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# Identification of papaya hybrids resistant to *Stagonosporopsis caricae* by heterosis: a possible reality?

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**Abstract** Papaya requires frequent applications of fungicides because of its high susceptibility to disease. However, no products capable of effectively managing the fungus *Stagonosporopsis caricae* are commercially available to date. Because of this limitation and the continuous demand for products free of chemical residues and that achieve higher yields, genetic improvement is necessary to obtain resistant and productive genotypes. The present study used lineages produced by backcrossing and hybrids obtained from the cross between these backcrossed lines and four elite genotypes (SS72-12, Sekati, JS-12, and 41/7) to identify genotypes with increased resistance to phoma spot. The analysis of the effects of heterosis evidenced the possibility of achieving high genetic gains. The evaluation of the incidence and severity of phoma spot indicated that hybrids Sekati × 1, 41/7 × 10, and JS-12 × 21 presented negative heterosis for phoma spot in all evaluated seasons. Considering standard heterosis, the hybrids Sekati × 1 and Sekati × 4 were the most resistant to disease. The Solo group genotypes SS × 04 and SS × 06 presented negative heterosis in at least one season for common and standard heterosis, evidencing that these cultivars were resistant to phoma spot. The obtained results on heterosis and papaya production allowed identifying promising cultivars.

**Keywords** Phoma spot · *Papaya* · Backcross · Resistance

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## Introduction

The papaya tree (*Carica papaya* L.) is susceptible to several diseases that decrease crop yield and restrict the expansion of the culture in Brazil and worldwide (Holliday 1980; Nishijima et al. 1994; Vivas et al. 2013) mainly because of the lower genetic variability and reduced number of cultivars used in commercial crops. Phoma spot is a disease caused by the fungus

*Stagonosporopsis caricae* (Sydow & P. Sydow) Aveskamp, Gruyter & Verkley (= *Phoma Carica-papaya* (Tarr) and is the second most important fungal disease in papaya crops. In the field, phoma spot is characterized by circular necrotic spots and concentric rings, usually with a ruptured or abscinded necrotic center. However, in most of the year, the most significant losses occur in fruits after harvest due to fruit rot or black rot (Rzende and Fancelli 2016).

Symptoms in fruits may appear in the field from the onset of maturation but are more common and pronounced after harvest. In the field, *S. caricae* colonizes primarily the lower and fully developed leaves and leaf petioles, which are sources of inoculum to fruits. Senescent and infected leaves and petioles produce fruiting bodies (pycnidia), which are arranged in concentric rings and synthesize conidia in mucilage, which in turn are transferred to healthy leaves and fruits (Oliveira et al. 2000; Michereff and Barros 2001; Liberato and Zambolim 2002; Rzende and Fancelli 2016). In fruits, in the presence of free water, the conidia germinate, and the hyphae invade wounds and the peduncle, leading to fruit rot. Lesions on fruits, initially superficial and pale, progress to a dark and depressed rot, covered by dark spots (picnids) (Michereff and Barros 2001; Rzende and Fancelli 2016). In an advanced state, these lesions become black, dry, and deep, and can be removed manually (Oliveira et al. 2000), and the popular names "fruit rot" and "black rot" originated from this characteristic.

Papaya production is only profitable with the management of fungal diseases in the field by frequent applications of fungicides. For post-harvest diseases, such as anthracnose and black rot, disease management should be initiated in the field during fruit development to avoid fruit contamination and post-harvest rot (Oliveira et al. 2000). However, chemical control is ineffective under conditions favorable to the disease, usually in rainy seasons and mild temperatures (Santos et al. 2017). Previous studies demonstrated the existence of genotypes of *Carica papaya* L with alleles favoring the development of phoma spot, and these alleles may be used to increase disease resistance (Dianese et al. 2007; Vivas et al. 2012, 2015). Although none of the genotypes identified to date are immune to this disease, disease resistance may be favored in crosses between and within heterotic papaya cultivars (Vivas et al. 2014). In these crosses, negative heterosis ("hybrid vigor") indicates the possibility of selecting resistance to phoma spot (Vivas et al. 2014, 2016).

