horticultura brasileira

Research

SILVA, JAS; PEREIRA, JWL; VALADARES, RN; LIMA, RSR; SILVA, FS; GUISELINI, C; MENEZES, D. 2022. Adaptability and stability of eggplant submitted to different levels of shading via REML/BLUP. *Horticultura Brasileira* 40: 099-106. DOI: http://dx.doi.org/10.1590/s0102-0536-20220113

Adaptability and stability of eggplant submitted to different levels of shading via REML/BLUP

Jordana Antônia dos S Silva [1]; Jacqueline Wanessa de L Pereira [2]; Ricardo de N Valadares [1]; Rayhonay SR de Lima [1]; Fabian S Silva [1]; Cristiane Guiselini [1]; Dimas Menezes [1]

[1]Universidade Federal Rural de Pernambuco, (UFRPE), Recife-PE, Brasil; jord.antonia@hotmail.com; rnvaladares@yahoo.com.br; rayhonaysouza@gmail.com; fabianufrpe@gmail.com; cristiane.guiselini@ufrpe.br; dimasufrpe@gmail.com. [2]Instituto Agronômico de Pernambuco (IPA), Recife-PE, Brasil; jacquelinewlp@gmail.com

ABSTRACT

This study aimed to evaluate the eggplant genotype x environment ineraction, using the REML/BLUP procedure, in order to identify genotypes with high productivity, adaptability and phenotypic stability. The experiments were carried out in agricultural greenhouses, in two seasons, with three types of shading: uncovered (UC); covered with plastic diffuser film (PD), 130 microns thick, covered with plastic diffuser film (130 micron) + 50% shading screen (SS). Twelve eggplant genotypes were evaluated, with four replicates and an experimental plot consisting of four plants. The traits evaluated in this study were: fruit set index, number of fruits per plant, average production of fruits/plant and *in vitro* pollen viability. To assess the adaptability and stability of the genotypes, statistical analyzes and estimation of genetic parameters were performed using the mixed-models of REML/BLUP type, with the aid of SELEGEN software and the statistical model 51. According to the results obtained, the authors verified an agreement between the three methods: Relative Performance of Genetic Values (PRVG), Harmonic Average of Genotypic Values (MHVG) and Harmonic Mean of Relative Performance of Genetic Values (MHPRVG) for average fruits production per plant (PP), number of fruits per plant (NF) and *in vitro* pollen viability (IVPV), showing the high degree of agreement in the ordering of materials. Thus, it is possible to indicate that the genotypes with the best productive performance, adaptability and stability in the evaluated environments were CNPH135×CNPH60, CNPH135×CNPH51, CNPH135×CNPH141, CNPH109, CNPH109×CNPH60 and CNPH109×CNPH141.

Keywords: *Solanum melongena*, genotype x environment interaction, mixed models.

RESUMO

Adaptabilidade e estabilidade de berinjela submetida a diferentes níveis de sombreamento via REML/BLUP

Objetivou-se avaliar a interação entre genótipos de berinjela e ambientes, utilizando o procedimento REML/BLUP com a finalidade de identificar genótipos com alta produtividade, adaptabilidade e estabilidade fenotípica. Os experimentos foram conduzidos em estufas agrícolas, em duas épocas, com três tipos de sombreamento: Sem cobertura (UC); Cobertura com plástico filme difusor de 130 micras (PD); Cobertura com plástico filme difusor de 130 micras + tela de sombreamento de 50% SS. Foram avaliados 12 genótipos de berinjela, com quatro repetições e a parcela experimental composta por quatro plantas. Os caracteres avaliados foram: Índice de pegamento de fruto, Número de frutos por planta, Produção média de frutos/planta e Viabilidade polínica *in vitro*. Para a avaliação da adaptabilidade e estabilidade dos genótipos foram realizadas as análises estatísticas e a estimação dos parâmetros genéticos baseadas em modelos mistos do tipo REML/BLUP, empregando o software SELEGEN e o modelo estatístico 51. De acordo com os resultados obtidos, houve concordância entre os três métodos: Performance Relativa dos Valores Genéticos (PRVG), Média Harmônica dos Valores Genotípicos (MHVG) e Média Harmônica da Performance Relativa dos Valores Genéticos (MHPRVG) para os caracteres Produção média de frutos por planta (PP), Número de frutos por planta (NF) e Viabilidade polínica *in vitro* (IVPV), evidenciando o alto grau de concordância no ordenamento dos materiais. A partir disto, é possível indicar que os genótipos com o melhor desempenho produtivo, adaptabilidade e estabilidade nos ambientes avaliados foram CNPH135×CNPH60, CNPH135×CNPH51, CNPH135×CNPH141, CNPH109, CNPH109×CNPH60 e CNPH109×CNPH141.

Palavras-chave: *Solanum melongena*, interação genótipo x ambiente, modelos mistos.

Received on May 10, 2021; accepted on January 7, 2022

Eggplant (*Solanum melongena*) belongs to Solanaceae family, it is mainly grown in Asia, being China and India the main producers (FAO, 2019). In Brazil, the main production area is in Central-South region, being the cultivated area around 1,550 ha/year (Boiteux *et al.*, 2016). No recent data on productivity and commercialization of this vegetable in Brazil are available, though (Delazari *et al.*, 2019).

