Adaptability and stability of strawberry cultivars using a mixed model

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ABSTRACT. Although strawberry crops have a strong socio-economic impact on the agricultural sector of Espírito Santo State, there are few studies on the performance of strawberry cultivars in different locations and years under a low tunnel management system (LT). Therefore, this study aimed to estimate the parameters of adaptability and stability of strawberry cultivars under LT-protected cultivation using the harmonic mean of the relative performance of genetically predicted values. Seven strawberry cultivars were assessed ('Dover', 'Camino Real', 'Ventana', 'Camarosa', 'Seascape', 'Diamante' and 'Aromas') in the agricultural years 2006/7, 2007/8 and 2008/9 in three locations in the mountainous region of Espírito Santo State. The experiment was arranged in a randomized block design, with 3 replications and 15 plants per plot. The analysis of deviance for the yield (ton. ha^{-1}) demonstrated that only the effects of genotype and the triple interaction genotype x location x year were significant, which indicates the presence of genetic variability among the cultivars and the inconsistency of the position among the genotypes for combinations of year and location. Considering the selection for yield, adaptability and stability, in LT-protected cultivation, cultivars Camarosa and Aromas are highlighted for expressing average values that were 22% higher than the overall mean of the cultivars (24.55 ton. há$^{-1}$) in the environments assessed.

Keywords: *Fragaria x ananassa*, REML/BLUP, MHPRVG method, genotype x environment interaction.

Adaptabilidade e estabilidade de cultivares de morango via modelos mistos

RESUMO. A cultura do morangueiro vem exercendo um importante papel sócio-econômico no setor agrícola do Estado do Espírito Santo, devido principalmente ao aumento de renda nas pequenas propriedades e na fixação de trabalhadores na área rural. Contudo, são escassos os estudos sobre o desempenho de cultivares de morango em diferentes locais e anos sob o sistema de manejo túnel baixo (TB). Portanto, o presente trabalho teve como objetivo avaliar a produtividade, adaptabilidade e estabilidade de cultivares de morango sob cultivo protegido TB, utilizando o método da média harmônica da performance relativa dos valores genéticos preditos. Foram avaliados sete cultivares de morango ('Dover', 'Camino Real', 'Ventana', 'Camarosa', 'Seascape', 'Diamante' e 'Aromas') nos anos agrícolas 2006/7, 2007/8 e 2008/9, em três locais da região Serrana do Estado do Espírito Santo. O delineamento experimental utilizado foi de blocos ao acaso com três repetições e 15 plantas por parcela. Pela análise de *deviance* em relação à produtividade (t ha^{-1}), apenas os efeitos de genótipos e da interação tripla genótipos x locais x anos foram significativas, evidenciando a presença de variabilidade genética entre as cultivares e a inconsistência da posição entre os genótipos para as combinações de anos e locais. Considerando s seleção para produtividade, adaptabilidade e estabilidade as duas cultivares que se destacaram foram 'Camarosa' e 'Aromas', tendo obtido valores superiores em média de 22% sobre a média geral das cultivares (24.55 t ha^{-1}) nos ambientes avaliados sob cultivo protegido TB.

Palavras-chave: *Fragaria* x *ananassa* Duch., REML/BLUP, método MHPRVG, interação genótipos x ambientes.

Introduction

Strawberry (*Fragaria x ananassa* Duch.) is an accidental hybrid of two native species, *F. chiloensis* and *F. virginiana*, and is one of the most appreciated fruits in the world due to its organoleptic properties and health benefits (BOMBARELY et al., 2010;

KURAS; KORBIN, 2010). In 2010, the world strawberry production reached 4.17 million tons, with the United States of America as the largest producer, accounting for 30% of the global production. In Brazil, the annual production is approximately of 100 thousand tons and is distributed in temperate and subtropical regions

where it is used both for fresh and industrial consumption (RADIN et al., 2011).

In Espírito Santo State, strawberry cultivation has increased over the years and has played an important socio-economic role, mainly due to the increased income of small farms and the establishment of workers in rural areas because much manual labor is required during the harvest season. Approximately 7200 tons are produced per year, involving more than 240 hectares and generating approximately 2500 direct jobs (INCAPER, 2012).

Espírito Santo producers have gradually been using protected cultivation to increase production. This management system has a number of advantages, particularly the protection of the crop against abiotic (winds, hail, rain, frost and low temperatures) and biotic (pests and diseases) factors (ANTUNES et al., 2007; CALVETE et al., 2008; WITTER et al., 2012). However, there are few studies on the performance of strawberry cultivars in different locations and years under this management system.