Heterosis is a natural phenomenon whereby hybrid offspring perform better than parental lines (Fu et al. 2014). In the case of disease-resistant genotypes, heterosis should be negative because hybrids with disease severity lower than that of parental lines (heterosis) or resistant parental lines (heterobeltiosis) are desired. Vivas et al. (2014, 2016) obtained negative heterosis and heterobeltiosis in crosses from the Sekati genotype (Formosa group containing large fruits) as the parental line, demonstrating the possible existence of favorable alleles that can be transferred to offspring, improving disease resistance. However, the studies performed to date evaluated only crosses between elite genotypes.

To select hybrids resistant to phoma spot, we evaluated backcrossed lines, derive from the "Cariflora" dioecious genotype, that presented adequate capacity of combinatorial expression (Barros et al. 2017) and topcross hybrids obtained from the cross between the backcrossed lines and four elite genotypes (testers), to identify the better hybrids combinations resistant and productive. Negative heterosis was used to indicate hybrids with low rates and severity of phoma spot. Of note, the use of field-resistant genotypes may reduce the incidence of black rot in fruits post-harvest.

## Materials and methods

The study was performed from 2014 to 2016 in a field station from Caliman Agrícola SA in the city of Linhares, Espírito Santo state, Brazil. Company records indicated the occurrence of epidemic outbreaks of phoma spot in this municipality in recent years. Ten superior lineages from the backcrossing between the Cariflora dioecious genotype and the elite 'Sunrise Solo 783' (SS 783) genotype were selected based on the agronomic characteristics described by da Silva et al. (2007), Ramos et al. (2011, 2014), and Barros et al. (2017). These lineages present different levels of endogamy in backcross generations (first and third). Topcross hybrids were obtained from the crosses of these ten lineages with the four testers, including three from the Formosa group (JS-12, Sekati, and 41/7) and one from the Solo group (SS-

72/12). Therefore, the study design included 36 treatments: 10 lineages, 20 hybrids (SS-72/12 × 1, SS-72/12 × 2, SS-72/12 × 4, SS-72/12 × 6, SS-72/12 × 9, SS-72/12 × 17, SS-72/12 × 19, Sekati × 1, Sekati × 2, Sekati × 4, Sekati × 6, Sekati × 9, Sekati × 10, Sekati × 17, Sekati × 20, 41/7 × 10, JS-12 × 1, JS-12 × 2, JS-12 × 17, JS-12 × 21), four commercial parental lines, and two controls from commercial cultivars (Golden and Tainung 01).

Planting was performed in January 2015 using a completely randomized block design with six replicates and three plants per plot, totaling 648 plants, with an inter-row spacing of 3.6 m and inter-plant spacing of 1.5 m. Three seedlings were transplanted per pit and, after sexing at 3 months after transplanting, only one hybrid plant was used per pit. All the three plants were within each plot were considered as the useful plot.

Three evaluations of phoma spot were carried out in the field, in August and November of 2015 and in March of 2016, to assess the activity of the pathogen in different seasons and environmental conditions. Disease severity was estimated using a diagrammatic scale used by Vivas et al. (2011), with injured areas of 1%, 2%, 4%, 8%, 16%, and 32% in the leaf below the petiole that contained the first newly opened inflorescence. The incidence of phoma spot was calculated by the ratio of the number of leaves with disease symptoms and the total number of leaves in the plant.

Joint and individual analyses of variance were performed for all studied variables using the evaluation period as a source of variation. The statistical model used is: $Yijk = \mu + ti + bj + \varepsilon ij$, where $\mu$ = overall treatment mean; ti = fixed effect of the i-th treatment; bj = effect of the j-th block; $\varepsilon ij$ = Experimental error associated to observation Yij. The averages were grouped using the Scott–Knott test at a level of significance of 5%. The analyses were performed using GENES software (Cruz 2013).

