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Productivity and analysis of morphological characters of experimental strawberry genotypes

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ABSTRACT

In the world the consumption of strawberries is very appreciated, both *in natura* or industrialized form. Brazilian production depends on the importation of strawberry seedlings from countries such as Spain, Chile and Argentina, which are cultivars improved in temperate climates and, consequently, not well adapted to the Brazilian tropical conditions. Thus, genetic breeding programs are essential for the generation of more adapted cultivars. The objective was to evaluate and characterize the performance of experimental strawberry genotypes. The statistical design adopted was in randomized blocks, with 12 treatments and 3 replications, the treatments consisting of seven experimental genotypes and five commercial cultivars. We evaluated the total production per plant (g/plant), average weight of fruits per plant (g/fruit), % of commercial fruits per plant, and morphological characterization. The experimental genotypes MFA443, MCA94, MDA23, MDA06 and MCA89 showed the highest strawberry yields per plant, respectively, 285 g, 254 g, 298 g, 295 g and 290 g, with emphasis on the genotype MFA12-443, which also presented the highest average weight of fruits (20.35 g) and percentage of commercial fruits (81%).

Keywords: *Fragaria* x *ananassa*, strawberry physiology, genetic breeding, productivity, sustainability.

RESUMO

Produtividade e análise de caracteres morfológicos de genótipos experimentais de morangueiro

Mundialmente o consumo de morangos é bastante apreciado, tanto na forma *in natura* ou industrializada. A produção brasileira depende da importação de mudas de morangueiro de países como Espanha, Chile e Argentina, as quais são cultivares melhoradas em climas temperados, e, consequentemente, não se adaptam bem às condições tropicais brasileiras. Assim, programas de melhoramento genético são fundamentais para geração de cultivares mais adaptadas. Objetivou-se avaliar e caracterizar o desempenho de genótipos experimentais de morangueiro. O delineamento experimental adotado foi em blocos cazualizados, com 12 tratamentos e 3 repetições, sendo os tratamentos constituídos de sete genótipos experimentais e cinco cultivares comerciais. Avaliou-se os parâmetros: produção total por planta (g/planta), peso médio de frutos por planta (g/fruto), % de frutos comerciais por planta, e caracterização morfológica. Os genótipos experimentais MFA12-443, MCA94, MDA23, MDA06 e MCA89 apresentaram as maiores produções de frutos por planta, respectivamente de 285 g, 254 g, 298 g, 295 g e 290 g, com destaque para o genótipo MFA12-443, que também apresentou maior peso médio de frutos (20,35 g) e porcentagem de frutos comerciais (81%).

Keywords: *Fragaria* x *ananassa*, fisiologia do morango, melhoramento genético, produtividade, sustentabilidade.

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Strawberry is highly appreciated by the population, being consumed *in natura* or industrialized. Its production is predominantly in small farms with family labor (Souza *et al*., 2022). The production is concentrated in specific locations, due to the climatic needs required by the plant for growth and development (Souza *et al*., 2017; Vieira *et al*., 2019).

In the state of Minas Gerais, the strawberry plant (*Fragaria x ananassa*) is cultivated largely in the extreme southern municipalities, namely Pouso Alegre, Senador Amaral, Bom Repouso and Estiva. The south of Minas Gerais accounts for 95% of the state production, which represents an annual production of approximately 120 thousand tons (Antunes *et al*., 2021). This region stands out in the production of the fruit, mainly because it has a favorable climate for cultivation, as well as a strategic location for transporting the product to large commercial centers (Pinheiro *et al*., 2021; Galvão *et al*., 2017).

To achieve high productivity, growers often choose to import strawberry seedlings from countries such as Spain, Chile, and Argentina. These cultivars are reported to be superior and have good characteristics of commercial interests such as flavor (aroma, taste, and texture), as well as greater resistance to biotic and abiotic factors (Zeist & Resende, 2019). However, more recently, the plants presented phytosanitary problems and clonal soma variation (Barth *et al*., 2022). Being these genotypes improved

in temperate climates, the same are not well adapted to tropical conditions like high temperatures and long photoperiods for fruit production. This process of acquiring imported seedlings ends up reducing the producer's final profit, arising from its high cost in the market, being one of the main inputs in demand and investment in strawberry culture (Vieira *et al*., 2017; Zeist & Resende, 2019). Considering the great importance of strawberry production in the southern Minas Gerais economy, it is essential to carry out the selection and development of new genotypes, which would promote greater profitability, reducing production costs and dependence on imported genetic material.