Nevertheless, eggplant cultivation tends to grow, since, the interest in high-quality vegetable products, with better organoleptic, nutritional and functional properties, has been increasing (Kyriacou *et al.*, 2016; Bisbis *et al.*, 2018). The eggplant stands out for its nutritional and medicinal value, being also a vegetable with high content of mineral salts, vitamins and fibers, helping out controlling cholesterol levels and blood pressure (Yahia *et al.*, 2019; Weber *et al.*, 2013).

In order to cultivate eggplant, the temperatures shall be between 25-35°C and relative humidity of 80% (Adamczewska-Sowińska & Krygier, 2013). In the Northeast, when the eggplant is grown under protected environment, the temperature inside the greenhouse exceeds 32ºC. During flowering, this temperature causes malformation and/or abortion of the fruits, reducing productivity (Valadares *et al.*, 2019). So that, it is necessary to use genotypes able to keep high productivity, even being cultivated in these environments at any time of the year.

To select superior eggplant genotypes, it is important to understand the productive performance that the inbred lines and/or hybrids have in different environments, in the field or in a protected environment, with their respective variations. Moreover, knowledge and capitalization of genotype x environment interaction is essential (Santos *et al.*, 2016).

Using adaptability and stability analyzes, we can verify the performance of a genotype in relation to environmental variations (Carvalho *et al.*, 2017). Considering the existing methods, REML/BLUP (Restricted Maximum Likelihood/Best Linear Unbiased Prediction) allows simultaneous selection for productivity, stability and adaptability, capitalizing or penalizing genotype x environment interaction effect (Resende, 2007a).

Given the above, this study aimed to estimate the adaptability and stability of eggplant genotypes under different types of shading and times of the year using REML/BLUP methods.

MATERIAL AND METHODS

The experiments were carried out in agricultural greenhouses located in Área de Fitotecnia, at Departamento de Agronomia da Universidade Federal Rural de Pernambuco, Dois Irmãos Campus, Recife (8°1'7"S, 34°56'46"W and 6.5 m altitude). According to Köppen's classification, the climate of the region is As', hot and humid (Alvares *et al.*, 2014).

The experimental design was of randomized blocks with 12 treatments, represented by eggplant genotypes (CNPH60, CNPH135, CNPH109 and CNPH410, CNPH109×CNPH141, CNPH135×CNPH60, CNPH135×CNPH51, CNPH47×CNPH60, CNPH135×CNPH141 and CNPH109×CNPH60) and two commercial cultivars, Ciça (hybrid developed by Embrapa, oblong fruits, bright dark purple color) and Embú (open-pollinated cultivar, oblong fruits, bright dark purple color), with four replicates and experimental plot consisting of four plants (Antonini, *et al.*, 2002).

The genotypes were evaluated in two sowing seasons, with the weather conditions (Figure 1) described below.

Sowing season 1 (S1): May-October, 2019 (average temperature: 24,7°C; rainfall: 282.4mm);

Sowing season 2 (S2): November, 2019 to April, 2020 (average temperature: 26.2°C; rainfall: 121.2mm).

These informations were obtained from Estação de Agricultura Irrigada Prof. Ronaldo de Freire Moura, Departamento de Engenharia Agrícola da Universidade Federal Rural de Pernambuco (8°1'6"S, 34°56'49"W, 6 m altitude), Geocentric Reference System for the Americas (SIRGAS2000).

The experiments were evaluated under three types of shading, as described below.

Uncovered (UC)

Covered with plastic diffuser film, 130 microns thick (PD);

Covered with plastic diffuser film (130 micron) + 50% shading screen (SS).

Combination (shading type X sowing season) originated the six evaluated environments: Environment 1 (S1-UC); environment 2 (S1-PD); environment 3 (S1-SS); environment 4 (S2-UC); environment 5 (S2-PD) and environment 6 (S2-SS).

In order to characterize the climate of the environments, we used the relative air temperature, relative air humidity, solar radiation balance and rainfall using HOBO miniature datalogger and from the Automatic Meteorological Station of the Department of Rural Technology at UFRPE (Figure 1).

Seeds were sown in 162-cell expanded polystyrene trays. The seedlings were kept in a greenhouse, under hydroponic subirrigaton system. When the seedlings showed four definitive leaves, they were transplanted into 0.4 dm^3 pots and after ten days, when the seedlings showed six definitive leaves, they were transplanted into 5.5 dm^3 pots. Washed coconut powder was used as substrate in the trays and pots.

Water was supplied via hydroponic drip system, controlled by a digital timer and adjusted according to the needs of the crop. For mineral nutrition, we used nutritive solution [$Ca(NO_3)_2$ (2.25 kg), KNO_3 (1.35 kg), $MgSO_4$ (1.20 kg), $(NH_4)H_2PO_4$ (600 g), KH_2PO_4 (450 g), Quelatec® (75 g) and Ultraferro® (75 g)] for 3000 liters of water.

To verify the effect of different types of shading, as well as cultivation season in development and production of eggplant, the following traits were evaluated: FSI [fruit set index (%)], NF (number of fruits per plant), PP [average fruit production per plant (g)] and IVPV [*in vitro* pollen viability (%)]. The homogeneity and normality of data was evaluated, being not necessary to transform the data.

