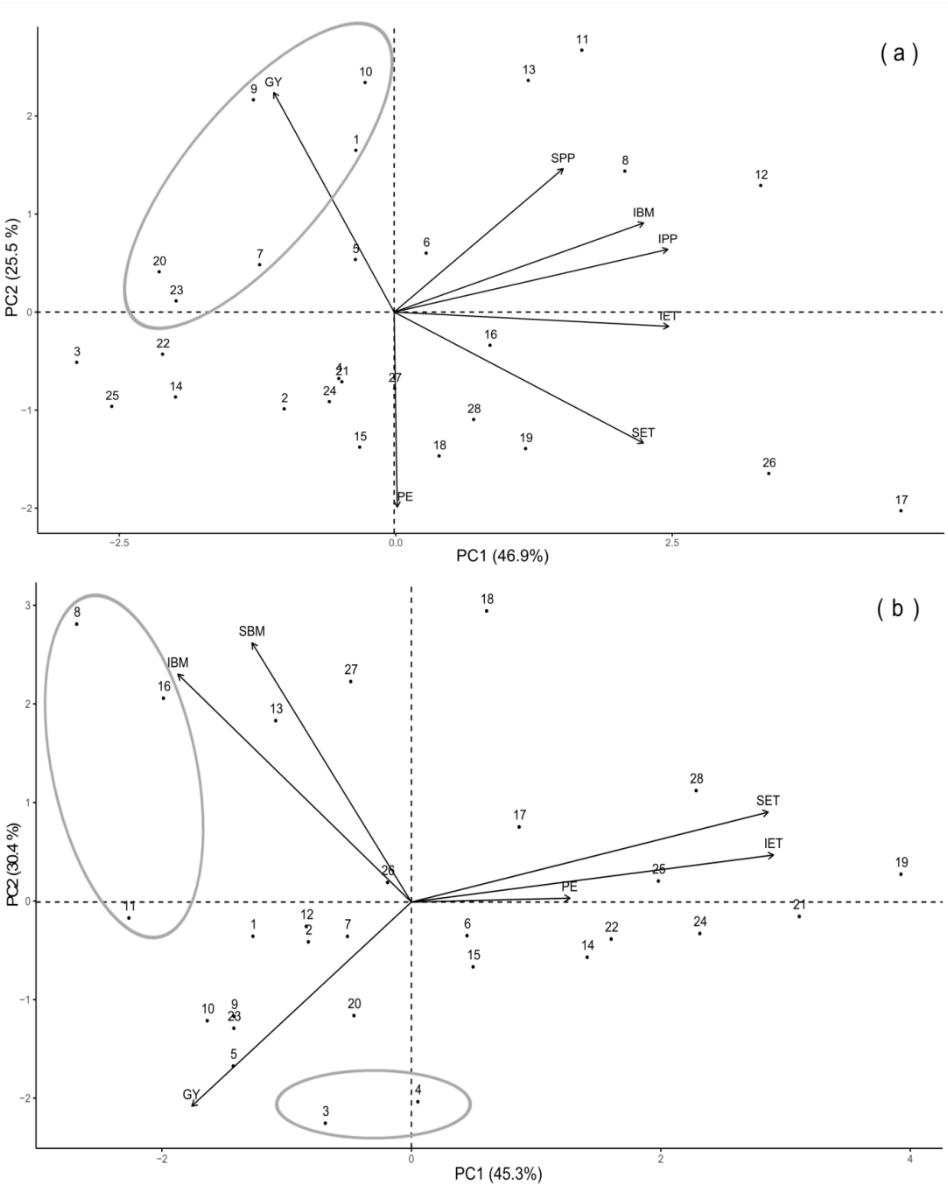

Fig 2. Biplot obtained with the values of the first two principal components, showing the dispersion of 28 popcorn hybrids and the projections of the characteristics: grain yield (GY), popping expansion (PE), incidence of *E. turcicum* (IET), severity of *E. turcicum* (SET); incidence of *B. maydis* (IBM), severity of *B. maydis* (SBM), incidence of *P. polysora* (IPP), severity of *P. polysora* (SPP), in two growing seasons. Campos dos Goytacazes - RJ, Brazil.
(a) summer harvest; (b) winter harvest.