Heterosis and standard heterosis were estimated in each season using the average of each treatment. Heterosis was calculated using the expression: $HPS = \left(\frac{AHS-APS}{APS}\right) * 100$, where HPS is the heterosis or heterosis based in parents average lineages, AHS is the average of hybrid, and APS is the average of parental lines. Standard heterosis was calculated using the expression: $SH = \left(\frac{AHS-MSS}{MSS}\right) * 100$, where SH is standard heterosis, AHS is the average of hybrid, and MSS is the mean of commercial cultivars.

For calculating standard heterosis, the Golden cultivar was used as the control for the samples from the Solo group (parental lineage SS72/12), and the Tainung cultivar was used as the control for the samples from the Formosa group (parental lines Sekati, JS/12, and 41/7).

## Results

The period with the highest incidence and severity of phoma spot was March 2016 (Table 1). For all variables, the effect of all sources of variation (genotype, season, and genotype × season interaction) was significant, demonstrating the potential of genetic improvement of parental, hybrid, and control lines. In view of the significant effect on the interaction genotype × season, each season was evaluated separately.

There was a significant effect of genotype on the incidence and severity of phoma spot in the second and third seasons (Table 1). The Scott–Knott's grouping test (1974), which was used to determine the incidence of phoma spot, indicated the formation of two groups in the second season and three groups in the third season. The data from the first season were extracted from the analysis due to the lack of significant differences between groups. The period with the highest environmental and genotypic effects to incidence e severity of phoma spot was in November 2015.

The genotypes with the lowest average rates of phoma spot in the two seasons were lineages 4, 6, and 20. Considering only the second season, the parental lines Sekati and JS-12 presented the lowest rates, with absolute rates lower than 30% and an intermediate rate in the third season (Table 1).

The hybrids with the highest incidence of phoma spot in the two seasons were Sekati × 1, Sekati × 4, Sekati × 9, Sekati × 10, Sekati × 20, 41/7 × 10, JS-12 × 17, and JS-12 × 21 (Table 1).

Three groups were formed according to the severity of phoma spot in the second and third seasons (Table 1). The most resistant genotypes were lineages 1, 4, 6, 20, and 21; the parental lines 41/7, Sekati, and SS-72/12, and the control strain Tainung. Of these, parental genotypes 4, 6, 20 presented relatively lower

**Table 1** Average incidence and severity of phoma leaf spot (*S. caricae*) in papaya genotypes in evaluations performed from November 2015 to March 2016 in Linhares, Espírito Santo, Brazil