To evaluate adaptability and stability of eggplant genotypes, we performed analysis via mixed REML/BLUP models using Selegen software (Resende, 2002). Model 51 was used to evaluate the highest values of harmonic average of genotypic values:

$$Y=X_r+Z_g+W_i+e$$

In which Y= data vector; r= vector of the effects of the local repetition combinations added to the general average; g= vector of genotypic effects; i= vector of the effects of genotype x environment interaction; e= error vector. The uppercase letters represent the incidence matrices for these effects. The distributions and structures of averages

(E) and variance (Var) assumed:

$$E = \begin{vmatrix} y \\ g \\ c \\ e \end{vmatrix} = \begin{vmatrix} Xr \\ 0 \\ 0 \\ 0 \end{vmatrix} ;$$

$$Var = \begin{vmatrix} g \\ i \\ e \end{vmatrix} = \begin{vmatrix} I\sigma_g^2 & 0 & 0 \\ 0 & I\sigma_i^2 & 0 \\ 0 & 0 & I\sigma_e^2 \end{vmatrix}$$

The model adjustment was obtained using equations of mixed model:

$$\begin{vmatrix} X'X & X'Z & X'W \\ Z'X & Z'Z+I\lambda_1 & Z'W \\ W'X & W'Z & W'W+I\lambda_1 \end{vmatrix} x \begin{vmatrix} \hat{r} \\ \hat{g} \\ \hat{i} \end{vmatrix} = \begin{vmatrix} X'y \\ Z'y \\ W'y \end{vmatrix}$$

In which

$$\lambda_1 = \frac{\sigma_e^2}{\sigma_g^2} = (1 - h_g^2 - c^2)/h_g^2$$

$$\lambda_2 = \frac{\sigma_e^2}{\sigma_c^2} = (1 - h_g^2 - c^2)/h_g^2$$

in which

$$h_g^2 = \sigma_g^2 / (\sigma_g^2 + \sigma_c^2 + \sigma_e^2)$$

corresponds to the individual heritability, broadly in the block;

$$c^2 = \sigma_c^2 (\sigma_g^2 + \sigma_c^2 + \sigma_e^2)$$

corresponds to coefficient of determination of effects of genotype × environment interaction; σ_g^2 is the genetic variation between the eggplant genotypes; σ_c^2 is the variance of genotype x environment interaction; σ_e^2 is the residual variance between plots.

The prediction of genotypic values capitalizing the average interaction in the different environments is given by µ̂j+ĝi+ĝem, being calculated by: µ̂+[(ˆσ2g+σ2c/n)/σ2g]xĝi, in which $\hat{\mu}$ is the overall average of all environments, n is the number of environments and $\hat{g}_i$ is the genotypic effect of the genotype i (Resende, 2007b). Values of MHVG to evaluate stability were obtained by the equation: MHVGi = n/Σnj=1(1/Vg_{ij}), in which n is the number of environments (n= 2) to evaluate genotype i and Vg_{ij} is the genotypic value of the genotype i in environment j, expressed as proportion of the average of this environment (Resende, 2007a). Values of PRVG for adaptability were obtained through the expression: PRVGi = 1/n×(Σnj=1Vg_{ij})/M_j, where M_j is the average of the traits evaluated in environment j. The joint selection, considering, simultaneously, traits, stability and adaptability, is given by the statistical model MHPRVG: $MHPRVG_i$ =n/(Σnj=1×1)/Vg_{ij}.

For genetic evaluation by the highest harmonic average values of the genotypic values, the method MHPRVG was used, as described by Resende (2002). These analyses were done using Selegen Software (Resende, 2007b).

RESULTS AND DISCUSSION

Table 1 shows genetic parameters (individual REML) in different environments for the production of 12 eggplant genotypes.

The coefficient of experimental variation (Cve) and accuracy of selection (ACgen) are used to quantify the experimental accuracy. In this study, such parameters showed values lower than 23% for Cve and higher than 93% for Acgen in all traits. These estimates showed an excellent experimental accuracy, pointing out greater security and credibility for selecting superior genotypes in relation to the studied traits (Caspitrano *et al.*, 2021).

The coefficients of individual genetic variation (CVgi) showed high values for IPF (41.73), moderate values for NF (25.19%) and PP (27.68%), and low values for IVPV (8.28%). The values indicated for this parameter were superior than the ones found for the coefficient of experimental variation (Cve) for all traits, considering a desirable characteristic for selection process (Cruz *et al.*, 2014).

The heritability of the average genotypes (h^2_{mg}) is estimated using averages as unit of selection and evaluation (Maia *et al.*, 2009). In this case, h^2_{mg} were considered of high magnitude (>88%) for all traits, allowing selecting genotypes based on genotypic averages. Moreover, this heritability reached high level of accuracy, due to the reduction of experimental errors (Rosado *et al.*, 2012).

The broad-sense heritability calculated on an individual basis was of high magnitude for NF and average for PP, FSI and IVPV. Such results are obtained with the observation of genotypic, environmental and phenotypic variances. For all traits, the genotypic variances were superior in relation to environments, showing that the phenotype was less influenced by the environment (Resende *et al.*, 2001).

