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Prediction of genetic gain from selection indices for disease resistance in papaya hybrids

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ABSTRACT

In order to select superior hybrids for the concentration of favorable alleles for resistance to papaya black spot, powdery mildew and phoma spot, 67 hybrids were evaluated in two seasons, in 2007, in a randomized block design with two replications. Genetic gains were estimated from the selection indices of Smith & Hazel, Pesek & Baker, Williams, Mulamba & Mock, with selection intensity of 22.39%, corresponding to 15 hybrids. The index of Mulamba & Mock showed gains more suitable for the five traits assessed when it was used the criterion of economic weight tentatively assigned. Together, severity of black spot on leaves and on fruits, characteristics considered most relevant to the selection of resistant materials, expressed percentage gain of -44.15%. In addition, there were gains for other characteristics, with negative predicted selective percentage gain. The results showed that the index of Mulamba & Mock is the most efficient procedure for simultaneous selection of papaya hybrid resistant to black spot, powdery mildew and phoma spot.

Key words: combined selection, genetic resistance, *Asperisporium caricaee*, *Streptopodium caracae*, *Phoma caricae-papayae*.

RESUMO

Predição de ganhos genéticos para resistência a doenças por índices de seleção em híbridos de mamoeiro

Com a finalidade de selecionar híbridos superiores para concentração de alelos favoráveis à resistência de mamoeiro à pinta-preta, oídio e mancha de phoma, foram avaliados, em duas épocas, em 2007, 67 híbridos simples, em delineamento de blocos casualizados com duas repetições. Os ganhos genéticos foram estimados a partir dos índices de seleção de Smith & Hazel, Pesek & Baker, Williams e Mulamba & Mock, com intensidade de seleção de 22,39%, correspondendo a 15 híbridos. O índice de Mulamba & Mock evidenciou ganhos mais adequados para as cinco características avaliadas, quando utilizado o critério de peso econômico atribuído por tentativas. Em conjunto, as severidades da pinta-preta em folhas e em frutos, características consideradas de maior interesse para a seleção de materiais resistentes, expressaram ganho percentual de -44,15%. Além disso, registraram-se ganhos para as demais características, com ganho percentual seletivo predito negativo. Conclui-se, portanto, que o uso do índice de Mulamba & Mock é o procedimento mais eficiente para seleção simultânea de híbridos de mamoeiro resistentes à pinta-preta, oídio e mancha de phoma.

Palavras-chave: seleção combinada, resistência genética, *Asperisporium caricaee*, *Streptopodium caracae*, *Phoma caricae-papayae*.

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INTRODUCTION

Papaya (*Carica papaya* L.) has been described as host of four species of powdery mildew fungi (Ascomycota, Erysiphales) in the world: *Ovulariopsis papaya*, Van der Bijl in South Africa; *Phyllactinia caricaefolia*, Viégas in Brazil, *Oidiopsis haplophylli* (Magnus) Rulamort, anamorph of *Leveillula taurica* (Lev.) G. Arnaud, in Australia, India and Portugal, and *Streptopodium caricae*, Liberato & RW Barreto in Brazil. Of these, the species, *S. caricae* is commonly observed, causing symptoms of powdery mildew on leaves of papaya in northern Espírito Santo (Liberato et al., 2004).

Another fungal disease, which was once considered secondary and that currently comes up constituting the main disease of the crop, is papaya black spot caused by *Asperisporium caricae* (Speg.) Maubl. The disease may cause severe production losses, by reducing the photosynthetic area of the leaves, and especially commercially depreciating the fruits (Rezende & Martins, 2005).

Phoma spot, caused by *Stagonosporopsis carical* (Sydow & P. Sydow) Aveskamp, Gruyter & Verkley, (Syn. Phoma caricae - papayae (Tarr) Punith) (Aveskamp et al., 212),, is considered the second most important post-harvest disease in Brazil (Rezende & Martins, 2005). The fungus is quite widespread in tropical climates with various symptoms. Phoma spot has proved difficult to control in commercial areas of the Caliman Agricultural Company S/A, in Linhares, Espírito Santo.