Therefore, a study on the genotype x environment interaction (GE) plays an important role in determining the adaptation and fitness of genotypes to the physical environment. GE interaction can be classified as simple, such as when it results only from genetic variability in a genotype, and complex, such as when there is no correlation between the measures of the same genotype in different environments. The latter indicates inconsistency of genotype superiority under environmental variations, which impedes the recommendation of cultivars with wide adaptability (CRUZ et al., 2004).

To minimize the effects of GE interactions and to achieve a higher performance predictability, the identification of the most stable genotypes and cultivars adapted to the specific conditions of each environment is necessary. Several methods have been described for examining stability and adaptability, as based on the analysis of variance, linear regression, nonlinear regression, multivariate analysis and nonparametric statistics (BASTOS et al., 2007; PENA et al., 2012).

Within the context of mixed models, the method of the harmonic mean of the relative performance of genetically predicted values proposed by Resende (2004) has shown good results for studies on stability and adaptability (BASTOS et al., 2007; CARBONELL et al., 2007; SILVA et al., 2011; SILVA et al., 2012). The advantages of this procedure include the following: i) allowing the simultaneous selection of yield, adaptability and stability; ii) considering the genotypic effects as random and, therefore, providing estimates of stability and adaptability for predicted and non-predicted genotypic values; iii) allowing the use of unbalanced data, non-orthogonal designs and heterogeneity of variance; iv) allowing the consideration of correlated errors within the locations in addition to stability and adaptability in the selection of individuals within progeny; v) providing genetic values already discounted (penalized) with regard to instability and allowing the application of any number of environments; and vi) generating results at the unit or scale of the evaluated trait, which can be directly interpreted as genetic values (RESENDE, 2002a).

Therefore, the present study aimed to estimate the adaptability and stability of strawberry cultivars under protected cultivation using the method of the harmonic mean of the relative performance of genetically predicted values.

Material and methods

The experiments were conducted during the agricultural years of 2006/7, 2007/8 and 2008/9 in three locations in the mountainous region of Espírito Santo State (municipalities Domingos Martins, Iúna and Muniz Freire). The elevations of the experimental sites in the municipalities were 700 m in Iúna, 950 m in Domingos Martins and 1100 m in Muniz Freire. The planting for the experiments was performed in late May, and the experiment was conducted until early January, with the exception of the experiment in 2007/8, which was conducted until March 2008. In all years, the harvests were performed twice a week, from the early harvest (usually in August) to the end of the cycle.

The experiment was arranged in a randomized block design, with 3 replications and 15 plants per plot. The study involved seven strawberry cultivars ('Dover', 'Camino Real', 'Ventana', 'Camarosa', 'Seascape', 'Diamante' and 'Aromas'). Plant spacing was 0.4 x 0.4 m, arranged in three rows on 30-cm high and 14-m long beds covered with black mulching. The environmental conditions for cultivation consisted of covering the plants with white plastic film, which was suspended over arcs of galvanized iron, at a height of approximately 1.0 m.

The values of productivity (ton. ha^{-1}) in the different environments were subjected to statistical analyses using the following linear model:

$$y_{ijkn} = \mu + g_i + b_{jkn} + a_k + l_n + ga_{ik} + gl_{kn} + gal_{ikn} + \varepsilon$$

where:

Y_{ijkn} is the observation value relating to treatment i in repetition j in year k within location n; μ is the general average; g_i is the effect of genotype i; b_{jkn} is the effect of block j within year k within location n; a_k is the effect of the planting year k; l_n is the effect of the location n; ga_{ik} is the effect of the genotype x planting year interaction; gl_{kn} is the effect of the genotype x location interaction; gal_{ikn} is the effect of the genotype x year x location interaction; and ϵ is the random error or residue.

In matrix form, the corresponding model is as follows:

$$Y = Xb + Z_g + Q_{ga} + T_{gl} + U_{gla} + \varepsilon$$

where:

Y is the vector of the observations; b is the vector of the effects of the block-local-year combinations (fixed effects) plus the overall average; g is the vector of the genotypic effects, g (assumed as random); ga is the vector of random effects of the genotype x year interaction; gl is the vector of random effects of the genotype x location interaction; gla is the vector of random effects of the triple interaction genotype x location x year; and ϵ is the vector of errors (random). X, Z, Q, T and U refer to the incidence matrices for these effects, respectively. The effects of the year, local and block-local-years are grouped into effect b, as they are environmental effects (RESENDE, 2007).

