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EARLY SELECTION OF EUCALYPTUS HYBRIDS TOLERANT TO WATER DEFICIT, PESTS, AND DISEASES

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ABSTRACT

The objective of this study was to perform early selection of the best progenies for traits related to tolerance to water deficit, pests, and diseases in *Eucalyptus* progeny tests. The experimental trials were set up in a randomized block design, with one plant per plot, and 20 replicates across three distinct locations (Buritizeiro/MG, Bocaiúva/MG, and Inhambupe/BA). At 6 months of age, the tested families were evaluated in terms of mean annual increment (MAI) and tolerance to pests and diseases. The analyses were conducted based on the genetic-statistics procedure of mixed models via REML/BLUP. The selection process was based on the estimated genetic values for the families, associating both traits in analyses using selection indices, namely the Multiplicative Selection Index and the Mulamba and Mock Selection Index, which allowed simultaneous selection for productivity (MAI) and tolerance to biotic agents. In Buritizeiro/MG and Bocaiúva/MG, plant tolerance to the psyllid (*Glycaspis brimblecombei*) was evaluated, while in Inhambupe/BA, tolerance to eucalyptus rust (*Austropuccinia psidii*) was assessed. For the trait of tolerance to biotic agents, heritabilities (h_g^2) were moderate across the three sites, with values of 0.20, 0.26, and 0.24 in Buritizeiro, Bocaiúva, and Inhambupe, respectively. The use of the Multiplicative Index (MI) and Mulamba and Mock Index (MMI) enabled the selection of genetic materials with better performance for both traits simultaneously.

Keywords: Water deficit; Drought tolerance; Pest tolerance

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SELEÇÃO PRECOCE DE HIBRIDOS DE EUCALIPTO TOLERANTES AO DÉFICIT HÍDRICO, A PRAGAS E DOENÇAS

RESUMO – O objetivo desse trabalho foi realizar a seleção precoce das melhores progênies para as características de tolerância ao déficit hídrico, a pragas e doenças, em testes de progênies de *Eucalyptus*. Os ensaios experimentais foram instalados em delineamento de blocos casualizados, com uma planta por parcela, com 20 repetições em três locais distintos (Buritizeiro/MG, Bocaiúva/MG e Inhambupe/BA). Aos 6 meses de idade, as famílias em teste foram avaliadas quanto ao incremento médio anual (IMA) e tolerância a pragas e doenças. As análises foram realizadas com base no procedimento genético-estatístico de modelos mistos via REML/BLUP. O processo seletivo baseou-se nos valores genéticos preditos para as famílias associando as duas características em analises através do uso de índices de seleção, sendo eles: os índices de seleção Multiplicativos e o índice de seleção de Mulamba e Mock, que permitiram a seleção simultânea para as características de produtividade (IMA) e tolerância à agentes bióticos. Em Buritizeiro/MG, Bocaiúva/MG foi avaliada a tolerância das plantas à incidência de psilídio de concha (*Glycaspis brimblecombei*), e em Inhambupe/BA foi avaliado à tolerância à ferrugem do eucalipto (*Austropuccinia psidii*). Para o caráter de tolerância a agentes bióticos, as herdabilidades (h_g^2) foram medianas nos três sites, apresentando valores de 0,20, 0,26 e 0,24 em Buritizeiro, Bocaiúva e Inhambupe, respectivamente. O uso dos índices Multiplicativo (IM) e de Mulamba e Mock (IMM) possibilitaram a seleção de materiais genéticos com melhor desempenho para as duas características de forma simultânea.

Palavras-Chave: Déficit hídrico; Tolerância a seca; Tolerância a pragas

1. INTRODUCTION

Species of the genus *Eucalyptus* exhibit rapid growth, excellent wood characteristics, and high yield, making them among the most widely cultivated in the world (Zhang and Wang, 2021). Brazil has approximately 10 million hectares of planted forests, 76% of which are occupied by eucalyptus species (IBA, 2023). The country's high productivity is due to a combination of favorable environmental conditions, silvicultural management, and genetic improvement (Hakamada et al., 2023).

With the expansion of the forestry sector in Brazil, robust eucalyptus genetic improvement programs have been developed, introducing several species and enabling the production of new hybrids. Generally, these programs primarily aim to increase productivity, improve wood quality, enhance tolerance to pests and diseases, and adaptability to different environments (Assis, 2014).

The maintenance of productivity in forest plantations remains a challenge for producers due to losses attributed to pests and diseases, abiotic stresses, and the occurrence of physiological disorders (Gonçalves et al., 2013; Ross and Brack, 2015). Additionally, climate change exacerbates these challenges, with water deficit significantly reducing growth and productivity in planted eucalyptus forests (García et al., 2023).

Predictions indicate a reduction in rainfall in the tropics, along with an increase in water deficit and air temperature (Hoegh-Guldberg et al., 2018). From 2012 to 2016, Brazil experienced a prolonged drought period with a significant reduction in historical average rainfall, negatively impacting the forestry sector and considerably reducing productivity. These events underscored the importance of developing genetic materials capable of maintaining high productivity levels, even under conditions of short-term or prolonged water stress.

In addition to water deficit, eucalyptus plantations also face biotic stress challenges that significantly reduce productivity. *Glycaspis brimblecombei*, commonly known as the red gum lerp psyllid, and *Austropuccinia psidii*, the causal agent of eucalyptus rust, are prominent examples of biotic agents affecting these plantations (Queiroz et al., 2013; Furtado et al., 2023).

Selecting genotypes tolerant to these pests and diseases is crucial for maintaining productivity in plantations while minimizing costs. In genetic improvement programs, selecting the best materials based on their genetic value is crucial. Therefore, REML/BLUP, a methodology of mixed models, is a valuable tool to enhance the effectiveness of forestry improvement programs. These methods tackle common challenges in forestry species improvement, including managing unbalanced data, non-orthogonal designs, variance heterogeneity, and incorporating pedigree information, thereby providing genetically penalized values (Silveira et al., 2024).