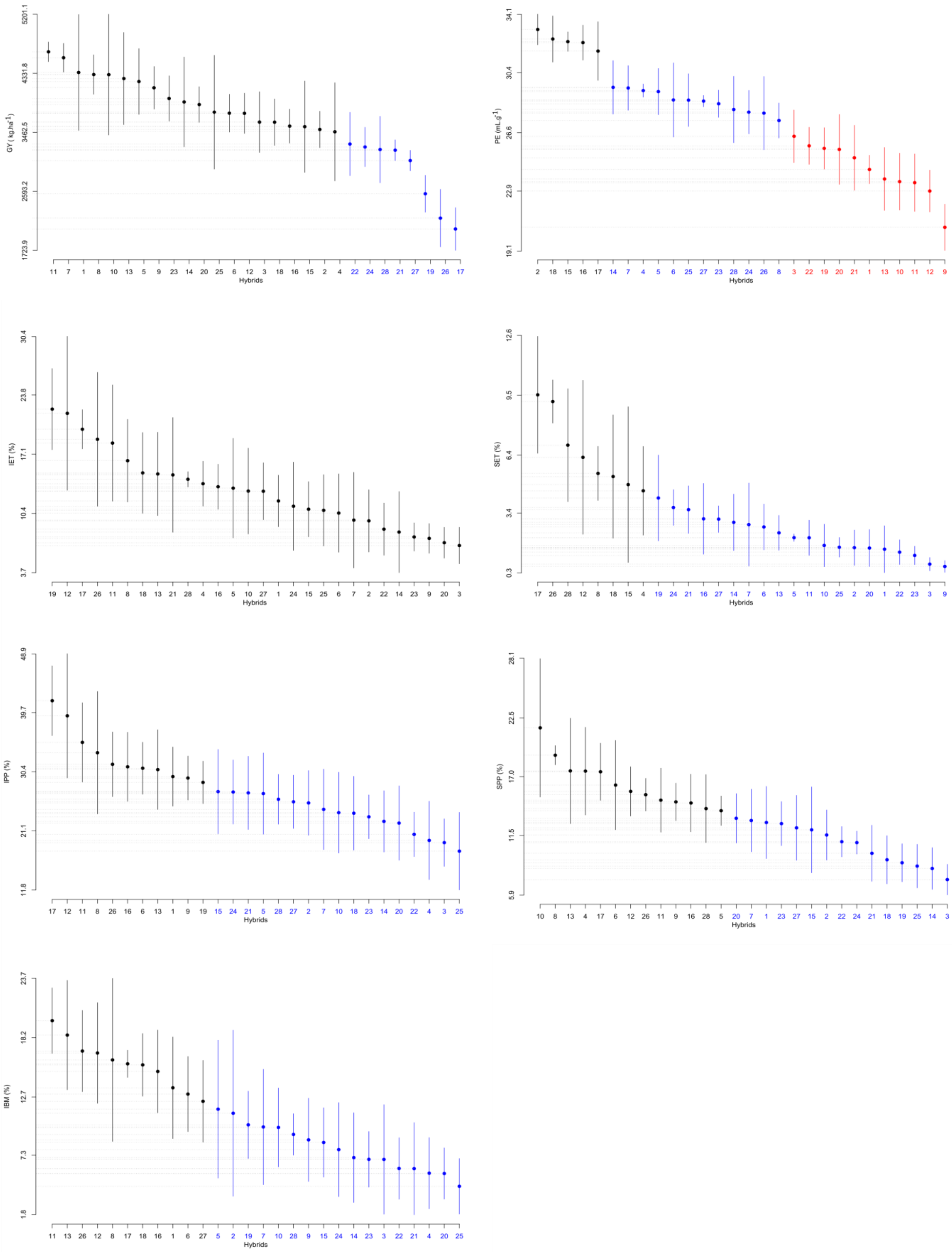

Fig 3. Mean performance of 28 hybrids ($F_{1's}$) in the summer harvest for GY = grain yield ($kg.ha^{-1}$); PE = popping expansion ($mL.g^{-1}$); IET = incidence of *E. turcicum* (%); SET = severity of *E. turcicum* (%); IPP = incidence of *P. polysora* (%); SPP = severity of *P. Polysora* (%); and IBM = incidence of *B. maydis* (%).The points = mean of the hybrid; the bars = standard error.