Consequently, there is a great need to develop new cultivars adapted to Brazilian soil and climate conditions, in order to meet market demands, as well as to make seedlings available at lower prices to producers (Carvalho *et al*., 2013; Souza *et al*., 2022). In turn, there are few genetic breeding programs aimed at the development and selection of new strawberry genotypes in Brazil (Zeist & Resende, 2019). Thus, the strawberry genetic breeding program in southern Minas Gerais was created in 2011, to obtain new materials well adapted to the edaphoclimatic conditions of the southern region of Minas Gerais, and consequently expanding this material to other regions. The genotypes were selected by crossing already-known commercial cultivars (Nunes *et al*., 2012). Currently, the genotypes are tested in the region of Alfenas-MG, aiming to create a base population for later hybridizations and to develop new cultivars with greater adaptability and productive stability in the region.

The objective of this research was to evaluate the productive performance and morphologically characterize experimental strawberry genotypes.

MATERIAL AND METHODS

The research was carried out in the Experimentation and Olericulture sector of the University José do Rosário Vellano (UNIFENAS), Alfenas-MG, on the premises of the Olericulture and Experimentation Sector ($21^{0}25'45''S$, $45^{0}56'50''W$, 880 m altitude).

The experimental design was of randomized blocks, with 12 treatments and 3 replications. Twelve strawberry genotypes were evaluated, being seven experimental genotypes belonging to the genetic breeding program of the Federal University of Lavras (UFLA) (MDA01, MDA06, MDA23, MCA89, MCA94, MFA443, and MOGSC468) previously selected according to the productive characteristics of the plant and the physicochemical quality of the fruits (Vieira *et al*., 2017; Souza *et al*., 2017); and five commercial cultivars (Albion, Aromas, Flórida Festival, Pircinque and San Andreas). The experimental hybrid populations were obtained from the combination of seven commercial cultivars as parents, as shown in Table 1. Seedlings of commercial cultivars were purchased on the market. The seedlings of the experimental genotypes were obtained by multiplying the matrices of each material by means of asexual propagation, which were placed in slabs.

The experiment was carried out in a greenhouse. The seedlings were planted on April, and transplanted to slabs (0.33 m x 1.60 m), in which four seedlings were spaced 30 cm apart. The slabs were filled with commercial substrate Tropstrato HT®, which in its composition has pine bark, vermiculite, PG Mix 14.16.18, potassium nitrate, simple superphosphate, and peat.

During the strawberry growth and production cycle drip irrigation was carried out, keeping the substrate always at field capacity. The management of pests and diseases was carried out through the preventive application of phytosanitary products based on extract of neem leaves (*Azadirachta indica*), garlic bulbs, and tobacco leaves (*Nicotiana tabacum*), which have fungicidal, bactericidal, and insecticidal actions. Applications were carried out fortnightly, alternating the mixtures of neem extract (1.5%, 13 applications), garlic (4%, 6 applications) and tobacco (2%, 6 applications), according to production techniques and application of the grouts described by Jesus (2021).

Inside the greenhouse, a hive of Jataí bees (*Tetragonisca angustula*) was inserted in order to help pollinate the flowers.

Plants were fertilized in the soil, according to technical recommendations for the crop (Ribeiro *et al.*, 1999; Passos *et al*., 2015), providing 0.5 g of NPK mineral formulated (Forth Frutas). Leaves were sprayed monthly with micronutrients in order to supply all the demands of the culture.