The selection of resistant genotypes is a sustainable alternative for the control of diseases in papaya crop. However, the complete resistance has not been observed in commercial genotypes of the species that have already gone through cycles of selection (Vivas et al., 2010, 2012). There is, however, the possibility of crosses generate hybrids that provide higher levels of resistance to fungal diseases. Thus, the improvement of the crop can contribute to the selection of resistant genotypes and/or to point out best hybrid combinations, using the hybrid vigor, which is also known as heterosis. Marin et al. (2006) reported that heterosis is a common effect in papaya hybrids, which confirms the assumptions about the manifestation of heterosis for traits related to resistance to diseases.

The identification of superior genotypes requires selection methods, capable to exploit efficiently the available genetic material, maximizing the genetic gain in relation to the characteristics of interest. In this context, the selection indices can generate a genotypic aggregate, on which selection is practiced, acting as an additional character, resulting from the combination of certain traits chosen by breeders, in which they wish to pursue simultaneous selection, allowing separate superior genotypes, regardless of the existence, or not, of correlations between traits (Smith, 1936, Hazel, 1943, Williams, 1962, Cruz & Regazzi, 2001, Vilarinho et al., 2003). Recently, selection indices have been used for obtaining hybrids that add favorable alleles for different traits of interest to the papaya crop (Ide, 2008).

The objective of this study was to predict genetic gains for resistance to papaya black spot, powdery mildew and phoma spot, and select superior hybrids for concentration of favorable alleles for resistance to these diseases.

MATERIAL AND METHODS

The experiment was conducted in the Macuco Farm, Caliman Agricultural Company S/A, Linhares, Espírito Santo, 21 m altitude. The region is located at latitude 19º 15' and longitude 40° 10', with annual rainfall of 1100 mm, average maximum temperature from 30.7 to 34 ºC and the average minimum temperature from 15.8 to 18.0 ºC (Suzuki et al. 2007). A total of 67 F_1 hybrids were evaluated. The hybrids were derived from the crossing of parents from the groups Solo and Formosa with the tester genotypes 'Sunrise Solo' '72/12' (Solo group) and 'JS 12', 'Americano', 'Maradol' and 'Sekati' (Formosa group); as well as the crosses of the hybrid 'UENF/CALIMAN01' with the genotypes Americano, Maradol, Sekati and Tailandia (Table 1).

The experiment was arranged in a randomized block design with two replications and 20 plants, arranged in double rows (10 plants in each row), spaced at 2.0 x 1.8 m. The spacing between the treatments, sideways, was 3.6 m. The four central plants of each row were selected for evaluations. Because the genotypes came from a germplasm collection and also to ensure production of fruits and seeds, biweekly sprays of fungicides recommended for the crop were carried out during the conduction of the experiments. Until 60 days before the first evaluation, the following active ingredients were sprayed: *pyraclostrobin* (16/04, 23/04 and 21/05) and *chlorothalonil* (30/04). Before the second evaluation the following active ingredients were sprayed: *azoxystrobin* (10/07 and 17/08), *chlorothalonil* (03/08), lime sulfur (10/08) and methyl thiophanate (27/07).

Two evaluations were performed: the first in late May and the second in late August 2007. It was evaluated the incidence of leaves with powdery mildew (*S. caricae*) (IO) and phoma spot (*P. caricae-papayae*) (IMP). The severity of black spot (SPP) and phoma spot (SMP) were estimated. SPP was estimated in percentage, with the leaf axil attached to first flower opened, based on a diagrammatic scale with percentage values of 0.2, 1.6, 3.5, 5.4, 7.6 and 12. 8% of diseased leaf area (Terra et al. 2008a). SMP was estimated in the leaf on the axil immediately below the first open flower, using the diagrammatic scale with percentage

values of 1, 3, 6, 11, 17 and 30% of diseased leaf area (Terra et al. , 2008b). Since at that moment there was no scale to estimate the severity in fruits, black spot lesions were counted on the surface of the fruit, at the stage 1 of ripening. Subsequently, the numbers of black spot lesions on the fruits were converted into injured surface area (PPF), based on the average estimate of lesions, which corresponded to 0.26% per lesion.