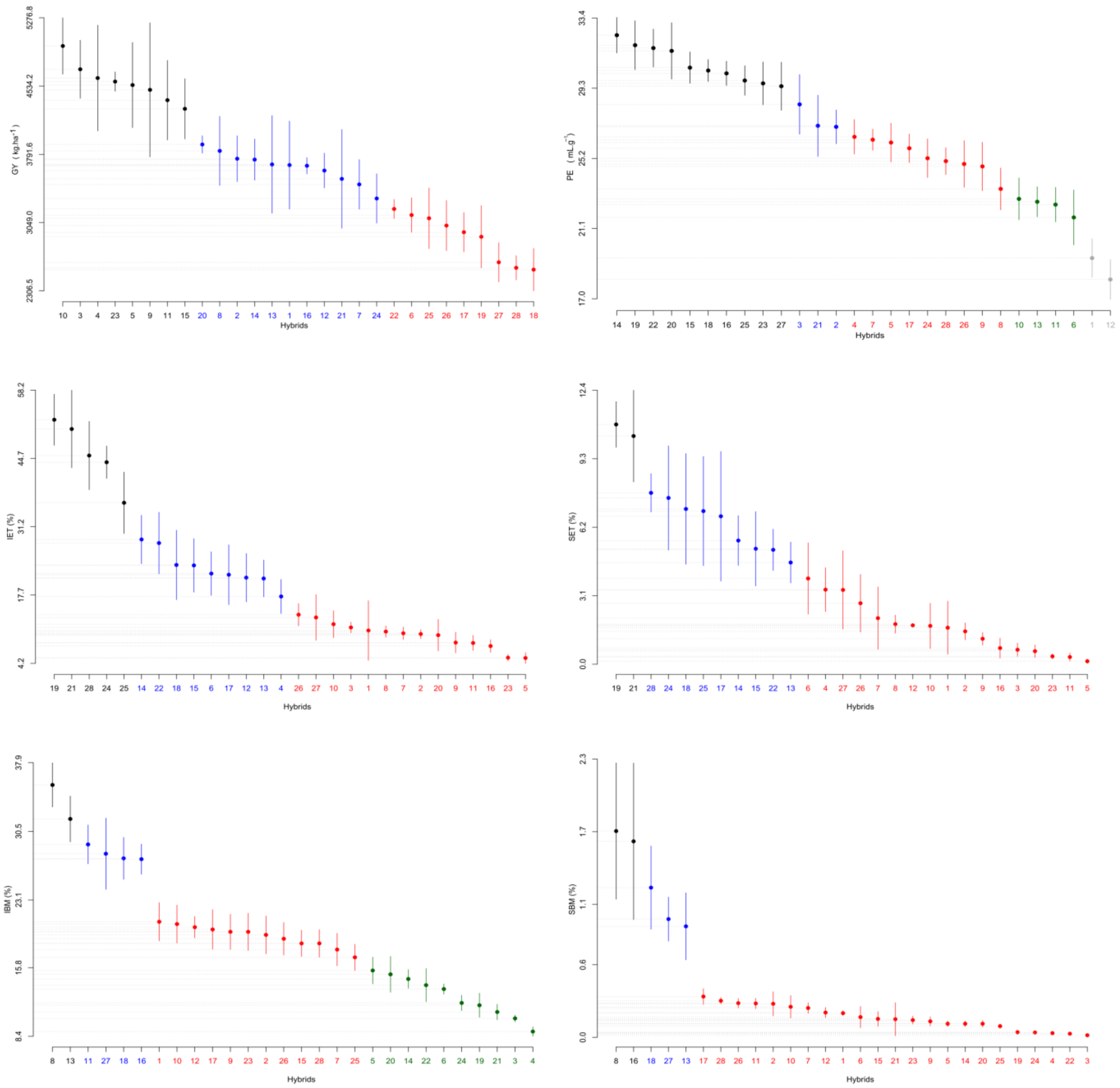

Fig 4. Mean performance of 28 hybrids ($F_{1's}$) in the winter harvest for GY = grain yield ($kg.ha^{-1}$); PE = popping expansion ($mL.g^{-1}$); IET = incidence of *E. turcicum* (%); SET = severity of *E. turcicum* (%); IBM = incidence of *B. maydis* (%); and SBM = severity of *B. maydis* (%). The points = mean of the hybrid; the bars = standard error.

The resistance in these lines may be a result of the origin of the material and the way they were developed. Strategies such as recurring selection are applied to increase to the level of resistance to foliar diseases in susceptible maize cultivars (Parteniani and Miranda Filho, 1978; Bleicher and Balmer, 1993). The L61, L70, and L76 parents, considered the most frequent, originated from the implementation of the recurrent selection, using cultivars that showed good performance for resistance to some leaf diseases mentioned in this study (Miranda et al., 2003; Arnhold et al., 2008).

Materials and Methods

Conduction of experimental

Two experiments were implemented at Colégio Estadual Agrícola Antônio Sarlo, in the municipality of Campos dos Goytacazes, in the north region of the state of Rio de Janeiro, Brazil. The first was conducted in the summer harvest, between October 2014 and January 2015, with average rainfall of 0.047 mm, temperature between 24 °C and 25 °C and relative humidity varying between 70% and 76% over the months. The second experiment was carried out in the winter harvest, between April and July 2015, with temperature between 21 °C and 23 °C, average rainfall of 0.085 mm and relative humidity with variations between 79% and 85%.

Plant materials

Twenty-eight simple hybrids (Table 2), derived from a complete diallel among eight lines (L55, L61, L70, L76, L77, L88, P1, and P8) were evaluated in the seventh generation of self-fertilization from the germplasm bank at the

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Experimental design

A randomized block design with four replicates was adopted. The experimental plots consisted of five-meter rows, with 25 plants per row spacing of 0.2 x 0.9 m among plants and rows, respectively.