After obtaining genetic values through REML/BLUP, selection indices can be used to integrate various agronomic traits of interest in breeding programs. This approach aims to develop superior genetic materials that meet diverse market demands. Therefore, this study aimed to analyze and select the best eucalyptus hybrids with potential tolerance to drought, and resistance to the incidence of *G. brimblecombei* and *A. psidii* across three distinct experimental sites.

2. MATERIAL AND METHODS

2.1 Subtítulo (se houver)

A total of two hundred and thirty-nine hybrid families, derived from controlled crosses between 29 parents and six pollen mixes (Table 1), were tested at three different sites. Overall, eight species of *Eucalyptus* were represented in the crosses, including pure species, simple hybrids, and triple hybrids (Table 1). The pollen mixes corresponded to

Table 1. Description of the parents used in controlled crossings, detailing the species that compose them and the frequency with which they were used as the female parent (FCM), male parent (FCP), and the total frequency of crossings (FTC)

Tabela 1. Descrição dos genitores utilizados nos cruzamentos controlados quanto as espécies que os compõem e a frequência que foram utilizados como genitor feminino (FCM), genitor masculino (FCP) e a frequência total de cruzamento (FTC)

Parent	Species	FCM	FCP	FTC
G1	*E. urophylla* x *E. grandis*	28	1	29
G2	*E. camaldulensis*	23	2	25
G3	*E. urophylla* x *E. camaldulensis*	13	11	24
G4	*E. urophylla*	13	11	24
G5	*E. urophylla*	22	1	23
G6	*E. urophylla*	19	4	23
G7	*E. urophylla* x (*E. camaldulensis* x *E. grandis*)	11	11	22
G8	*E. grandis*	19	3	22
G9	*E. urophylla*	13	9	22
G10	*E. urophylla*	15	5	20
G11	*E. camaldulensis*	11	9	20
G12	*E. urophylla* x *E. grandis*	1	19	20
G13	*E. urophylla*	6	13	19
G14	*E. camaldulensis*	16	3	19
G15	*E. urophylla* x *E. tereticornis*	9	9	18
G16	*E. urophylla* x (*E. camaldulensis* x *E. grandis*)	7	9	16
G17	(*E. grandis* x *E. brassiana*) x *E. pellita*	6	9	15
G18	*E. brassiana*	6	8	14
G19	*E. pellita* x *E. brassiana*	1	8	9
G20	*E. camaldulensis*	0	1	1

Cont...

Cont...

Genitor	Species	FCM	FCP	FTC
G20	*E. camaldulensis*	0	1	1
G21	*E. camaldulensis*	0	2	2
G22	*E. urophylla*	0	1	1
G23	*E. camaldulensis*	0	2	2
G24	*E. longirostrata*	0	2	2
G25	*E. longirostrata*	0	2	2
G26	*E. urophylla* x *E. grandis*	0	8	8
G27	*E. urophylla* x *E. grandis*	0	8	8
G28	*E. camaldulensis*	0	13	13
G29	*E. camaldulensis*	0	8	8
G30	*E. brassiana*	0	9	9
G31	*E. camaldulensis*	0	7	7
G32	*E. longirostrata*	0	4	4
G33	*E. pellita*	0	10	10
G34	*E. resinifera*	0	4	4
G35	*E. tereticornis*	0	12	12

FCT= FCM +FCP

pure species thriving in regions characterized by significant water deficit in their native sites, Australia. Each pollen mix was meticulously composed from at least six elite genotypes, represented in Table 1 by codes G30 (*E. brassiana*), G31 (*E. camaldulensis*), G32 (*E. longirostrata*), G33 (*E. pellita*), G34 (*E. resinifera*), and G35 (*E. tereticornis*).

For controlled pollination, the artificially induced protogyny technique (IPT) was employed, involving the removal of the top operculum of the floral bud and excising the upper third of the stylet at the pre-anthesis stage while the flower is still closed. Subsequently, pollen grains were deposited onto the excised region of the floral bud (Assis et al., 2005).

2.2 Areas and Experimental Design

The hybrid families obtained from the controlled crossing process were allocated to three distinct locations: Buritizeiro - MG (16°54'50" S and 44°56'51.6" W), Bocaiúva - MG (17°19'44.8" S and 43°49'23.2" W), and Inhambupe - BA (11°52'10.2" S and 38°23'21.3" W) (Figure 1).

Progeny tests were established in the field in 2019, using a complete randomized block design with a single tree per plot and 9 m² spacing per tree, with 20 replications. The sites in Bocaiúva, Buritizeiro, and Inhambupe received 194, 213, and 210 hybrid families, respectively. Additionally, at all sites, six control varieties were included: GG1980, GG1923, GG2673, I144, VM01, and AEC1528.

The climate classification in Buritizeiro/MG, according to Köppen, can be defined as Aw (tropical with dry winters), with an average annual temperature of 23.7 °C and average annual precipitation of 1126 mm. In Bocaiúva/MG, the climate is classified as Aw (tropical with dry winters), with an average annual temperature of 22.3 °C and average annual precipitation of 1058 mm. Lastly, in Inhambupe-BA, the climate classification is Aw (tropical with dry winters), with an average annual temperature of 23.5°C and average annual precipitation of 905 mm (Figure 2).