The data (average of the two evaluations) were subjected to analysis of variance to obtain matrices of means, phenotypic and genotypic variances and covariances, necessary for the estimation of the gains from the selection indices. The selection indices used to predict the gains were the Classic of Smith (1936) and Hazel (1943), the one proposed by Pesek & Baker (1969), of Williams (1962), and the one suggested by Mulamba & Mock (1978). The selection intensity applied was 22.39%, corresponding to 15 hybrids. The economic weights used were: a) genetic variation coefficient (CVg); b) genetic standard deviation (DPg); c) heritability (h^2); and d) values tentatively assigned (PT) of magnitudes of 10, 10, 100, 100 and 100, respectively, to the characteristics IO, IMP, SPP, SMP and PPF. The magnitudes of PT refer to optimal values to obtain gains for all characteristics randomly obtained after assignment of different magnitudes. Analyses were performed using the software GENES (Cruz, 2006).

RESULTS AND DISCUSSION

The predicted percentage gain for the selection index of Smith (1936) and Hazel (1943) allowed the obtaining of negative gains for the five characteristics assessed (Table 2). The largest combined predicted percentage gain was -57.74%, which was obtained when the economic weight was assigned tentatively (PT). With the allocation of economic weights for the genetic variation coefficient (CVg), genetic standard deviation (DPg) and heritability (h^2), the predicted percentage gains were -56.10, -48.72 and -49.63, respectively. Although DPg and h^2 have expressed the smallest combined percentage gains, they were those with the best distribution of gains among the three diseases evaluated. Thus, DPg and h^2 contributed to further reduction of means for all diseases, which makes the criterion of economic weight the one with the greatest efficiency to select plants with lower means of black spot and powdery mildew. On the other hand, the criterion of arbitrary weights, tentatively assigned (PT), proved to be more suitable for the simultaneous selection of the three diseases.

Paula et al. (2002) evaluated the total predicted gains using various selection criteria for six growth traits in half-sib families of *Eucalyptus camaldulensis* and concluded that the classic selection index of Smith (1936) and Hazel (1943) is promise for the improvement of multiple characteristics, as it surpasses other selection criteria in terms of total gains, when the economic weight is established, in each characteristic, as equivalent to the genetic variation between families.

Comparing the total gains predicted by different selection criteria applied to progenies of *Eucalyptus camaldulensis*, Paula et al. (2002) found that the index based on desired gains of Pesek & Baker (1969) yielded similar results to those of other selection criteria. However, in this study, this index yielded simultaneous positive gains for most characteristics when using the criteria CVg, DPg and h^2 as economic weights (Table 2). The percentage

Table 1. Parents and respective heterotic groups of 67 papaya hybrids. Linhares, ES, 2007

Tester	Group	Male Parent ([1])
'Sunrise Solo 72/12'	Solo	'Mamão Roxo'
	Formosa	'Americano', 'Costa Rica', 'Tailândia', 'Mamão Bené', 'Maradol', 'Maradol GL' and 'Sekati';
'UENF/CALIMAN01'	Formosa	'Americano', 'Maradol', 'Sekati' and 'Tailândia'
'JS 12'	Solo	'BSA', 'Golden', 'C GB', 'C M5', 'C SG', 'Diva', 'Grampola', 'KS PA', 'KS PV', 'São Mateus', 'SS', 'SS PT', 'Taiwan et' and 'Waimanalo'.
	Formosa	'Maradol'
'Americano'	Solo	'BSA', 'Baixinho Super', 'C AM', 'Golden', 'C GB', 'C M5', 'C SG', 'Diva', 'Grampola', 'KS PV', 'Taiwan et', 'Mamão Roxo', 'São Mateus' 'SS', 'SS PT', 'STZ – 52', 'SS 783', 'SS TJ' and 'Waimanalo'
	Formosa	'Costa Rica' and 'Sekati'
'Sekati'	Solo	'Golden', 'C AM', 'C SG', 'SS', 'Diva', 'C M5' and 'C GB'
	Formosa	'JS 11'e 'JS 12'
'Maradol'	Solo	'SS 72/12', 'Golden', 'C AM', 'C SG', 'SS', 'Diva', 'C M5', 'SS PT' and 'Taiwan et'.
	Formosa	'JS 12'

([1]) C = Caliman; BSA = Baixinho de Santa Amália; KS = Kapoho Solo, and SS = Sunrise Solo.

value of the predicted gain for these characteristics all together was positive in all the chosen criteria and surpassed the estimates of combined gains, which were expressed by the other selection indices used.