During the experiment, fruits were harvested in 24 seasons, between July and November 2021. The fruit yield was evaluated as follows: total fruit production per plant (fruits/plant in grams), average fruit weight per plant (g/fruit), and percentage of commercial fruits per plant (%), in addition to the descriptive and morphological indices of each experimental genotype. For these evaluations, not damaged or deformed fruits with a weight equal to or greater than 10 g were considered (Galvão *et al*., 2017).

The parametric results were submitted to analysis of variance by the Sisvar software (Ferreira, 2014). When significant, the means with differences were submitted to the Scott-Knott cluster test (5%).

For morphological evaluation of the plants, the average scores were used for characteristics based on the following morphological descriptors of the plant: growth habit, interveinal bulging, base shape, margin shape, and size of the calyces in relation to the flowers, according to indications from the UPOV [International Union for the Protection of New Varieties of Plants (UPOV, 2012)]. The evaluations consisted of observations and monthly records of the averages of the characteristics. Data were evaluated using nonparametric statistics through the Kruskal-Wallis test, in order to identify possible differences between the plant's morphology of each strawberry genotype. For non-parametric tests, the Real Statistics Software (Zaoint, 2020) was used.

In order to enable the complete characterization and grouping of the genotypes, taking into account all evaluated production variables, a hierarchical similarity dendrogram was

prepared, according to the Euclidean distance of the samples, with the aid of the Chemoface program, version 1.4 (Nunes *et al.*, 2012). Using the same software, the results were also submitted to principal component analysis (Johnson & Wichern, 2002). The results of these statistical analyzes were expressed in "biplot" graphs, in order to determine possible trends and patterns in the results.

RESULTS AND DISCUSSION

The experimental genotypes showed differences of total production, commercial production, and average fruit weight. These results are described in Table 2. The genotypes MDA23, MDA06, MCA89, MFA443, and MCA94 showed the highest total strawberry yields, not differing from the controls San Andreas and Aromas, which together, on average, produced 283 g/plant in the total evaluated period. In turn, the genotypes MDA01 and MOGSC468 presented the lowest average yields in total and did not differ from the controls Albion, Festival Florida, and Pircinque, which, on average, produced 194.4 g/plant in the total evaluated period.

Regarding the percentage of commercial fruits per plant, the genotypes MFA443 and MCA94 stood out, presenting an average of 76% of commercial fruits over the total produced. These genotypes did not differ from the controls Albion, Pircinque, and Aromas. The genotypes MDA06, MOGSC468, MCA89, MDA23, and MDA01 presented lower percentages of commercial fruits, on average 64%, which did not differ from the controls San Andreas and Flórida Festival.

Regarding the average weight of each fruit, the genotypes MFA443 and MCA89 stood out, presenting an average of 26.82 g/fruit, not differing from the cultivar Albion.

The genotype MFA443 stood out in all evaluated traits. However, in a research developed by Santos (2019), the MFA443 presented the lowest fruit yield, 21.17 g/plant in the Campo das Vertentes-MG region. This productive difference is related to the adaptability of this genotype to different edaphoclimatic conditions of each region. It is worth mentioning that this genotype originates from the hybridization of the Florida Festival and Aromas cultivars, which already

Table 1. Description of the evaluated hybrid populations generated from seven commercial strawberry cultivars. Alfenas, UNIFENAS, 2022.

Population	Parents		Population	Parents	
	♀	♂		♀	♂
1	Dov	Arom	7	S Ch	Arom
2	Oso G	Arom	8	Tud	Arom
3	Cam	Arom	9	Tud	S Ch
4	Dov	S Ch	10	Cam	S Ch
5	Oso G	Tud	11	Fest	Arom
6	Fest	S Ch	12	Oso G	S Ch

♀ = female parent, ♂ = male parent, Arom = Aromas, Cam = Camarosa, Dov = Dover, Fest = Festival, Oso G = Oso Grande, S Ch = Sweet Charlie, Tud = Tudla.

Table 2. Total yield (g/plant), percentage (%) of commercial fruits per plant and average weight (g) of fruit per plant of different experimental strawberry genotypes. Alfenas, UNIFENAS, 2022.