| Parental lines and hybrids | Rate of phoma leaf spot* | | Severity of phoma leaf spot (%)* | |
|---|---|---|---|---|
| | November 2015 | March 2016 | November 2015 | March 2016 |
| L–1 | 22.92a | 21.17b | 0.87c | 0.00c |
| L–2 | 13.77a | 10.09c | 2.00a | 0.00c |
| L–4 | 8.14b | 12.12c | 0.73c | 0.07c |
| L–06 | 8.84b | 12.50c | 0.58c | 0.06c |
| L–09 | 36.94a | 24.37b | 0.30c | 0.29b |
| L–10 | 6.52b | 18.86b | 0.81c | 0.53b |
| L–17 | 10.91b | 18.42b | 0.97b | 0.06c |
| L–19 | 0.68b | 30.86a | 0.00c | 1.00a |
| L–20 | 7.54b | 7.78c | 0.58c | 0.14c |
| L–21 | 15.05a | 18.88b | 0.61c | 0.00c |
| SS[1] × L–1 | 15.91a | 17.15c | 1.20b | 0.00c |
| SS × L–2 | 21.40a | 17.18c | 0.83c | 0.08c |
| SS × L–4 | 15.40a | 16.31c | 0.00c | 0.00c |
| SS × L–6 | 14.09a | 20.87b | 0.97b | 0.10c |
| SS × L–9 | 18.51a | 14.82c | 0.83c | 0.21c |
| SS × L–17 | 23.36a | 19.84b | 1.47a | 0.20c |
| SS × L–19 | 22.93a | 20.28b | 0.83c | 0.33b |
| Sekati × L–1 | 0.41b | 12.38c | 0.06c | 0.00c |
| Sekati × L–2 | 8.53b | 21.11b | 0.60c | 0.00c |
| Sekati × L–4 | 10.43b | 14.50c | 0.22c | 0.00c |
| Sekati × L–6 | 5.32b | 27.27a | 0.06c | 0.08c |
| Sekati × L–9 | 7.14b | 16.97c | 0.36c | 0.31b |
| Sekati × L–10 | 6.90b | 17.91c | 0.25c | 0.14c |
| Sekati × L–17 | 11.15b | 21.79b | 0.70c | 0.23c |
| Sekati × L–20 | 7.77b | 11.81c | 0.72c | 0.25c |
| 41/7 × 10 | 5.02b | 16.41c | 0.31c | 0.22c |
| JS-12 × 1 | 18.93a | 16.95c | 1.17b | 0.25c |
| JS-12 × 2 | 17.61a | 10.49c | 1.25b | 0.14c |
| JS-12 × 17 | 8.30b | 8.82c | 1.56a | 0.13c |
| JS-12 × 21 | 7.13b | 17.34c | 0.53c | 0.06c |
| 41/7 | 3.76b | 27.35a | 0.25c | 0.17c |
| Sekati | 4.39b | 24.24b | 0.22c | 0.14c |
| JS-12 | 10.87b | 18.80b | 0.95b | 0.45b |
| SS-72/12 | 22.81a | 19.71b | 0.58c | 0.07c |
| TAINUNG | 19.84a | 21.18b | 0.42c | 0.06c |
| GOLDEN | 14.58a | 32.95a | 0.61c | 0.50b |
| Mean | 11.91 | 17.70 | 0.68 | 0.17 |
| Amplitude | 36.53 | 25.17 | 2.00 | 1.00 |

The letters a, b, c, reference to Scott–Knott test at a level of significance of 5% in each evaluation. The letter "a" reference the group with more disease, the letter "b" has intermediary disease and the letter "c" reference to the group with less disease. The group c is the best group for this research

*The means were grouped using the Scott–Knott test at a level of significance of 5% in each evaluation period and each study site.[1] SS–SS72/12

average rates and were selected as potential lineages to obtain cultivars resistant to phoma spot. With respect to the crosses between these genotypes, the average rates were lower for the hybrids SS-72/12 × 2, SS-72/12 × 4, SS-72/12 × 9, Sekati × 1, Sekati × 2, Sekati × 4, Sekati × 6, Sekati × 10, Sekati × 17, Sekati × 20, 41/7 × 10, and JS-12 × 21.

None of the evaluated genotypes were immune to the disease, i.e., all presented foliar lesions. However, some genotypes had no symptoms on the leaf below the first open flower in at least one season, including parental lines 1, 2, 19, and 21, and hybrids SS 72/12 × 1, SS 72/12 × 4, Sekati × 1, Sekati × 2, and Sekati × 4.

Disease severity was decreased up to 100% in at least one season, and the incidence of phoma spot was decreased up to 80% in some of these genotypes (Table 1).

Heterosis was estimated only in the evaluation periods in which a significant effect of genotypes was observed, i.e., the second and third periods. The combinations with negative heterosis for the incidence of phoma spot in both periods were SS 72/12 × 1 (− 30.43; − 16.09), SS 72/12 × 9 (− 21.80; − 9.99), Sekati × 1 (− 97.02; − 45.47), Sekati × 9 (− 65.46; − 30.16), 41/7 × 10 (− 2.34; − 28.98); JS-12 × 17 (− 23.74; − 52.63); and JS-12 × 21 (− 45.01; − 7.99) (Table 2).