Table 1. Genetic parameters (individual REML) considering the six environments for PP (production per plant, g), FSI (fruit set index), NF (number of fruit per plant) and IVPV (*in vitro* pollen viability, %). Recife, UFRPE, 2019-2020.

Parameters	NF	PP	FSI	IVPV
V_g	4.92	461390.78	14.97	44.87
V_{int}	3.60	299358.68	4.91	17.01
V_e	3.53	249577.05	11.32	26.82
V_f	12.53	1042775.71	32.73	92.28
h^2_g	0.86	0.44	0.45	0.48
c^2_{int}	0.28	0.28	0.15	0.18
h^2_{mg}	0.88	0.89	0.92	0.93
A_{cgen}	0.93	0.94	0.96	0.96
r_{gloc}	0.57	0.60	0.75	0.72
$CV_{gi\%}$	25.19	27.68	41.73	8.28
$CV_{e\%}$	13.18	12.55	22.50	3.96
Average	8.80	2453.57	9.27	80.82

V_g: genotypic variance; **V_{int}:** genotype x environment interaction variance; **V_e:** residual variance; **V_f:** individual phenotypic variance; **h^2_g:** broad-sense heritability of individual plots; **c^2_{int}:** coefficient of determination of genotype x environment interaction effect; **h^2_{mg}:** heritability of the average of genotypes; **A_{cgen}:** accuracy of genotype selection; **r_{gloc}:** genotypic correlation considering the performance in various environments; **$CV_{gi\%}$:** coefficient of genotypic variation; **$CV_{e\%}$:** coefficient of residual variation.

Table 2. Ordering of eggplant genotypes, in the six environments together for PP (production per plant, g), FSI (fruit set index), NF (number of fruits per plant) and IVPV (*in vitro* pollen viability). Recife, UFRPE, 2019-2020.

Trait	Ordering	Genotype (CNPH)	G	u+g	Gain	New average	U+g+gem
NF	1st	135x141	4.38	13.19	4.38	13.19	13.72
	2nd	109	1.90	10.71	3.14	11.95	10.94
	3rd	135x51	1.84	10.65	2.71	11.52	10.87
	4th	135x60	0.93	9.73	2.26	11.07	9.85
	5th	Ciça	0.32	9.13	1.88	10.68	9.17
	6th	109x141	-0.07	8.72	1.55	10.36	8.71
	7th	Embú	-0.09	8.71	1.31	10.12	8.70
	8th	109x60	-0.49	8.31	1.09	9.89	8.25
	9th	47x60	-1.78	7.01	0.77	9.57	6.80
	10th	60	-2.13	6.67	0.48	9.28	6.41
	11th	135	-2.39	6.41	0.22	9.02	6.12
	12th	410	-2.42	6.37	0.00	8.80	6.08
PP	1st	135x60	827.46	3281.03	827.46	3281.03	3370.51
	2nd	135x51	563.48	3017.05	695.47	3149.04	3077.98
	3rd	47x60	531.57	2985.14	640.83	3094.40	3042.62
	4th	Ciça	436.40	2889.97	589.72	3043.30	2937.16
	5th	135x141	340.31	2793.88	539.84	2993.41	2830.68
	6th	109x60	261.25	2714.82	493.41	2946.98	2743.08
	7th	109	74.35	2527.92	433.54	2887.12	2535.96
	8th	Embú	66.88	2520.45	387.71	2841.28	2527.68
	9th	135	-448.11	2005.45	294.84	2748.41	1956.99
	10th	109x141	-545.94	1907.62	210.76	2664.33	1848.58
	11th	60	-844.22	1609.34	114.85	2568.42	1518.05
	12th	410	-1263.44	1190.13	0.00	2453.57	1053.50
FSI	1st	135x141	6.57	15.84	6.57	15.84	16.20
	2nd	135x51	4.51	13.78	5.54	14.81	14.03
	3rd	135x60	2.62	11.89	4.57	13.84	12.04
	4th	109x141	2.15	11.42	3.96	13.23	11.53
	5th	Ciça	2.06	11.33	3.58	12.85	11.44
	6th	109	0.90	10.18	3.14	12.41	10.23
	7th	47x60	-1.79	7.47	2.43	11.70	7.37
	8th	Embú	-1.98	7.28	1.88	11.15	7.17
	9th	109x60	-2.29	6.97	1.41	10.68	6.84
	10th	135	-3.86	5.41	0.88	10.16	5.19
	11th	60	-4.42	4.84	0.40	9.67	4.60
	12th	410	-4.47	4.79	0.00	9.27	4.55
IVPV	1st	410	6.51	87.34	6.51	87.34	87.75
	2nd	Ciça	4.16	84.99	5.34	86.16	85.25
	3rd	109x60	3.27	84.09	4.65	85.47	84.30
	4th	109	3.23	84.05	4.29	85.12	84.26
	5th	109x141	2.48	83.31	3.93	84.76	83.47
	6th	47x60	2.31	83.14	3.66	84.49	83.28
	7th	Embú	2.24	83.06	3.46	84.28	83.20
	8th	135x60	1.02	81.84	3.15	83.98	81.90
	9th	135x141	0.08	80.90	2.81	83.64	80.91
	10th	60	-1.23	79.59	2.41	83.23	79.51
	11th	135x51	-6.52	74.30	1.59	82.42	73.89
	12th	135	-17.59	63.22	0.00	80.82	62.117

g: predicted genotypic effects; **u+g:** predicted genotypic averages; u+g+gem: average genotypic value in the various environments and capitalizes on an average interaction with all environments.