Traits measured

The traits under evaluation were reactions to the following leaf diseases: polysora rust, northern leaf blight, and southern leaf blight; besides the agronomic traits: popping expansion and grain yield. Three disease evaluations were performed at seven-day intervals after the female flowering.
Only the five central plants of the plot were considered in the evaluations of leaf diseases, as performed by Santos et al. (2017).
The treatment response to leaf diseases was monitored by means of the appearance of symptoms by a natural infection in the field, using incidence estimates and symptom severity. The incidence of *P. polysora* (IPP), *B. maydis* (IBM), and *E. turcicum* (IET) consisted of the percentage of leaves with symptoms in relation to asymptomatic leaves. This evaluation was conducted according to the score range established by Agroceres (1996), with scores varying from 1 to 9, in which score 1 indicates 0% incidence; 2 – 0.5% incidence; 3 – 10% incidence; 4 – 30% incidence; 5 – 50% incidence; 6 – 70% incidence; 7 – 80% incidence; 8 – 90% incidence; and 9 – 100% incidence of leaf.
The severity evaluation of leaf diseases, which defines the leaf tissue area injured, was carried out using a diagrammatic scale. In evaluating the severity of *E. turcicum* (SET), the diagrammatic scale proposed by Vieira et al. (2014) was used, based on percentages of 0.5; 1.6; 5.0; 15; 37; 66; 87; and 96% of the leaf area injured. The severity of *B. maydis* (SBM) was evaluated based on the diagrammatic scale with percentages of 1, 5, 25, and 50% of the leaf area injured, following the methodology proposed by James (1971). The severity of *P. polysora* (SPP) was estimated from the Cobb diagrammatic scale, with changes (Chester, 1950), based on percentage values between 5 and 100% of the leaf area injured.
The grain yield (GY) was determined by weighing the grains after removing the ear and expressed in kg.ha^{-1}. The popping expansion (PE) was established by the mean of two replicates per treatment, each represented by 30 g of grains. Beans were placed in a microwave oven with a 1,000-watt power and heated for 2 minutes and 20 seconds. After expanding the grains, the popcorn volume was quantified at a beaker of 2,000 mL, and the result was adjusted in relation to the initial weight of 30 grams, expressed in mL of popcorn /g of grains.

Statistical analysis

Data referring to evaluations of incidence and severity of leaf diseases and agronomic traits were submitted to the analysis of variance with the significance of the effects verified by the F test at 5% probability (no data were shown). Hence, further analyses were conducted only for traits with significant effect for each growing season. In this way, in the summer harvest, the following traits were observed: IBM, IET, SET, IPP, SPP, GY, and PE. In the winter harvest, the traits taken into account comprised of IBM, SBM, IET, SET, GY, and PE. The hybrids means were clustered according to the Scott-Knott test at 5% probability.
Multicollinearity was established by means of the condition number analysis (CN), which considers the ratio between the highest and the lowest eigenvalue of the correlation matrix. As stated by Montgomery and Peck (1981), if $CN < 1{,}000$, collinearity is low; if $100 < CN < 1{,}000$, collinearity is moderate to strong; and if $CN > 1{,}000$, collinearity is severe. Once low collinearity was detected, the principal component analysis was carried out employing all the significant traits. The previously mentioned analyses were executed using the GENES statistical software (Cruz, 2013).
All data were standardized and started presenting mean = 0 and variance = 1. The principal component analysis was performed on a phenotypic correlation matrix. The Kaiser method (1958) was adopted to establish the principal component number that explains most of the data variation. Biplot was obtained based on genotype values, using PC1 on the horizontal axis and PC2 on the vertical axis. The analyses were processed in the R Core Team software (2014).

Conclusions

The IET and IPP; IET and SET traits were the most contributed to distinguish the hybrids, in the summer and winter harvests, respectively. There is a positive correlation among all leaf diseases during the summer harvest. In the winter harvest, a strong and positive correlation was seen between the incidence and severity of *B. maydis* and *E. turcicum*. Popping expansion correlates positively with resistance to *E. turcicum* and negatively with grain yield. The P8 x L76 and L70 x P8 hybrids were distinguished for their resistance to multiple diseases and high productivity and popping expansion in the summer harvest. In the winter harvest, the L77 x L61 hybrid provided the best capability for the set of variables studied. In the summer harvest, L61 x L76, P1 x L76, L61 x P8, L77 x L61, P1 x L61, L77 x L70, and P1 x L70 hybrids are relevant to be used as sources of resistance to multiple diseases. In the winter harvest, L61 x L76, L70 x L76, L77 x L76, L61 x L88, L70 x L88, L77 x L61, and L55 x L77 hybrids were the most promising sources of resistance to *B. maydis* and *E. turcicum*.

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