The values of the harmonic mean of the genotypic values (MHVG) to evaluate stability, the relative performance of the genotypic values (PRVG) for adaptability and the harmonic mean of the relative performance of the genotypic values (MHPRVG) for stability, adaptability and productivity, simultaneously, for all genotypes, were obtained according to the expressions:

$$MHVG = \frac{1}{\sum_{i=1}^{l}\frac{1}{VG_j}}, \; PRVG = \frac{1}{l}\left(\frac{\sum VG_j}{M_j}\right) \text{ and}$$

$$MHPRVG = \frac{1}{\sum_{l=1}^{l}\frac{1}{PRVG_j}}$$

where:

l is the number of locations, VG is the genotypic value, and j is the genotype.

The significance of the effects of the model was estimated by an analysis of deviance, as recommended by Resende (2002a). The deviances were obtained through analyses with and without

the effects of g, ga, gl and gla. The deviance without the mentioned effect was then subtracted from each full-model deviance and was compared to the value of chi-square, with one degree of freedom, at 1 and 5% probability. The Selegen software system (RESENDE, 2002b) was used for the analyses.

Results and discussion

The analysis of deviance in relation to productivity (ton. ha^{-1}) showed that the effects of genotype and the triple interaction genotype x location x year were statistically significant (p $\leq$ 0.05 and p $\leq$ 0.01, respectively). In contrast, no significance was observed for the genotype x location and genotype x year interactions (Table 1). These results demonstrate the presence of genetic variability among the strawberry cultivars tested and that the genotype x location and genotype x year interactions did not cause changes in the performance of the genotypes in the different locations and years. However, for the triple interaction genotype x location x year, an inconsistency in the position among the genotypes was verified for all the combinations of year and location. According to Allard and Bradshaw (1964), this type of interaction is caused by unpredictable environmental variations, such as precipitation, temperature, relative humidity and the occurrence of pests and diseases.

Table 1. Deviance, variance components and coefficients of determination related to the global joint analysis involving seven strawberry cultivars evaluated in nine environments.

Effect	Deviance	LRT ($\chi 2$)	Component of variance	Coefficient of determination
Genotype	825.79[+]	5.64[*]	Vg = 25.465	h^2_g = 0.306
Genotype x Location	820.17[+]	0.02ns	Vgl = 0.206ns	c^2_{gl} = 0.002[ns]
Genotype x Year	821.24[+]	1.09ns	Vga = 7.186ns	c^2_{ga} = 0.086[ns]
Genotype x Location x Year	858.34[+]	38.19[**]	Vgla = 28.014	c^2_{gla} = 0.337
Residue			Ve = 22.289	c^2res = 0.269
Complete Model	820.15			C^2total = 1.00

[+]Deviance of the adjusted model without the corresponding effects. [*] and [**]Significant by the chi-square test at 5% (3.84) and 1% (6.63), respectively.

The coefficients of determination (c^2_{gl} for the genotype x location interaction, c^2_{ga} for the genotype x year interaction, and c^2_{gla} for the genotype x location x year interaction) indicate how much each component contributes to the total phenotypic variance. Thus, the genotype x location, genotype x year, and genotype x location x year interactions contributed 0.24, 8.60 and 33.70%, respectively, and demonstrated the importance of the triple interaction in the total phenotypic variance. The

heritability estimate of the broad-sense individual plots (h_g^2) for productivity was 30.60%. This result is explained by the fact that productivity is a polygenic character and is therefore greatly influenced by the environment.

The genotypic correlation of the cultivars across the locations and years was 0.4183, showing a moderate level of complex interaction, which indicates that the ranking of the cultivars across environments (locations and years) will not necessarily be the same, i.e., a cultivar rated with excellent productivity in environment 1 may not be excellent in environment 2 or in any other environment.

Table 2 shows the cultivars with the respective genotypic values (μ+g+ge) for each cultivation location in the different agricultural harvests. The Dover cultivar presented the lowest genotypic values for most environments evaluated, whereas cultivar Camarosa presented the best genotypic values for most environments and occupied the first or second position in eight of the nine environments assessed. Resende et al. (2010) evaluated the effect of three cultivation systems (high tunnel, low tunnel and field) on strawberry productivity in Guarapuava, Paraná State, and reported that the cultivars Camarosa and Oso Grande achieved the highest productivity rates (56.66 and 53.76 ton. ha^{-1},

respectively) and differed statistically from cultivars Sweet Charlie (45.70 ton. ha^{-1}) and Dover (36.98 ton. ha^{-1}) under low tunnel-protected cultivation.