Coefficients of determination of the effects of genotype x environment interaction (c^2_{int}) were 0.15 for IPF, 0.18 for IVPV and 0.28 for NF and PP. These values are related to the proportion of total phenotypic variability explained by G x E interaction (Borges *et al.*, 2010; Mrode, 2014). Thus, phenotypic variance (Vf) for NF and PP was more influenced by genotype x environment interaction.

Through the genotypic correlation between the performance in the different environments (r_{gloc}), we verified the reliability of how constant the "ranking" of the genotypes will be in the different environments tested (Maia *et al.*, 2009). The values of r_{gloc} for PP and NF were intermediate, 0.60 and 0.57, respectively. In these cases, a moderate level of complex interaction is observed, that is, the genotypes did not have the same behavior in the different environments where they were evaluated. Thus, adaptability and stability for selection purposes shall be considered. On the other hand, the values for FSI and IVPV were 0.75 and 0.72, showing that the genotypes had the same behavior in different environments.

Using Table 2, it is possible to infer the predicted genotypic values without interference (u + g) and with environment interference (u + g + gem), the gain and the new average, in addition to the genotypic effect (g). When the predicted genotypic effect values are negative, an indication that the genotype is below the overall average for each trait is noticed. Therefore, we recommend to discard such genotypes. According to the obtained data, the genotypes CNPH135 and CNPH60 were below average for all evaluated traits (Maia *et al.*, 2009).

According to Resende (2007b), REML/BLUP method allows to order the potential genotypes for selection; thus, it allows to exploit all genotypic variation between and within progenies for each trait separately. In this case, genetic gains are evaluated by comparing interaction-free predicted genotypic values (u+g) and predicted genotypic values with average interaction between environments (u+g+gem).

Table 2 shows that the predicted genotypic averages (u + g) for all traits were very similar to the new average, highlighting accuracy of the selection of REML/BLUP method. To classify the predicted genotypic averages (u + g) considering the six environments together, the cultivar Ciça stands out, positioning itself among the six genotypes with the highest value of (u+g), for all evaluated traits. The genotypes CNPH109, CNPH135×CNPH141, CNPH135× CNPH51, CNPH 135×CNPH60 and CNPH109×CNPH141 also stood out, being one of the six best genotypes for three evaluated traits. When it comes to genotypic averages to rank the genotypes, we can say that these genotypes can be grown in different places from those evaluated ones, since this estimate is not accumulating the effect of the genotype x environment interaction. Therefore, we expect the same behavior of the genotypes even being in different environments (Freitas *et al.*, 2013).

We also noticed that the classification of the 12 genotypes shows the same order by the criteria u + g and u + g + gem (Table 2). However, despite these two selections being identical with regard to the selected genotypes, the predictions of genotypic values are higher in u + g + gem. Nevertheless, this superiority will be only capitalized if these genotypes are planted in areas showing the same

Table 3. Stability of genotypic values (MHVG), adaptability of genotypic values (PRVG), stability and adaptability of genotypic values (MHPRVG) of eggplant genotypes for PP, FSI, NF and IVPV. Recife, UFRPE, 2019-2020.

Genotypes	PP (g)			FSI (%)		
(CNPH)	PRVG	MHVG	MHPRVG	PRVG	MHVG	MHPRVG
135	0.77	837.02	0.76	-0.06	18.08	0.73
47x60	1.26	1468.29	1.25	0.68	1.60	0.49
410	0.27	9.97	0.01	0.60	6.91	0.59
60	0.48	91.68	0.15	0.60	6.20	0.56
109	1.03	1169.47	1.03	1.29	4.80	1.23
109x60	1.18	1363.33	1.13	0.74	3.37	0.71
109x141	0.78	677.63	0.67	1.76	7.15	1.42
135x60	1.48	1690.23	1.39	1.45	9.91	1.36
135x51	1.41	1861.09	1.36	2.04	8.46	1.76
135x141	1.25	1607.33	1.22	3.36	13.55	2.05
Ciça	1.11	914.28	1.00	1.13	13.01	1.11
Embú	0.93	845.77	0.88	0.80	9.14	0.79
	NF			IVPV (%)		
135	0.66	2.61	0.63	0.76	61.65	0.76
47x60	0.70	2.51	0.66	1.03	83.12	1.02
410	0.55	0.82	0.31	1.08	87.70	1.08
60	0.62	1.51	0.47	0.98	79.39	0.98
109	1.31	6.22	1.29	1.04	84.19	1.04
109x60	0.96	3.99	0.90	1.04	84.22	1.04
109x141	1.09	4.56	0.96	1.03	83.14	1.03
135x60	1.17	4.78	1.07	1.01	81.74	1.01
135x51	1.35	6.79	1.31	0.91	73.61	0.91
135x141	1.72	8.65	1.67	1.00	80.48	0.99
Ciça	0.94	2.96	0.84	1.05	85.18	1.05
Embú	0.89	3.18	0.84	1.02	83.06	1.02