The index of Williams (1962) provided simultaneous genetic gains in all criteria used as economic weight (Table 3). However, the largest percentage gains were achieved when CVg and PT were used as economic weight. In contrast, Granate et al. (2002), examining the feasibility of using the selection index of Williams (1962) in popcorn using the CVg as economic weight, concluded that this coefficient did not allow the obtaining of estimates of predicted simultaneous gains in traits of greater interest in that crop. In this study, not only CVg and PT, but all other criteria of economic weights used for the index of Williams (1962) showed combined negative percentage gains. However, DPg and H^2 indicated gains below those provided by the other criteria for characteristics related to black spot, although for powdery mildew they have shown the greatest gains (Table 3).

Crosbie et al. (1980) compared the efficiency of various selection indices and predicted gains for each of them in improving cold resistance in two maize populations. They found that the selection indices of Mulamba & Mock (1978) and Williams (1962) were among those that provided the best gains in all traits. The authors discussed further that these indices have the advantage of not being affected by the inequality of trait variances, as well as not requiring the estimation of genetic parameters. In this study, it was possible to obtain satisfactory gains for the five traits assessed with the selection indices of Smith (1936) and Hazel (1943), Williams (1962) and Mulamba & Mock (1978).

The estimates of predicted gains by the method of Mulamba & Mock (1978) showed that it was the index that provided, in magnitude, the largest combined predicted percentage gain (-65.21), when the criterion CVg was used as economic weight (Table 3). However, among the choices of economic weights used to obtain gains by the selective index of Mulamba & Mock (1978), the arbitrary weights tentatively assigned (PT) were those that provided the best distribution of gains for the five traits assessed, with negative predicted selective percentage gain. Thus, similarly to that found by Santos et al. (2007), the index of Mulamba & Mock (1978), based on arbitrary weights, led to the best results for the selection

Table 2. Estimates of the percentage gains for simultaneous selection based on four criteria of economic weights (1) for five traits (2) evaluated in 67 papaya hybrids derived from crosses between the tester genotypes 'JS 12', 'American', 'Sekati', 'Maradol' and 'SS 72/12'

Trait	SMITH & HAZEL				ESEK & BAKER			
	CVg	DPg	h^2	PT	CVg	DPg	h^2	PT
IPM	-0.96	-1.20	-1.18	-0.84	0.57	0.39	0.51	0.43
IMP	-3.14	-3.84	-3.77	-3.01	0.36	1.2	0.15	-0.10
SPP	-5.78	-8.40	-9.94	-7.59	19.17	-1.07	18.92	18.4
SMP	-17.39	-10.28	-11.29	-17.97	-5.79	14.11	-5.10	-5.33
PPF	-28.83	-25.00	-23.45	-28.33	7.08	45.66	1.65	-7.67
Total Gain	-56.10	-48.72	-49.63	-57.74	21.39	60.29	16.13	5.73

(1) CVg = genetic variation coefficient; DPg = genetic standard deviation, h^2 = heritability, and PT = weights tentatively assigned (10, 10, 100, 100 and 100).

(2) IPM = Incidence of powdery mildew; IMP = incidence of phoma spot; SPP = Severity of black spot; SMP = severity of phoma spot, and PPF = area of fruit damaged by black spot.

Table 3. Estimates of the percentage gains for simultaneous selection based on four criteria of economic weights (1) for five traits (2) evaluated in 67 papaya hybrids derived from crosses between the tester genotypes JS 12, American, Sekati, Maradol and SS 72/12

Trait	WILLIAMS				MULAMBA & MOCK			
	CVg	DPg	h^2	PT	CVg	DPg	h^2	PT
IPM	-0.74	-1.04	-1.14	-0.77	-0.35	-1.15	-0.97	-0.52
IMP	-3.13	-4.38	-4.30	-2.88	-2.21	-4.24	-3.69	-2.23
SPP	-6.45	-2.94	-2.21	-7.18	-8.82	-3.15	-10.56	-15.43
SMP	-18.94	-7.85	-8.13	-19.60	-8.69	-8.68	-11.61	-12.75
PPF	-21.13	-9.00	-10.38	-19.27	-45.14	-11.2	-31.27	-28.72
Total Gain	-50.39	-25.21	-26.16	-49.70	-65.21	-28.42	-58.10	-59.65

(1) CVg = genetic variation coefficient; DPg = genetic standard deviation, h^2 = heritability, and PT = weights tentatively assigned (10, 10, 100, 100 and 100).