2.3 Determination of Insect/Disease of Importance

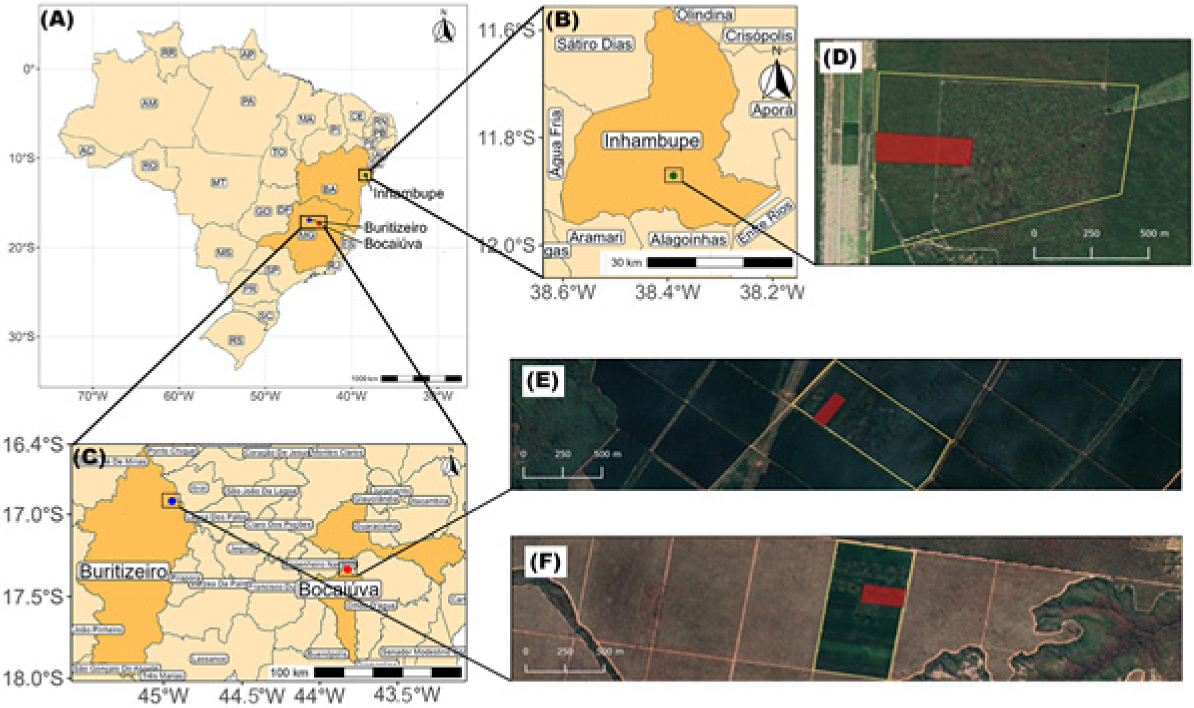

Figure 1. (A) Geographic representation of the territorial area of Brazil, highlighted by the states of Bahia and Minas Gerais where the three experimental sites were installed: Inhambupe, identified by the green dot; Bocaiúva-MG, by the red dot; and Buritizeiro-MG, by the blue dot. (B) Municipality of Inhambupe in Bahia, where the green dot indicates the geographical location of the experimental site. (C) Municipalities of Minas Gerais with emphasis on Buritizeiro and Bocaiúva, where the experimental sites are indicated by blue and red dots, respectively. Aerial views of the areas where the experimental tests were installed in Inhambupe-BA (D), Bocaiúva-MG (E), and Buritizeiro-MG (F). Map generated with the free environmental software R.

Figura 1. (A) Representação geográfica da área territorial do Brasil, em destaque é identificado o estado da Bahia e Minas Gerais onde foram instalados os três sites experimentais: Inhambupe identificado pelo ponto verde, Bocaiúva-MG pelo ponto vermelho e Buritizeiro-MG pelo ponto azul; (B) Munício de Inhambupe na Bahia, ponto verde indica a localização geográfica do sítio experimental; (C) Municípios de Minas Gerais com ênfase aos municípios de Buritizeiro e Bocaiúva, sítios experimentais indicados pelos pontos azul e vermelho; Visão aérea da área onde os ensaios experimentais foram instalados em Inhambupe-BA (D), Bocaiúva-MG (E) e Buritizeiro-MG (F). Mapa gerado com software de ambiente livre R.

The process of identifying the key insect/pest and disease involved preliminary field visits, during which thorough surveys were conducted across the experimental area to identify insects and pathogens that pose potential economic damage and are most prevalent in the region.

Following these visits, it was determined that the most important insect for the Bocaiúva and Buritizeiro sites was *G. brimblecombei* (red gum lerp psyllid), as it was widespread in both sites and distributed across the entire planting area. However, at the Inhambupe site, the presence of *G. brimblecombei* was not observed. Instead, the presence of the fungus *A. psidii* (eucalyptus rust) occurred extensively. Therefore, this pathogen was considered the most important, with the main diagnostic symptom being intense yellowish spore production on affected organs.

The symptoms and signs of attack by *G. brimblecombei* and *A. psidii* on the hybrid *Eucalyptus* progenies tested in the field in this study can be seen in Figure 3.