Total production (g)		Commercial fruits (%)		Weight/plant (g)	
Genotypes	Averages	Genotypes	Averages	Genotypes	Averages
(p=*0,000)		(p=*0,0113)		(p=*0,0336)	
San Andreas	299 a	Albion	83 a	MCA89	33.3 a
MDA23	298 a	MFA443	81 a	Albion	23.67 a
MDA06	295 a	Pircinque	78 a	MFA443	20.35 a
MCA89	290 a	Aromas	77 a	San Andreas	14.03 b
MFA443	285 a	MCA94	71 a	Pircinque	13.34 b
Aromas	260 a	MDA06	69 b	MDA06	13.28 b
MCA94	254 a	San Andreas	69 b	MDA23	12.11 b
Albion	223 b	MOGSC468	69 b	Aromas	11.87 b
Festival	204 b	MCA89	68 b	MDA01	11.82 b
MDA01	193 b	Festival	68 b	Festival	11.32 b
Pircinque	190 b	MDA23	60 b	MCA94	10.36 b
MOGSC468	162 b	MDA01	56 b	MOGSC468	9.14 b

*Averages followed by same letters in the same column do not differ statistically at a level of 5% by the Scott-Knott test.

Box 1. Characterization of the aerial part of the strawberry genotypes according to the predominance of the average scores of the morphological descriptors for growth habit, interveinal bulging of the leaf, leaf base shape, leaf margin shape and calyx size in relation to the flowers (UPOV, 2012). Alfenas, UNIFENAS, 2022.

Genotype	Plant growth habit	Interveinal bulging	Base shape	Margin shape	Chalice size
			Leaves		
MCA94	Semi-erect	Dense	Obtuse	serrated to crenada	the same size
MDA23	Semi-erect	Dense	Obtuse	serrated to crenada	the same size
MCA89	Semi-erect	Medium	Obtuse	serrated to crenada	the same size
MDA01	Semi-erect	Dense	Obtuse	serrated to crenada	the same size
MFA443	Semi-erect	Dense	Obtuse	serrated to crenada	the same size
MDA06	Semi-erect	Dense	Acute	serrated to crenada	the same size
MOGSC468	Semi-erect	Dense	Obtuse	serrated to crenada	the same size
Kruskal-Wallis (p)	0.228032699	0.219157603	0.1774435	0.1202917	0.4673159

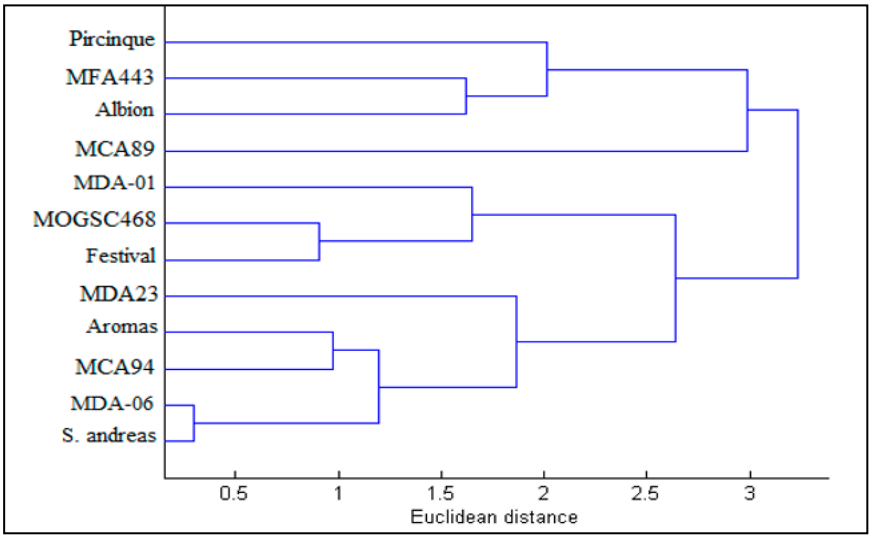

Figure 1. Dendrogram of similarity produced according to observations carried out on experimental strawberry genotypes. Alfenas, UNIFENAS, 2022.

have good product characteristics. In turn, the hybrid MFA443 was more productive, and, mainly, presented higher average values of fruit weight, as well as percentage of commercial fruits, in comparison to the values observed of its parents, indicating positive values for heterosis (Pereira *et al*., 2022).