With respect to the severity of phoma spot, only the hybrid SS 72/12 × 4 (− 100; − 100) from the Solo group showed negative heterosis. In contrast, almost all the hybrids from the Formosa group showed negative heterosis, including Sekati × 1 (− 89.89; − 100), Sekati × 2 (− 45.95; − 100), Sekati × 4 (− 53.41; − 100), Sekati × 6 (− 86.28; − 13.81), Sekati × 10 (− 51.22; − 58.51), 41/7 × 10 (− 42.18; − 36.35), JS-12 × 2 (− 15.11; − 37.84), and JS-12 × 21 (− 32.05; − 75.28) (Table 2).

Standard heterosis indicates the extent to which each hybrid outperforms the most commonly cultivated standard cultivar. In this case, only one genotype from the Solo group presented negative standard heterosis for the rate of phoma spot, SS72-12 × 6 (− 3.34; − 36.67), i.e., its resistance to phoma spot was higher than that of the Golden control. The crosses from the Formosa group Sekati × 1 (− 97.95; − 41.55), Sekati × 2 (− 57.01; − 0.30), Sekati × 4 (− 47.45; − 31.52), Sekati × 9 (− 64.02; − 19.85), Sekati × 10 (− 65.24; − 15.43), Sekati × 20 (− 60.85; − 44.24) 41/7 × 10 (− 74.71; − 22.51), JS-12 × 1 (− 4.60; − 19.95), JS-12 × 2 (− 11.24; − 50.45), JS-12 × 17 (− 58.16; − 58.37), and JS-12 × 21 (− 64.09; − 18.13) presented higher absolute negative heterosis (Table 3). In these cases, the disease resistance of these hybrids was higher than that of the Tainung control.

**Table 2** Estimated heterosis for the rate and severity of phoma leaf spot in papaya genotypes derived from crosses with testers from the Solo and Formosa groups in the years 2015 and 2016 in Linhares, Espírito Santo, Brazil

| Hybrids | IMPFo[1] | | SMPFo[2] | |
|---|---|---|---|---|
| | November 2015 | March 2016 | November 2015 | March 2016 |
| SS[3] × L-1 | − 30.43 | − 16.09 | 64.65 | − 100 |
| SS × L-2 | 17.01 | 15.30 | − 35.49 | 144.98 |
| SS × L-4 | − 0.46 | 2.47 | − 100 | − 100 |
| SS × L-6 | − 10.95 | 29.57 | 66.82 | 64.34 |
| SS × L-9 | − 21.80 | − 9.99 | 88.32 | 16.24 |
| SS × L-17 | 9.80 | − 22.28 | 88.64 | 228.68 |
| SS × L-19 | 95.22 | − 19.82 | 185.72 | − 37.51 |
| Sekati × L-1 | − 97.02 | − 45.47 | − 89.89 | − 100 |
| Sekati × L-2 | − 6.04 | 23.01 | − 45.95 | − 100 |
| Sekati × L-4 | 66.40 | − 20.22 | − 53.41 | − 100 |
| Sekati × L-6 | − 19.68 | 48.49 | − 86.28 | − 13.81 |
| Sekati × L-9 | − 65.46 | − 30.16 | 39.12 | 41.86 |
| Sekati × L-10 | 26.43 | − 16.88 | − 51.22 | − 58.51 |
| Sekati × L-17 | 45.74 | 2.17 | 17.19 | 139.73 |
| Sekati × L-20 | 30.22 | − 26.23 | 80.04 | 80.77 |
| 41/7 × L-10 | − 2.34 | − 28.98 | − 42.18 | − 36.35 |
| JS-12 × L-1 | 12.04 | − 15.17 | 28.68 | 12.36 |
| JS-12 × L-2 | 42.99 | − 27.36 | − 15.11 | − 37.84 |
| JS-12 × L-17 | − 23.74 | − 52.63 | 62.26 | − 46.68 |
| JS-12 × L-21 | − 45.01 | − 7.99 | − 32.05 | − 75.28 |

[1]IMPFr, rate of phoma leaf spot; [2]SMPFo, severity of phoma leaf spot; [3]SS, SS72/12