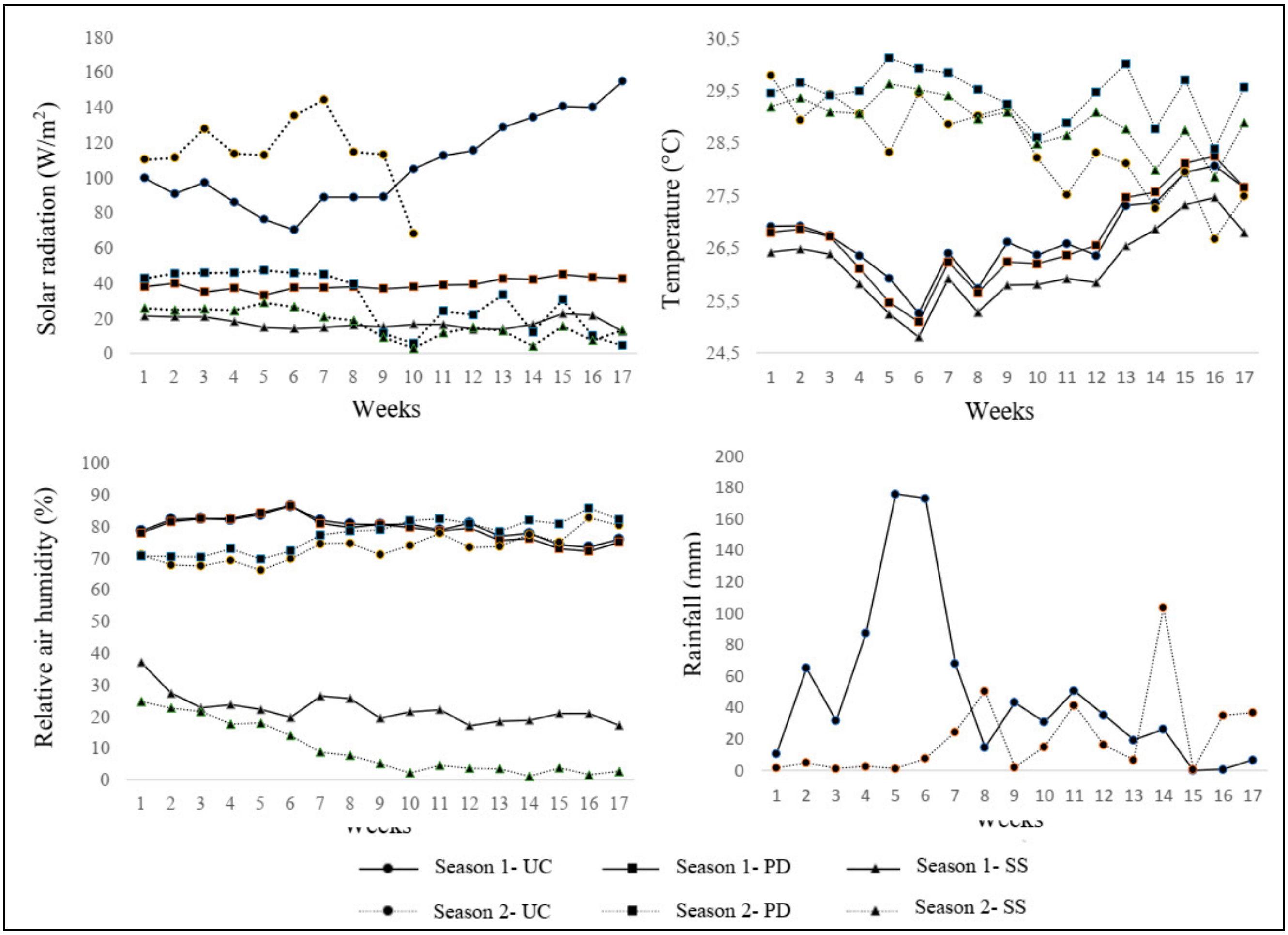

Figure 1. Average values of solar radiation, air temperature, relative air humidity and rainfall of the six environments for eggplant cultivation. Recife, UFRPE, 2019/2020.

genotype x environment interaction of this research. Thus, genotypic averages based on u + g are safer (Borges *et al.*, 2012).

The expected results for PP, FSI, NF and IVPV penalizing or capitalizing the genotypes according to their performance in relation to stability (MHVG), adaptability (PRVG) and adaptability and stability (MHPRVG) are in Table 3.

According to Cruz *et al.* (2014), adaptability is the ability of genotypes to benefit from environmental stimuli. That means, the ability of the genotypes to respond favorably to the improvement of the environment. To predict the adaptability of genotypic values, Relative Performance of Genetic Values (PRVG) can be used. In this methodology, the predicted genotypic values are expressed as a proportion of the overall average for each location and, afterwards, the average value of this proportion is obtained (Resende, 2007a; Silva *et al.*, 2011).