Previous studies, evaluating the same genotypes (Santos, 2019), showed that genotype MCA89 was considered promising, presenting about 37.28% of commercial fruits, 125.08 g of fruits/plant, and 14.92 fruits/plant, data that corroborate with the results observed in Alfenas-MG for the same genotype, which presented 68% of commercial fruits at an average weight of 33.3 g/fruit, and 290 g of fruits/plant. It can be reaffirmed that this genotype has adaptive and productive characteristics of interest for the development of the next stages of the strawberry breeding program in the southern region of Minas Gerais. This genotype was produced by hybridizing the cultivars Aromas and Camarosa, which have good yielding characteristics, and Camarosa, in particular, high-average weight of fruits (Antunes *et al*., 2016; Galvão *et al*., 2017, Vieira *et al*., 2019).

In an experiment reported by Ferraz (2015), the hybrid MOGSC468 was the one that presented the best productive results in Lavras-MG, and this indicates that it has great potential in this region; however, this genotype did not present satisfactory results on the region of Uberlândia-MG and Alfenas-MG. This hybrid (MOGSC468) presented in Alfenas the lowest averages of total production and weight of fruits, being respectively 162 g/plant and 9.14 g/fruit. Gabriel *et al*. (2020) and Resende *et al*. (2020) also found genotype x environment interaction on the evaluation of commercial strawberry cultivars in Lavras-MG, Uberlândia-MG, and Guarapuava-PR. These authors reported that the climatic differences between these locations were probably the main determinants of the differentiated responses between the cultivars evaluated for production and post-harvest characters.

As discussed by Guerra (2021), the genotype MDA23, cultivated in Lavras-MG obtained about 28% of commercial fruits, a much lower value compared to the same genotype cultivated in the region of Alfenas-MG, where it presented 60% of commercial fruits. This statistical difference proves a greater adaptation capacity of this genotype to the edaphoclimatic conditions in the city of Alfenas-MG. This genotype stood out on total production of fruits; it was obtained from the hybridization of cultivars Dover and Aromas, both standing out for productivity, especially the cultivar Dover (Galvão *et al*., 2017). Barth *et al*. (2020) obtained productive genotypes when these same parents were used in intraparietal crosses.

Multivariate analysis and analysis of the principal components were performed, considering the similarities

between the experimental genotypes and the commercial cultivars evaluated, where the formation of three large groups can be observed, according to the dendrogram (Figure 1). The first group consisted of the genotypes Pircinque, MFA443, Albion, and MCA89; the second group was formed by the genotypes MDA01, MOGSC468, and Flórida Festival; and the third was formed by the genotypes MDA23, Aromas, MCA94, MDA06 and San Andreas. Souza *et al.* (2022), evaluating the same experimental genotypes in the region of Lavras-MG, observed that the evaluated materials present high similarity to each other in terms of morphological characterization, which corroborates the results of this work.

However, the divergences observed point to potential parents for the next stages of the program, emphasizing that divergent materials have greater potential to be used as parents in new crosses in order to increase the genetic variability of the program.

The analysis of the principal components is illustrated in Figure 2. Observing the results in the biplot plot, it is possible to verify two principal components illustrated by the X and Y axes, representing 81.87% of all the observed variation and the characteristics of similarities between the different genotypes observed, which indicates that the methodology was adequate for these evaluations.

The genotypes Pircinque, MFA443, Albion, and MCA89 formed a similarity group in the dendrogram, which is located in the quadrants on the right side of the biplot plot, where they were grouped through their similar characteristics, mainly related to higher average fruit weight. Fruits with higher average weight are preferably indicated for the fresh strawberry market. From this group, the MFA443 genotype stood out, as it presented higher values for all the evaluated characteristics.

The second group of similarities was composed of the genotypes MCA94, MDA23, MDA, San Andreas, and Aromas. All these genotypes stood out for the highest yields, however, they presented the lowest values observed for average fruit weight.