(2) IPM = Incidence of powdery mildew; IMP = incidence of phoma spot; SPP = Severity of black spot; SMP = severity of phoma spot, and PPF = area of fruit damaged by black spot.

Table 4. Means of the top 15 papaya hybrids selected by the index of Mulamba & Mock (1978)

Selected Hybrid	Trait Evaluated				
	IPM	IMP	SPP	SMP	PPF
'Americano x Waimanalo'	68.84	54.3	0.01	2.91	0.08
'Maradol x Sunrise Solo 72/12'	80.90	70.95	0.02	3.44	0.06
'UENF/CALIMAN01 x Tailândia'	84.33	79.97	0.02	1.38	0.16
'Maradol x Sunrise Solo PT'	85.20	80.75	0.02	3.10	0.16
'Maradol x Caliman M5'	84.41	73.23	0.03	2.66	0.11
'Sekati x Golden'	82.53	76.56	0.03	4.01	0.10
'Americano x São Mateus'	83.59	76.89	0.03	4.77	0.07
'Sunrise Solo 72/12 x Grampola'	83.82	79.71	0.02	5.51	0.10
'Maradol x Diva'	83.61	82.66	0.02	3.29	0.25
'UENF/CALIMAN01 x Maradol'	84.46	74.04	0.03	1.63	0.29
'Americano x Baixinho de Santa Amália'	86.16	75.37	0.02	5.22	0.15
'Sunrise Solo 72/12 x Sunrise Solo'	79.48	75.60	0.03	2.56	0.43
'Maradol x Golden'	84.02	77.89	0.02	3.93	0.25
'Sekati x Caliman GB'	83.01	77.70	0.03	4.68	0.11
'Americano x Sunrise Solo'	87.32	83.38	0.02	5.36	0.08
X_O	83.67	78.78	0.04	5.00	0.27
X_S	82.78	75.93	0.02	3.63	0.16

[1] IPM = Incidence of powdery mildew (%); IMP = incidence of phoma spot (%); SPP = Severity of black spot (%) = SMP severity of phoma spot (%); and PPF = area of fruit injured by black spot (%).

of hybrids. Based on this criterion, the top 15 papaya hybrids were selected (Table 4).

Using the index of desired gains, proposed by Pesek & Baker (1969), to obtain genetic gains for the main traits related to production and fruit quality of papaya, Ide (2008) selected the hybrids 'JS12 x Caliman SG', 'Sunrise Solo 72/12 x Mamão Bené', 'Sunrise Solo 72/12 x Costa Rica', 'JS 12 x Sunrise Solo 72/12' and 'JS 12 x Taiwan' et. In this study, these hybrids were submitted to analysis of disease resistance, which was not previously evaluated.

Among the hybrid parents, some are important sources of resistance to the diseases evaluated. Ide et al. (2001) and Vivas et al. (2012) reported the genotype 'Maradol' as resistant to black spot. Dianese et al. (2007) reported that genotype 'Sekati' showed the lowest severity of black spot on leaves. Santos et al (2009) pointed out genotype 'Tailandia' as resistant to powdery mildew, as it showed the lowest incidence of papaya leaves with this disease symptoms, in a greenhouse. Vivas et al. (2010) highlighted the genotypes 'Americano', 'JS 12', 'Baixinho de Santa Amália', 'Waimanalo', 'Sekati', 'Maradol' and 'Tailandia' as resistant to phoma spot. Thus, there is possibility of obtaining hybrids that have lower levels of black spot, powdery mildew and phoma spot, considering that nearly 90% of the selected hybrids had at least one parent of the genotypes mentioned above.

Overall, the predicted gains with the selection index of Smith (1936) and Hazel (1943), Williams (1962) and Mulamba & Mock (1978) were higher than those predicted based on desired gains of Pesek & Baker (1969) . However, for the selection of superior hybrids, the selection index proposed by Mulamba & Mock (1978) gave the greatest gains and the best gain distribution for the different diseases, therefore, in the conditions of this experiment, the most suitable procedure for the selection of superior hybrids resistant papaya.

CONCLUSION

The selection index proposed by Mulamba & Mock (1978) is the most efficient procedure for simultaneous selection of papaya hybrids resistant to black spot, powdery mildew and phoma spot.

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