According to PRVG, the five genotypes with the highest adaptative capacity in the six evaluated environments, in a decreasing order, for PP were: CNPH135×CNPH60, CNPH135×CNPH51, CNPH47×CNPH 60, CNPH135×CNPH141 and CNPH109×CNPH60; for FSI: CNPH135×CNPH141, CNPH 135×CNPH51, CNPH 109×CNPH141, CNPH135×CNPH60 and CNPH109; for NF: CNPH135×CNPH141, CNPH135×CNPH51, CNPH109, CNPH135×CNPH60 and CNPH 109×CNPH141 and for IVPV: CNPH 410, Ciça F_1, CNPH109×CNPH60, CNPH109 and CNPH109×CNPH141 (Table 3). Table 2 shows that the average genotypic value in the various environments (u + g + gem) generated results very similar to those shown above.

Stability is related to predictable behavior of the genotype in relation to environmental changes (Cruz *et al.*, 2014). We can predict stability using MHVG values (Harmonic Average of Genotypic Values) (Table 3). Thus, the selection based on these values simultaneously contemplates good performance for the traits (PP, IPF, NF and VPIV) and stability.

According to this criterion, the five genotypes which associated both attributes were: CNPH135×CNPH51, CNPH135×CNPH60, CNPH 135×CNPH141, CNPH47×CNPH60 and CNPH109×CNPH60 for PP; CNPH135×CNPH141, CNPH135×CNPH 51, CNPH109, CNPH135×CNPH60 and CNPH109×CNPH141 for NF; CNPH410, Ciça, CNPH109, CNPH109×CNPH60 and CNPH109×CNPH141 for IVPV;

CNPH135 and CNPH135×CNPH141, Ciça, CNPH135×CNPH60 and Embú for FSI (Table 3). Such results are similar to the genotypic values shown in Table 2, except for FSI. For this trait, from the five best genotypes found for MHVG, the CNPH135, Ciça and Embú are not among the best classified genotypes using the joint analysis of genotypic values. Generally, we can notice that the best genotypes classified for MHVG are also for PRVG.

MHPRVG method (Harmonic Average of the Relative Performance of Genetic Values) proposed by Resende (2004) is used for simultaneous selection for trait, adaptability and stability (Table 3). MHPRVG method is based on predicted genotypic values, via mixed models, and groups, in a single statistic, the three parameters, facilitating the selection of superior genotypes (Regitano Neto *et al.*, 2013; Rosado *et al.*, 2012). Simultaneous selection, considering the three parameters, the following genotypes stand out: CNPH135×CNPH60, CNPH135×CNPH 51, CNPH 135×CNPH 141, CNPH109, CNPH109×CNPH60 and CNPH109×CNPH141, considering that these genotypes are among the five first ones for the three evaluated traits (Table 3).

We noticed accordance with the three methods for PP, NF and IVPV, highlighting the occurrence of order maintenance of the materials by the three proposed methods. The authors verified that PRVG, MHVG and MHPRVG showed high degree of agreement in the ordering of materials (Maia *et al.*, 2009).

Given the above, we can indicate the genotypes with the best productive performance, adaptability and stability in the evaluated environments: CNPH135×CNPH60, CNPH135×CNPH51, CNPH 135×CNPH 141, CNPH109, CNPH109×CNPH60 and CNPH 109×CNPH141 for production per plant, number of fruits per plant and fruit set index.

ACKNOWLEDGEMENTS

The authors thank to Embrapa Hortaliças for allowing using the space for this study and The Coordination of Improvement of Higher Education Personnel (CAPES) for granting the research scholarship.

REFERENCES

ADAMCZEWSKA-SOWIŃSKA, K; KRYGIER, M. 2013. Yield quantity and quality of field cultivated eggplant in relation to its cultivar and the degree of fruit maturity. *Acta Scientiarum Polonorum-Hortorum Cultus* 12: 13-23.

ALVARES, CA; STAPE, JL; SENTELHAS, PC; GONÇALVES, JLM. 2014. Sparovek, mapa de classificação climática de G. Köppen para o Brasil. *Meteorologische Zeitschrift* 22: 711-728.

ANTONINI, ACC; ROBLES, WGR; TESSARIOLI NETO, J; KLUGE, RA. 2002. Capacidade produtiva de cultivares de berinjela. *Horticultura Brasileira* 20: 646-648.

BISBIS, MB; GRUDA, N; BLANKE, M. 2018. Potential impacts of climate change on vegetable production and product quality – A review. *Journal of Cleaner Production* 170: 1602-1620.

BOITEUX, LS; MENDONÇA, LJ; FONSECA, MEN; REIS, A; VILELA, NJ; GONZÁLEZ-ARCOS, M; NASCIMENTO, MN. 2016. Melhoramento de berinjela. In: NICK, C; BORÉM, A (eds). *Melhoramento de Hortaliças*. Viçosa: Editora UFV. p.15-192.

BORGES, V; FERREIRA, PV; SOARES, L; SANTOS, GM; SANTOS, AMM. 2010. Seleção de clones de batata-doce pelo procedimento REML/BLUP. *Acta Scientiarum Agronomy* 32: 643-649.

BORGES, V; SOARES, AA; RESENDE, MDV; REIS, MS; CORNELIO, VMO; LEITE, NA; SOARES, PC; COSTA JÚNIOR, GT. 2012. Value for cultivation and use of upland rice cultivars tested in multi-environments. *Crop Breeding and Applied Biotechnology* 12: 25-33.