The third and last group of similarities is represented by the genotypes MOGSC468, MDA01, and Flórida Festival, which presented the lowest averages observed for the evaluated traits.

To select potential parents for future hybridizations and to continue the strawberry genetic breeding program in the region, it is essential to select genetically divergent parents. The parents with greater genetic divergence are more likely to produce better hybrids, due to the heterosis resulting from the possible combinations between the genotypes. However, in strawberry, it is a little more complicated, given the octoploid condition of the species, which, when in crosses, provide a high intensity of segregation, thus forcing the breeder to work with large populations during the selection process (Corrêa *et al.*, 2021).

Aiming at the morphological characterization of the experimental strawberry genotypes, the growth habit of the plants, the interveinal bulging of the leaves, the shape of the leaf base, the leaf margin shape, and the size of the flowers' calyx were characterized (Box 1), according to standards established by UPOV (2012). The genotypes did not differ from each other for any morphological trait. However, the averages were used for the characterization of each material.

The characterization of morphological descriptions is of paramount importance to expand the knowledge of each genotype and also aiming at the launch and future registration of new cultivars, in view of being a requirement of the Ministry of Agriculture, Livestock and Supply, MAPA.

The experimental genotypes MFA443, MCA94, MDA23, MDA06, and MCA89 showed the highest fruit yields per plant, especially MFA443, which also showed the best characteristics of average fruit weight and percentage of commercial fruits. These genotypes can, in short term, be considered possible cultivars to be made available to farmers. However, studies

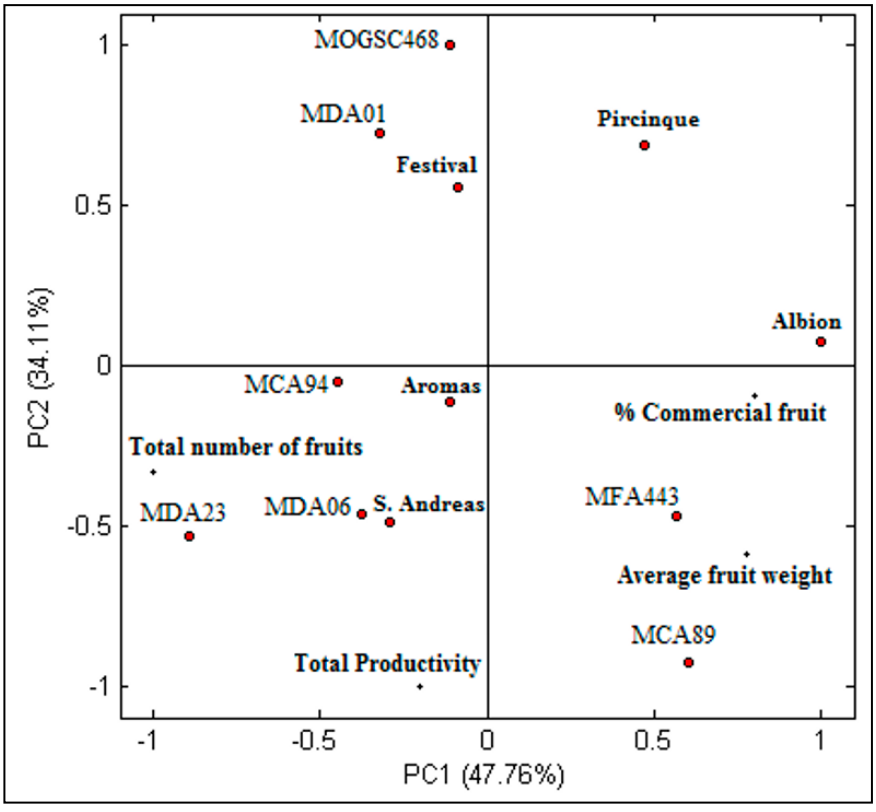

Figure 2. Analysis of the principal components as a function of the variation observed in the strawberry genotypes for the evaluated traits. Alfenas, UNIFENAS, 2022.

of adaptability and stability must be carried out to obtain greater security of the potential of the materials.

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