2.4 Phenotyping

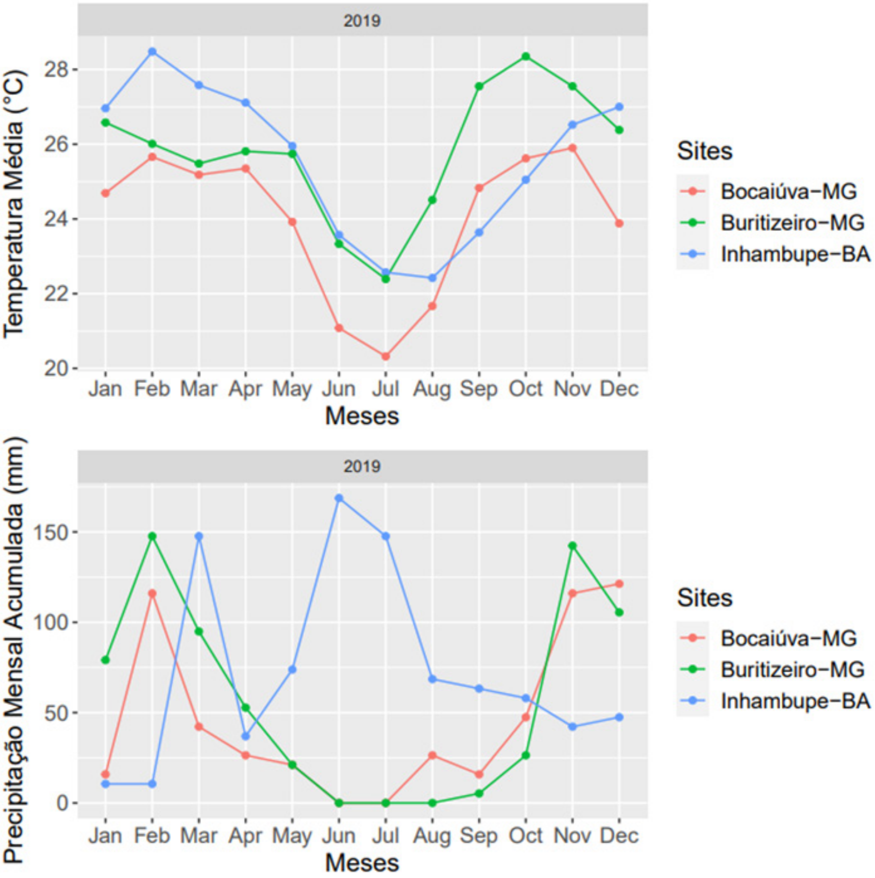

Figure 2. Graphical representation of climate data, average temperature (ºC) and accumulated monthly precipitation (mm), from the year of implantation and measurement to 6 months of age, from the sites of Bocaiúva-MG, Buritizeiro-MG and Inhambupe-BA

Figura 2. Representação gráfica dos dados climáticos, temperatura média (ºC) e precipitação mensal acumulada (mm), do ano de implantação e medição aos 6 meses de idade, dos sites de Bocaiúva-MG, Buritizeiro-MG e Inhambupe-BA

The phenotyping process was conducted at 6 months after planting. Characteristics related to wood productivity included total plant height (HGT), measured in meters using a graduated pole, and diameter at breast height (DBH), in centimeters, measured with a measuring tape at 1.30 meters above ground level. The circumference of each plant was recorded to obtain DBH (cm), and the data were transformed using the equation below:

$$DBH = \frac{CBH}{\pi} \qquad (Eq.\ 1)$$

where CBH is the circumference at breast height in centimeters, measured at 1.30 meters above ground level.

Volume (VOL), in cubic meters (m³), was estimated using the equations below based on HGT and DBH:

$$VOL = \frac{\pi * DBH^2}{40000} * HGT * f \qquad (Eq.\ 2)$$

where *f* is the average form factor (*f* = 0.45 in the present study).

The mean annual increment (MAI), estimated in $m^3.ha^{-1}.year^{-1}$, was calculated using the equation:

$$MAIvol = VOL * \frac{10000}{S} * \frac{12}{A} \qquad (Eq.\ 3)$$

where S is the spacing between plants (9 m²) and A is the age of the individuals in months.