**Table 3** Standard heterosis for the rate and severity of phoma leaf spot in papaya genotypes derived from crosses with Solo and Formosa control groups in the years 2015 and 2016 in Linhares, Espírito Santo, Brazil

| Hybrids | IMPFo[1] | | SMPFo[2] | |
|---|---|---|---|---|
| | November 2015 | March 2016 | November 2015 | March 2016 |
| SS[3] × L-1 | 9.10 | − 47.95 | 95.90 | − 100 |
| SS × L-2 | 46.76 | − 47.86 | 36.61 | − 83.66 |
| SS × L-4 | 5.65 | − 50.50 | − 100 | − 100 |
| SS × L-6 | − 3.34 | − 36.67 | 59.30 | − 80.00 |
| SS × L-9 | 60.23 | − 39.79 | 36.34 | − 58.34 |
| SS × L-17 | 26.95 | − 55.03 | 140.44 | − 60.00 |
| SS × L-19 | 57.27 | − 38.46 | 36.61 | − 33.34 |
| Sekati × L-1 | − 97.95 | − 41.55 | − 86.80 | − 100 |
| Sekati × L-2 | − 57.01 | − 0.30 | 43.99 | − 100 |
| Sekati × L-4 | − 47.45 | − 31.52 | − 46.80 | − 100 |
| Sekati × L-6 | − 73.21 | 28.79 | − 86.80 | 51.45 |
| Sekati × L-9 | − 64.02 | − 19.85 | − 13.20 | 454.55 |
| Sekati × L10 | − 65.24 | − 15.43 | − 40.00 | 151.45 |
| Sekati × L17 | − 43.81 | 2.90 | 67.58 | 321.27 |
| Sekati × L20 | − 60.85 | − 44.24 | 73.19 | 354.55 |
| 41/7 × L-10 | − 74.71 | − 22.51 | − 26.81 | 303.09 |
| JS-12 × L-1 | − 4.60 | − 19.95 | 179.99 | 354.55 |
| JS-12 × L-2 | − 11.24 | − 50.45 | 199.98 | 151.45 |
| JS-12 × L-17 | − 58.16 | − 58.37 | 273.17 | 142.36 |
| JS-12 × L-21 | − 64.09 | − 18.13 | 26.78 | 0.00 |

[1]IMPFr, rate of phoma leaf spot; [2]SMPFo, severity of phoma leaf spot; [3]SS, SS72/12

With respect to standard heterosis for the severity of phoma spot, the hybrids SS 72/12 × 4 (− 100; − 100), Sekati × 1 (− 86.80; − 100), and Sekati × 4 (− 46.80; − 100) were better in the two seasons compared to the Solo Golden group and the Formosa Tainung group (Table 3).

## Discussion

The results indicated that the incidence of phoma spot was higher in the second evaluation period (March 2015). In contrast, Lucena (2016) found that the incidence of this disease in papaya crops was intermediate in March in Espírito Santo, and the rate was highest in August; however, this result was not observed in our study. In August (the first evaluation period of this study), the activity of this fungal pathogen was low because of the low rainfall index, which is atypical for this period of the year.

There was a significant effect of the interaction genotype × season. Therefore, each season was analyzed separately. Cruz and Regazzi (1997) reported that the separate analysis of study periods and environments is necessary to determine the magnitude of genetic variability and the discrepancies between the residual variances in each environment. Vivas et al. (2010, 2014) found that the average incidence of disease were comparatively lower in the JS-12 genotype, which corroborates the results of our study. In addition the potential the genotypes themselves, the potential of parental lines in hybrid combinations was assessed in the studies cited above and in this study.

With the exception of three hybrids—Sekati × 1, JS-12 × 17, and JS-12 × 21—hybrids Sekati × 4, Sekati × 9, Sekati × 10, Sekati × 20, 41/7 × 10 presented lower average heterosis for black spot (Poltronieri et al. 2017). Vivas et al. (2015) observed that genetic crosses with JS-12 had lower average heterosis for phoma spot, corroborating the results of the present study.