CAPISTRANO, MC; ANDRADE NETO, RC; SANTOS, VB; LESSA, LS; RESENDE, MDV; MESQUITA, AGG; GURGEL, FL. 2021. Use of the REML/BLUP methodology for the selection of sweet orange genotypes. *Pesquisa Agropecuária Brasileira* 56: e02032.

CARVALHO, ADF; SILVA, GO; RESENDE, FV. 2017. Adaptabilidade e estabilidade de populações de cenoura pelo método REML/BLUP. *Horticultura Brasileira* 35: 69-74.

CRUZ, CD; CARNEIRO, PCS; REGAZZI, AJ. 2014. *Modelos biométricos aplicados ao melhoramento genético*. 3ª ed. Viçosa: Editora UFV. 668p.

DELAZARI, FT; SILVA, DJH; PICANÇO, MC; GOMIDE, ES. 2019. Eggplant (*Solanum melongena* L.). In: PAULA JÚNIOR, TJ; VENZON. M (eds). 101 Crops - *Agricultural Technologies Handbook*. Belo Horizonte: EPAMIG. p.180-185.

FAO. 2019. Food and agriculture organization of the United Nations. Available at <http://www.fao.org/faostat> Toegang verkry Accessed April 13, 2020.

FREITAS, ILJ; AMARAL JUNIOR, AT; VIANA, AP; PENA, GF; CABRAL, PS; VITTORAZZI, C; SILVA, TRC. 2013. Ganho genético avaliado com índices de seleção e com REML/BLUP em milho-pipoca. *Pesquisa Agropecuária Brasileira* 48: 1464-1471.

KYRIACOU, MC; ROUPHAEL, Y; GIOIA, F; KYRATZIS, A; SERIO, F; RENNA, M; PASCALE, S; SANTAMARIA, P. 2016. Micro-scale vegetable production and the rise of microgreens. *Trends in Food Science & Technology* 57: 103-115.

MAIA, MCC; RESENDE, MDV; PAIVA, JR; CAVALCANTI, JJV; BARROS, LM. 2009. Seleção simultânea para produção, adaptabilidade e estabilidade genotípicas em clones de cajueiro, via modelos mistos. *Pesquisa Agropecuária Tropical* 39: 43-50.

MRODE, RA. 2014. Linear models for the prediction of animal breeding values. 3rd ed. Bosto]: CABI. 360p.

REGITANO NETO, A; RAMOS JUNIOR, EU; GALLO, PB; FREITAS, JG; AZZINI, LE. 2013. Comportamento de genótipos de arroz de terras altas no estado de São Paulo. *Revista Ciência Agronômica* 44: 512-519.

RESENDE, MDV. 2002. Genética biométrica e estatística no melhoramento de plantas perenes. Brasília: Embrapa Informação Tecnológica: Colombo: Embrapa Florestas, 975p.

RESENDE, MDV. 2004. *Métodos estatísticos ótimos na análise de experimentos de campo*. Embrapa Florestas, Documentos (INFOTECA-E).

RESENDE, MDV. 2007a. *Matemática e estatística na análise de experimentos e no melhoramento genético*. Embrapa Florestas.

RESENDE, MDV. 2007b. *Selegen-Reml/Blup: sistema estatístico e seleção genética computadorizada via modelos lineares mistos*. Colombo: Embrapa Florestas. 359p.

RESENDE, MDV; FURLANI JÚNIOR, E; MORAES, MLT; FAZUOLI, LC. 2001. Estimativas de parâmetros genéticos e predição de valores genotípicos no melhoramento do cafeeiro pelo procedimento REML/BLUP. *Bragantia* 60: 185-193.

ROSADO, AM; ROSADO, TB; ALVES, AA; LAVIOLA, BG; BHERING, LL. 2012. Seleção simultânea de clones de eucalipto de acordo com produtividade, estabilidade e adaptabilidade. *Pesquisa Agropecuária Brasileira* 47: 964-971.

SANTOS, A; CECCON, G; TEODORO, PE; CORREA, AM; ALVAREZ, RCF; SILVA, JF; ALVES, VB. 2016. Adaptabilidade e estabilidade de genótipos de feijão caupi ereto via REML/BLUP e GGE Biplot. *Bragantia* 75: 299-306.

SILVA, GO; CARVALHO, ADF; VIEIRA, JV; BENIN, G. 2011. Verificação da adaptabilidade e estabilidade de populações de cenoura pelos métodos AMMI, GGE biplot e REML/BLUP. *Bragantia* 70: 494-501.

VALADARES, RN; NÓBREGA, DA; MOREIRA, CS; SILVA, JAS; MENDES, AQ; SILVA, FS; COSTA, ÍJN; MENEZES, D. 2019. Selection of eggplant genotypes tolerant to high temperatures. *Journal of Experimental Agriculture International* 1-10.

WEBER, LC; LOPES, ACA; BOITEUX, LS; NASCIMENTO, WM. 2013. Produção e qualidade de sementes híbridas de berinjela em função do número de frutos por planta. *Horticultura Brasileira* 31: 461-466.

YAHIA, EM; SÓLIS, PG; CELIS, MEM. 2019. *Contribution of fruits and vegetables to human nutrition and health*. In: YAHIA, EM; LÓPEZ, AC. (eds). Postharvest Physiology and Biochemistry of Fruits and Vegetables. Woodhead Publishing.), p.19-45.