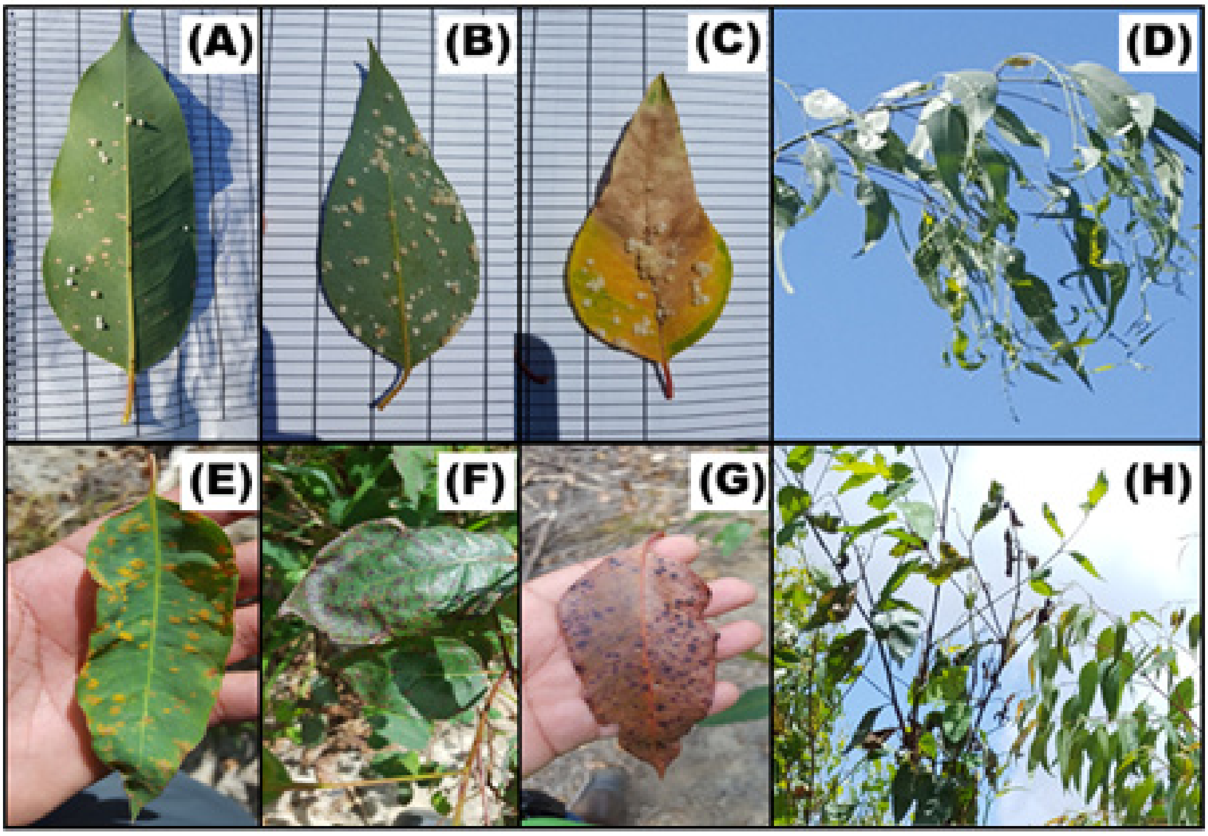

Figure 3. (A) Shells of *G. brimblecombei* produced during the first instars. (B) *Eucalyptus* hybrid leaf showing high shell psyllid infestation. (C) *Eucalyptus* hybrid leaf in an advanced stage of necrosis and senescence due to severe shell psyllid attack. (D) *Eucalyptus* hybrid shoot in a progeny test displaying overgrowth and twisted leaves resulting from a shell psyllid attack. (E, F, and G) Leaves of an *Eucalyptus* hybrid in a progeny test with an incidence of *Austropuccinia psidii* (eucalyptus rust). (H) *Eucalyptus* hybrid in a progeny test exhibiting leaves with pustules and abundant production of *Austropuccinia psidii* spores, in addition to leaves with permanent damage due to the incidence of the fungus

Figura 3. (A) Conchas de *G. brimblecombei* fabricadas durante os primeiros instares; (B) folha de híbrido de *Eucalyptus* apresentando alta infestação de psilídeo-de-concha; (C) folha de híbrido de *Eucalyptus* em processo avançado de necrose e senescência devido ao severo ataque do psilídeo-de-concha; (D) ponteiro de híbrido de *Eucalyptus* em teste de progênie apresentando superbrotação e folhas retorcidas decorrente do ataque do psilídeo-de-concha. (E, F e G) Folhas de híbrido de *Eucalyptus* em teste de progênie com incidência de *Austropuccinia psidii* (ferrugem do eucalipto); (H) híbrido de *Eucalyptus* em teste de progênie apresentando folhas com pústulas evidenciando abundante produção de esporos de *Austropuccinia psidii*, além de folhas com danos permanentes devido a incidência do fungo

Field evaluations of plant resistance were conducted visually by the same evaluator, following the rating system proposed by Eloy et al. (2013). Each plant was individually assessed and assigned a score of 0, 1, 3, or 5, representing the incidence or signs of insect or disease attack.

A score of 0 indicated no incidence or signs of attack. A score of 1 was given to plants with mild incidence of the insect or disease. Moderate incidence was scored as 3, and plants with high incidence or signs received a score of 5.

2.5 Statistical Analyses

Using the collected dataset, genetic analyses were conducted by estimating variance components through Restricted Maximum Likelihood (REML) and predicting genetic values using Best Linear Unbiased Prediction (BLUP) with the Selegen REML/BLUP software (Resende 2016). These analyses were performed individually for each trait at each site, according to the model described below:

$$y = W_r + Z_g + \varepsilon \qquad \text{(Eq. 4)}$$

where: y is the vector of observed field data; W is the incidence matrix for block effects, considered random; r is the vector of block effects with $r \sim N(0, I\sigma_b^2)$, where I is the identity matrix and σ_b^2 is the block variance, Z is the incidence matrix of random family effects, g is the vector of genetic effects considered random with $g \sim N(0, I\sigma_g^2)$, where σ_g^2 is the genetic variance, ε is the residual vector assumed random with $\varepsilon \sim N(0, I\sigma_\varepsilon^2)$, where σ_ε^2 is the residual variance.

The control clones included in the progeny test were analyzed separately using the same model as described above.

2.6 Selection

To select genetic materials with higher wood productivity potential and tolerance to insects or diseases, characteristics MAI and tolerance were considered. Selection was performed based on two indices: the multiplicative index (Subandi et al., 1973) (MI) and the index by Mulamba and Mock (1978) (MMI), which considered selection for MAI in the positive direction and selection for lower susceptibility in the negative direction.

The multiplicative index was obtained by multiplying the genetic values of families for each variable obtained from individual models, as shown in the equations below:

$$MI1 = (GV.MAI * GV.PSI) \qquad \text{(Eq. 5)}$$

$$MI2 = (GV.MAI * GV.RUS) \qquad \text{(Eq. 6)}$$

where MI1 refers to the multiplicative index for the sites Bocaiúva and Buritizeiro, and MI2 refers to the multiplicative index for the site Inhambupe. GV.MAI: Genetic value of the family for the MAI variable; GV.PSI: Genetic value for the psyllid tolerance variable; GV.RUS: Genetic value for eucalyptus rust tolerance variable. A weight of 1 was adopted for all variables.

For selection based on MMI, families were ranked hierarchically based on their genetic values in the desired direction. Thus, ranks were distributed for each measured characteristic, and their sums were subsequently calculated for each family. Ultimately, the best individuals were those that appeared in the top positions after ranking the sum of ranks.

For both selection methods, the selection intensity applied in this study was approximately 8.37%. This means that out of 239 hybrid families obtained from crossing 29 parents, 20 elite families were selected for better performance in MAI and pest/disease tolerance.

3. RESULTS

3.1 Description of Field Conditions

Among the insects and pathogens observed in the planting areas of Minas Gerais, the only one that showed widespread distribution was the red gum lerp psyllid (*Glycaspis brimblecombei*), thus considered the most influential pest in Bocaiúva and Buritizeiro.