The lineage 9, derived from genotype Cariflora, is potentially resistant because it presented the lowest average incidence and severity of disease in all genetic crosses for phoma spot (Table 1) and black spot in leaves and fruits (Poltronieri et al. 2017). Cariflora is a dioecious genotype developed in the United States with tolerance to the papaya ringspot virus (Conover et al. 1986). The cross between genotypes Cariflora and Solo generates vigorous and productive hybrids; however, these hybrids are heterogeneous and have many heterozygous loci (Marin et al. 2006). This result evidences that lineages derived from dioecious genotypes may have higher disease resistance, which justifies the study of native or wild-type dioecious cultivars in papaya breeding programs.

The results indicated that genotype SS-72/12 might be resistant to phoma spot, demonstrated by the lower average heterosis in severity. A similar result was also reported by Vivas et al. (2015).

The separate analysis of cultivars from the Solo group with small fruits indicated that the hybrids SS-72/12 × 2, SS-72/12 × 4, and SS-72/12 × 9 presented lower severity of phoma spot and higher yields (Santa-Catarina 2016). The large-sized hybrids originated from the Formosa group Sekati × 1, Sekati × 4, Sekati × 10, and Sekati × 20 showed lower combined average rate and severity of phoma spot and the most favorable morpho-agronomic characteristics (Santa-Catarina 2016). These results suggest the potential cultivation of hybrids from the Solo and Formosa groups with higher agronomic performance and higher resistance to phoma spot. The ability to obtain cultivars with increased resistance within the groups and between groups was confirmed by Vivas et al. (2014) when evaluating germplasm and hybrids of papaya cultivars resistant to phoma spot under field conditions.

The results of heterosis for the incidence of phoma spot revealed negative heterosis in crosses with the parental strain SS 72/12, and similar results were reported by Vivas et al. (2014), evidencing the possibility of obtaining hybrids from the Solo group with high levels of resistance to disease. A similar result was found for the severity of phoma spot and was corroborated by Vivas et al. (2016). These authors observed that heterosis for resistance to black spot and phoma spot was negative, especially in the genotypes Sekati, JS-12, and SS72/12, which are considered resistant to phoma spot.

The degree of resistance of the parental lines Sekati and SS 72/12 to phoma spot can be transferred to future generations, and the Sekati genotype has improved resistance to phoma spot and black spot (Poltronieri et al. 2017). Santa-Catarina (2016) studied the same genotypes from the Solo group and found that heterosis was better in the hybrid SS 72/12 × 4, with lower standard heterosis for yield and disease resistance. Furthermore, this author observed that the hybrid SS 72/12 × 6 presented the lowest average heterosis for firmness of fruits and pulp. This hybrid was also selected in the present study because of its higher resistance to disease. For the hybrids from the Formosa group, Santa-Catarina (2016) found that yield was higher in the hybrids Sekati × 1, Sekati × 4, and Sekati × 20, whereas soluble solids content was higher in the hybrids Sekati × 4 and Sekati × 20, and these hybrids presented negative heterosis for disease resistance based on the results of the present study.

## Conclusion

The genotypes with the lowest average incidence and severity of phoma spot were parental lines 4, 6, and 20, and the hybrids Sekati × 1, Sekati × 4, Sekati × 9, Sekati × 10, Sekati × 20, 41/7 × 10, and JS-12 × 21. The hybrids from the Solo group with the lowest average severity of phoma spot were SS 72/12 × 2, SS72/12 × 4, and SS 72/12 × 9. The results allowed identifying hybrids with improved resistance to phoma spot. The analysis of the effects of heterosis highlighted the possibility of achieving significant genetic gains in hybrids from the Solo and Formosa groups. The hybrids with negative heterosis for the incidence and severity of phoma spot were Sekati × 1, 41/7 × 10, and JS-12 × 21. Considering the standard heterosis, the hybrids with negative heterosis for incidence and severity of phoma spot were Sekati × 1 and Sekati × 4.

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