According to the expected results (in ton. ha^{-1}) for stability (MHVG), adaptability (PRVG), and stability and adaptability (MHPRVG) for the set of locations, either harming or favoring cultivars, according to their performance, it was observed that cultivar Camorosa was superior, followed by cultivars Aromas, Diamante, Camino Real, Seascape, Ventana and Dover (Table 3). Therefore, the two best cultivars (Camarosa and Aromas) by the MHPRVG criterion were, on average, 22% superior to the overall average of the nine environments (24.55 kg ha^{-1}). The MHPRVG method has the advantage of providing results for the scale of trait measurement, which can be directly interpreted as predicted genetic values for productivity, stability and adaptability (BASTOS et al., 2007; CARBONELL et al., 2007; VERARDI et al., 2009).

Silva et al. (2011) compared the methods of adaptability and stability and verified that the REML/BLUP-MHPRVG analysis stood out from the others (AMMI and GGE biplot). Although the method does not provide information about the grouping of similar sites, the results are according to the genotypic values when considering the parameters of adaptability and stability.

Table 2. Estimates of the genotypic values (μ + g + ge) related to the yield trait of seven strawberry cultivars evaluated in nine environments.

Cultivar	Domingos Martins		Muniz Freire		Iúna	
	μ + g + ge	Gain	μ + g + ge	Gain	μ + g + ge	Gain
Agricultural Year 2006/2007						
Dover	17.78	0.00	9.25	0.00	5.67	0.00
Camino Real	25.88	2.80	19.73	4.08	11.54	2.85
Ventana	26.12	3.35	12.54	1.37	6.19	1.23
Camarosa	30.05	5.76	23.74	6.27	16.49	4.36
Seascape	18.72	1.25	16.18	2.63	17.00	4.81
Diamante	26.30	4.19	19.66	3.61	15.71	3.93
Aromas	32.00	6.74	21.19	4.99	18.72	5.67
Agricultural Year 2007/2008						
Dover	19.83	0.00	27.87	0.00	7.41	0.00
Camino Real	38.07	7.66	39.53	9.03	10.56	2.15
Ventana	21.53	2.19	33.28	5.67	12.19	3.39
Camarosa	42.72	9.72	55.49	17.79	18.33	5.25
Seascape	35.14	6.29	32.31	3.46	17.65	4.92
Diamante	41.20	8.96	45.19	12.64	8.64	1.00
Aromas	32.50	4.93	30.23	1.63	18.95	5.56
Agricultural Year 2008/2009						
Dover	32.06	0.00	3.10	0.00	19.32	1.54
Camino Real	41.82	5.19	7.36	2.61	30.14	5.07
Ventana	46.99	7.62	6.00	0.95	18.97	0.00
Camarosa	51.20	9.72	12.42	5.25	37.74	9.51
Seascape	37.98	1.57	10.24	3.97	32.71	7.00
Diamante	39.57	2.58	6.92	1.71	32.61	6.12
Aromas	40.70	3.70	15.73	6.90	26.10	3.63

It is important to mention that the three cultivars with the highest values for MHVG, PRVG and MHPRVG have excellent performance for firmness and a good balance between the total soluble solids and acidity, such that they will be widely accepted by both consumers and industry. Within this context, such information on the stability and adaptability of strawberry cultivars under protected cultivation (low tunnel) are important because they allow recommendations for cultivation and the verification of the performance of these cultivars in different strawberry-producing regions in the state of Espírito Santo.

Table 3. Stability of genotypic values (MHVG), adaptability of genotypic values (PRVG), stability and adaptability of genotypic values (MHPRVG) for the yield trait in seven strawberry cultivars evaluated in nine environments.

Cultivar	Genotypic value		
	MHVG	PRVG	MHPRVG
Dover	14.65	16.23	16.03
Camino Real	23.40	24.92	24.92
Ventana	19.09	20.61	20.57
Camarosa	29.97	31.63	31.54
Seascape	22.73	24.23	24.23
Diamante	24.56	26.10	26.10
Aromas	26.61	29.13	28.50

Conclusion

Based on selection for yield, adaptability and stability, the Camarosa and Aromas cultivars may be indicated for a low tunnel management system.

Acknowledgements

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