Certain genotypes within these experimental sites were severely affected, with 100% of their leaves covered by the insect, while other genotypes showed minimal signs of infestation or damage.

In the experiment installed in Inhambupe, the presence of the red gum lerp psyllid was not observed. In contrast, there was widespread presence and distribution of *Austropuccinia psidii*, the causal agent of eucalyptus rust. Deformations, necrosis, hypertrophy, and tissue and shoot death were observed in affected individuals (Figure 2).

3.2 Genetic Parameters

The heritability (h_g^2) showed estimates ranging from 0.20 (Buritizeiro) to 0.26 (Bocaiúva) for psyllid/rust tolerance, and estimates ranging from 0.01 (Inhambupe) to 0.21 (Buritizeiro) for MAI (Table 2).

The mean progeny heritability (h_{mp}^2) ranged from 0.21 (Inhambupe) to 0.60 (Bocaiúva) for MAI, and from 0.76 (Buritizeiro) to 0.93

Table 2. Estimates of genetic parameters for tolerance to pests/diseases and Average Annual Increment (AAI) (m³/ha/year) in a *Eucalyptus* hybrid progeny test at six months of age at the Buritizeiro-MG, Bocaiúva-MG, and Inhambupe-BA sites

Tabela 2 Estimativas de parâmetros genéticos para tolerância a pragas/doenças (tolerância) e Incremento médio anual (IMA) (m3/ha/ano) em teste de progênie híbrida de *Eucalyptus* aos seis meses de idade nos sites de Buritizeiro-MG, Bocaiúva-MG e Inhambupe-BA

Parâmetros	Buritizeiro		Bocaiúva		Inhambupe	
	IMA	Tolerância	IMA	Tolerância	IMA	Tolerância
h_g^2	0,21	0,2	0,1	0,26	0,01	0,24
h_{mp}^2	0,51	0,76	0,6	0,8	0,21	0,93
h_{ad}^2	0,13	0,12	0,06	0,16	~0,0	0,14
Ac_{prog}	0,86	0,83	0,71	0,87	0,21	0,85
c_{bloc}^2	0,1	0,03	0,03	0,03	0,01	0,01
Média geral	0,79	3,1	1,51	3,34	3,41	2,49

h_g^2: broad sense heritability; c_{bloc}^2: Coefficient of determination of block effects; h_{mp}^2: heritability of the progeny average, assuming complete survival; Ac_{prog}: progeny selection accuracy, assuming complete survival; h_{ad}^2: additive heritability within plot

h_g^2: herdabilidade de sentido amplo; c_{bloc}^2: Coeficiente de determinação dos efeitos de bloco; h_{mp}^2: herdabilidade da média de progênies, assumindo sobrevivência completa; Ac_{prog}: acurácia da seleção de progênies, assumindo sobrevivência completa; h_{ad}^2: herdabilidade aditiva dentro de parcela.

(Inhambupe) for pest/disease tolerance. Within-plot heritability (h_{ad}^2) ranged from ~0.00 (Inhambupe) to 0.13 (Buritizeiro) for MAI, and from 0.12 (Buritizeiro) to 0.16 (Bocaiúva) for insect and pest tolerance (Table 3).

The accuracy values found in this study were highly significant, ranging from 0.76 for insect tolerance in Buritizeiro to 0.93 for disease tolerance in Inhambupe (Table 3). For the MAI trait, the accuracies of predicted genetic values ranged from 0.21 in Inhambupe to 0.87 in Bocaiúva (Table 3).

The c_{bloc}^2 for MAI showed no difference compared to h_g^2 at the Inhambupe site. For other situations, heritability surpassed local variability ($h_g^2 > c_{bloc}^2$). Concerning the overall test mean, the highest MAI productivity values were observed at the Inhambupe-BA site, while the lowest values were recorded at the Buritizeiro-MG site.

3.3 Selection

For the Buritizeiro/MG site, the multiplicative index showed gains of 2% and 8% (Table 4) compared to the best control in the test (Table 5). The two best families classified at this site were G2 x G18 (*E. camaldulensis* x *E. brassiana*) and G4 x G31 (*E. urophylla* HE x *E. camaldulensis*). The remaining families showed negative gains compared to the best control (GG1980 – *E. urophylla* HE) (Table 5).

For the Bocaiúva/MG site, the multiplicative index showed gains from 1% to 14% (Table 3) compared to the best control in the test, which was clone GG1980 (Table 4). This material repeated its superior performance compared to other controls, as observed at the Buritizeiro/MG site.

For the Inhambupe/BA site, all 20 selected families showed positive gains compared to the best control, clone GG1980, and it performed the best across all sites (Table 3). The gains observed among the families selected by the multiplicative index for tolerance and MAI ranged from 12% (G6xG30) to 42% (G5xG6).

The Mulamba and Mock (1978) index reclassifies the progenies based on the position each family occupied in the individual rankings for each evaluated parameter. Table 5 presents the top 20 families classified according to this

Table 3. Classification of families according to multiplicative index, for each experimental site

Tabela 3. Classificação das famílias segundo índice multiplicativo, para cada site experimental

Order	Buritizeiro			Bocaiúva			Inhambupe		
	Families	**Value**	**Gain**	**Families**	**Value**	**Gain**	**Families**	**Value**	**Gain**
1	G2xG18	4,96	8%	G7xG35	7,51	14%	G5xG6	13,83	42%
2	G4xG31	4,71	2%	G15xG3	7,34	11%	G6xG9	13,08	34%
3	G2xG12	4,46	-3%	G7xG31	7,29	11%	G1xG6	12,36	27%
4	G8xG19	4,44	-4%	G17xG20	7,13	8%	G5xG8	12,23	26%
5	G10xG18	4,43	-4%	G4xG12	7,09	8%	G9xG27	11,75	21%
6	G7xG24	4,25	-8%	G13xG13	6,91	5%	G6xG17	11,73	20%
7	G3xG12	4,22	-8%	G20xG35	6,88	4%	G6xG13	11,69	20%
8	G6xG17	4,15	-10%	G4xG28	6,87	4%	G1xG1	11,52	18%
9	G7xG35	4,15	-10%	G10xG18	6,75	2%	G6xG15	11,45	18%
10	G2xG33	4,13	-10%	G18xG15	6,67	1%	G5xG9	11,37	17%
11	G7xG25	4,13	-11%	G15xG4	6,64	1%	G7xG6	11,36	17%
12	G3xG28	4,1	-11%	G2xG19	6,5	-1%	G6xG18	11,34	16%
13	G2xG19	4,08	-12%	G13xG12	6,48	-2%	G6xG14	11,33	16%
14	G8xG18	4,05	-12%	G3xG35	6,39	-3%	G5xG5	11,2	15%
15	G6xG15	4,03	-13%	G13xG30	6,38	-3%	G5xG20	11,17	15%
16	G1xG18	3,99	-13%	G9xG32	6,38	-3%	G6xG29	11,14	14%
17	G20xG3	3,97	-14%	G13xG31	6,27	-5%	G5xG27	11,02	13%
18	G5xG15	3,96	-14%	G2xG27	6,26	-5%	G7xG16	10,95	12%
19	G2xG15	3,95	-14%	G7xG16	6,17	-6%	G2xG13	10,93	12%
20	G1xG17	3,95	-14%	G18xG18	6,14	-7%	G6xG30	10,92	12%

Table 4. Classification of witness families according to multiplicative index, for each experimental site

Tabela 4. Classificação das testemunhas famílias segundo índice multiplicativo, para cada site experimental

Order	Buritizeiro		Bocaiúva		Inhambupe	
	Witness	**Gain**	**Witness**	**Gain**	**Witness**	**Gain**
1	GG1980	4,61	GG1980	6,59	GG1980	9,74
2	GG1923	3,31	VM1	6,48	GG2673	5,5
3	GG2673	3,31	GG2673	4,93	I144	5,13
4	VM1	1,86	I144	4,01	VM1	4,98
5	AEC1528	0,72	GG1923	3,97	AEC1528	3,65
6	I144	0,35	AEC1528	3,83	GG1923	3,19

Table 5. Classification via the Mulamba Mock index (1978) of eucalyptus hybrid materials for productivity and tolerance to shell psyllid (PSI) and eucalyptus rust (FER)

Tabela 5. Classificação via índice Mulamba Mock (1978) de materiais híbridos de eucalipto para produtividade e tolerância a psilídeo-de-concha (PSI) e a ferrugem do eucalipto (FER)

Order	**Buritizeiro**			
	Families	**Rank**		
		MMI	**MAI**	**PSI**
1	G4xG28	21,5	21	22
2	G7xG32	37,5	63	12
3	G5xG7	43,5	66	21
4	G7xG25	44	3	85
5	G8xG19	44	1	87
6	G5xG30	46	91	1
7	G5xG5	46	88	4
8	G3xG32	48,5	56	41
9	G8xG15	49,5	29	70
10	G5xG15	50	6	94
11	G4xG27	51,5	78	25
12	G8xG12	55	76	34
13	G9xG28	56	49	63
14	G6xG19	56	46	66
15	G1xG23	56,5	54	59
16	G1xG18	58	7	109
17	G8xG7	58,5	48	69
18	G20xG4	59,5	33	86
19	G14xG20	59,5	96	23
20	G8xG4	60,5	59	62
	Bocaiúva			
1	G1xG7	11,5	9	14
2	G8xG10	16,5	17	16
3	G14xG4	19	34	4
4	G4xG9	21,5	28	15
5	G8xG16	26	10	42
6	G5xG5	26,5	43	10
7	G5xG27	29,5	56	3
8	G5xG10	29,5	33	26
9	G5xG33	30,5	26	35
10	G4xG35	35	51	19
11	G4xG30	35	40	30
12	G14xG18	35,5	30	41
13	G4xG12	38,5	1	76

Cont...

Cont...

Order	Bocaiúva			
	Families	Rank		
		MMI	MAI	PSI
13	G4xG12	38,5	1	76
14	G6xG7	39	76	2
15	G7xG34	41,5	12	71
16	G13xG30	43,5	7	80
17	G3xG33	43,5	39	48
18	G4xG28	44,5	3	86
19	G5xG28	44,5	36	53
20	G9xG32	45	8	82
	Inhambupe			
1	G3xG31	6	7	5
2	G10xG28	10,5	8	13
3	G20xG4	15,5	12	19
4	G3xG34	17	14	20
5	G7xG27	18,5	19	18
6	G14xG18	21	40	2
7	G10xG17	22,5	15	30
8	G8xG19	22,5	13	32
9	G18xG16	24,5	26	23
10	G3xG4	26	28	24
11	G4xG35	32	47	17
12	G17xG17	34,5	4	65
13	G9xG35	36	46	26
14	G5xG14	37	2	72
15	G9xG29	40,5	18	63
16	G10xG7	42	37	47
17	G10xG13	42,5	6	79
18	G20xG28	44	21	67
19	G3xG33	44,5	74	15
20	G1xG10	44,5	77	12

rank for MAI and Tolerance.

Analyzing the Buritizeiro/MG site, the top three families in the Mulamba-rank were G4xG28 (*E. urophylla* HE x *E. camaldulensis*), G7xG32 ((*E. urophylla* x (*E. camaldulensis* x *E. grandis*)) x (*E. longirostrata*)), and G5xG7 ((*E. urophylla*) x (*E. urophylla* x (*E. camaldulensis* x *E. grandis*))) (Table 5).

For the Bocaiúva/MG site, the families occupying the top three positions in the Mulamba-rank were G1xG7 ((*E. urophylla* x *E. grandis*) x (*E. urophylla* x (*E. camaldulensis* x *E. grandis*))), G8xG10 ((*E. grandis* HE) x (*E. urophylla*)), and G14xG4 (*E. camaldulensis* x *E. urophylla* HE).

Regarding the Inhambupe/BA site, the cross G3xG31 ((*E. urophylla* x *E. camaldulensis*) x

(*E. camaldulensis*)) showed good consistency in ranking for both traits (MAI and tolerance to *G. brimblecomblei*) when selected individually, being classified in 7th and 5th positions for MAI and tolerance, respectively.

4. DISCUSSION

4.1 Description of data and field conditions

Damage associated with the gum psyllid (*Glycaspis brimblecombei*) attack includes leaf size reduction, deformation, necroses in circular areas where protective shell-like structures are formed by the sugary excrement expelled by the insect (Alfenas et al., 2009). Productivity loss is caused by sooty mold production and severe defoliation, which reduce light interception and consequently carbon fixation through photosynthesis (Mattos et al., 2020).

In the Inhambupe site, the widespread incidence of the fungus *Austropuccinia psidii* has made it the most relevant disease. Native in origin, this fungus has become a common and severe disease in Brazilian eucalypt plantations under two years of age (Ferreira, 1983). The fungus primarily attacks young leaves and shoots, conditions observed in the evaluated experiment, causing deformations and impairing photosynthesis and tree growth (Auer et al., 2010).

4.2 Genetic parameters

Heritability estimates ranging from 0.01 to 0.15 are considered low, from 0.15 to 0.50 moderate, while values exceeding 0.50 are considered high (Resende, 2002). In this context, for the trait of interest, pest/disease tolerance, individual heritability (h_g^2) in genotype selection showed moderate magnitude across the three experimental sites (Buritizeiro, Bocaiúva, and Inhambupe), ranging between 0.20 and 0.26. However, for the productivity trait (IMA), the estimate was moderate only at the Buritizeiro-MG site and low at all other sites.

The h_g^2 estimates for MAI were lower than those reported by Nogueira et al. (2019), suggesting potential for higher h_g^2 values for MAI. The low to moderate h_g^2 estimates for MAI are supported by Henriques et al. (2017), who observed similar results ($h_g^2 = 0.13$) at 12 months of age in progeny tests of *Eucalyptus urophylla*. However, these estimates may increase over time, as observed for traits influencing MAI estimation such as DBH and height (Henriques et al., 2017).

Accuracy refers to the correlation between predicted genetic values of individuals and their true genetic values (Resende and Duarte, 2007). In the present study, except for MAI in Inhambupe, the accuracy values were satisfactory for selecting families for introduction into genetic improvement programs. According to Resende and Duarte (2007), accuracy should be above 0.70 to proceed with selection cycles and above 0.90 for final cultivar recommendation.

In Inhambupe, there was a greater influence of environmental effects compared to the other two locations.

4.3 Selection

At the Buritizeiro site, combined selection for wood productivity and resistance to the gum psyllid using the multiplicative index showed that clone GG 1980 outperformed over 99% of the tested families. Additionally, G2 x G18 (*E. camaldulensis* x *E. brassiana*) and G4 x G31 (*E. urophylla* HE x *E. camaldulensis*) exhibited potential for good productivity even under water deficit conditions, and also showed good performance in terms of resistance to psyllid attack.

The three top-performing families at the Bocaiúva site, highlighted by gains exceeding 10%, were G7xG35 ((*E. urophylla* x (*E. camaldulensis* x *E. grandis*)) x (*E. tereticornis*)), G15xG3 ((*E. urophylla* x *E. tereticornis*) x (*E. urophylla* x *E. camaldulensis*)), and G7xG31, with gains of 14%, 11%, and 11%, respectively.

Overall, at this site, eleven families showed positive gains over the best check (GG1980 – *E. urophylla* HE), indicating that when considering both productivity and susceptibility to gum psyllid, clone GG 1980 outperformed over 94% of the tested families.

Among the checks, clone GG1980 performed the best across all three sites based on the multiplicative index ranking. This genetic material was developed by Gerdau Florestal in their internal breeding program in the Três Marias/MG region, which is also affected by prolonged water deficit.

Using the Mulamba and Mock (1978) index at the Buritizeiro/MG site, the top-ranked material in the ranking occupied the 21st and 22nd positions for MAI and resistance to gum psyllid, respectively. In contrast to Buritizeiro, at the Bocaiúva site, the top two ranked families (G4xG28 and G7xG32) were also listed among the top 20 families for MAI and resistance to *G. brimblecomblei*, if selection were conducted individually.

In Inhambupe, the family G3XG31 was the highest-ranked among the progenies. The families ranked second and third in the ranking were also among the top 20 families in individual rankings for MAI and tolerance to gum psyllid, indicating their relevance for selection targeting either of these traits, or considering joint selection for both characteristics.

5. CONCLUSION

The results of this study demonstrated significant differences in pest and pathogen presence among the evaluated sites, influencing genotypic selection and the observed genetic parameters. In Minas Gerais, the gum psyllid was the predominant pest, while in Inhambupe, the fungus *Austropuccinia psidii* caused severe damage. Heritability estimates varied among sites, with Bocaiúva showing the highest heritabilities for mean annual increment (MAI) and Buritizeiro for pest tolerance.

Selection indices indicated positive genetic gains at all sites. Genotypic selection using the Multiplicative and Mulamba and Mock selection indices proved effective for selecting genotypes that meet various demands of the forest production sector. These results underscore the importance of considering local variabilities and the efficacy of methods used to identify superior families, thereby maximizing genetic gains across different environments.

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AUTHOR CONTRIBUTIONS

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