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Breeding new improved clones for strawberry production in Brazil

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ABSTRACT. Breeding different strawberry genotypes and plant selection in Brazil could result in new cultivars with better environmental adaptations. The aim was to develop and select new F_1 strawberry plants with higher potential yields. Twelve hybrid populations were obtained from breeding the cultivars Aromas, Camarosa, Dover, Festival, Oso Grande, Sweet Charlie and Tudla, and 42 F_1 hybrids were obtained from each population. An augmented randomized block design was used. Productive traits were measured and heterosis was calculated for all traits. The breedings Dover x Aromas and Camarosa x Aromas both showed 28.6% of their hybrids with a total fruit mass that was higher than that of cv. Aromas, and 9.5 and 14.3% were higher than that of cv. Camarosa, respectively. The breeding of Camarosa x Aromas produced hybrids with high potential yields and a large average fruit mass that reached the commercial standard. Hybrids MCA12-93, MFA12-443 and MCA12-89 showed high potential yields and can be used as parents in strawberry breeding programs.

Keywords: crossing, *fragaria x ananassa* Duch., heterosis.

Clones melhorados de morangueiro para cultivo no Brasil

RESUMO. A hibridação de diferentes genótipos de morangueiro e a seleção de plantas no Brasil pode resultar em novas cultivares com melhor adaptação ambiental. Objetivou-se neste trabalho desenvolver e selecionar novas plantas F_1 de morangueiro com potencial produtivo superior. Foram avaliadas 12 populações híbridas a partir de cruzamentos entre as cultivares Aromas, Camarosa, Dover, Festival, Oso Grande, Sweet Charlie e Tudla e 42 híbridos F_1 de cada população. O delineamento experimental foi de blocos aumentados. Foram avaliadas características de produtividade e calculada a heterose para cada uma delas. As populações provenientes dos cruzamentos 'Dover x Aromas' e 'Camarosa x Aromas', apresentaram 28,6% dos híbridos com massa total de frutos superior a cv. Aromas, e 9,5 e 14,3%, dos híbridos, superiores a cv. Camarosa, respectivamente. O cruzamento entre as cultivares 'Camarosa x Aromas' resultou em híbridos de alta produtividade e maior massa de frutos atingindo padrões comerciais. Os híbridos MCA12-93, MFA12-443 e MCA12-89 possuem elevado potencial produtivo e podem ser utilizados como genitores em programas de melhoramento genético do morangueiro.

Palavras chave: cruzamento, *fragaria x ananassa* Duch., heterose.

Introduction

The strawberry (*Fragaria* x *ananassa* Duch) is cultivated in several temperate and tropical countries, mainly on the European and American continents. Strawberry fruits are consumed fresh or in prepared foods; they are valued due to their typical flavor, aroma and bright red color. The United States is the world's largest producer. In this country, the earliest studies on strawberry breeding date back to the beginning of the 19th century. Worldwide, although some developments had been reached after the first few studies, the greatest breakthroughs were achieved over the past 50 years through uncountable public and private institutions (Gil-Ariza, Amaya, López-Aranda, & Sánchez-Sevilla, 2009).

There are more than 40 strawberry breeding programs around the world, wherein considerable genetic variation in the available germplasm is of great economic interest (Chandler, Folta, & Dale, Whitaker, & Herrington, 2012). In Brazil, strawberry breeding programs have stalled over the past few decades. Therefore, the main cultivars grown in this country have been imported from the United States, Spain and other countries.

Aromas, Camarosa, Dover, Festival, Oso Grande and Sweet Charlie, which are cultivated in the United States, and Tudla, which is cultivated in Spain, can be highlighted among the most widely cultivated strawberry cultivars in Brazil. Aromas is considered a day-neutral photoperiod plant with uniform and medium-sized fruits. Camarosa is considered a short-day photoperiod plant that is highly productive with intensely red fruits. Dover is highly productive with small fruits. Festival is considered a short-day photoperiod plant with large red fruits. Oso Grande is a short-day photoperiod plant that is highly productive with large fruits. Sweet Charlie has excellent flavor and heart-shaped fruits. Tudla is a short-day photoperiod plant with large fruits and a high ºBRIX (Resende et al., 2010; Pereira, Souza, Yuri, & Ferreira, 2013). In this way, the production costs become higher because the farmers indirectly pay royalties to use these cultivars.

This situation shows that the development of the cultivation of strawberries in Brazil is still dependent on imported cultivars, which are not adapted to the environment and are therefore unproductive and vulnerable to biotic and abiotic factors (Barneche & Bonow, 2012) in the producing region. To exemplify this problem, we can highlight the susceptibility of the imported cultivars to common leaf spot (*Mycosphaerella fragariae* Tul.), gray mold (*Botrytis cinerea* Pers ex Fr.) and anthracnose (*Colletotrichum acutatum* Duch.), among other diseases, which are responsible for significant losses in production. In Brazil, strawberry cultivars are more susceptible to diseases due to climatic conditions such as high relative humidity and high temperature, which are propitious to fungal and bacterial proliferation.

Brazil has no active strawberry breeding programs due to the lack of interest of private and public companies. Therefore, it is clear that Brazil must reestablish a new strawberry breeding program because new cultivars could be better adapted to subtropical and tropical conditions. They could be more productive with better post-harvest quality and higher disease resistance. The development of new cultivars could also decrease the time between harvests and select for day-neutral plants that can produce over the entire year, in contrast to short-day cultivars, which experience a peak in production between winter and spring. The hybridization of cultivars that demand a short day photoperiod with those that are day neutral could create progenies with high genetic variation and increased heterosis.

To decrease the dependence on imported cultivars, this study aimed to obtain and select F_1 plants (hybrids) with productive potential that is superior to that of the most commonly grown imported cultivars.

Material and methods

This study was carried out in an experimental area belonging to the Olericulture Sector of the Universidade Federal de Lavras (UFLA) in Lavras, Minas Gerais State (21° 14' South and 40° 17' West, elevation 918.80) between October 2011 and November 2013. The regional climate is classified as Cwb according to Köppen, with annual temperature and rainfall averages of 19.4°C and 1.529 mm, respectively (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013; Moura et al., 2012).

The parental cultivars were previously selected from among the introduced cultivars that are widely grown in Brazil according to their most striking features: Aromas - ARO, Camarosa - CAM, Dover - DOV, Festival - FES, Oso Grande - OSO, Sweet Charlie - SWT and Tudla - TUD.

The parental cultivars were obtained from the company Multiplanta® Tecnologia Vegetal (Andradas, Minas Gerais State). After acquiring the seedlings (October 2011), they were grown in pots with substrate (50% soil and 50% Plantmax® substrate) and kept in a protected environment. The cultivation was carried out according to culture recommendations. Twelve hybrid populations were created by combining short-day and day-neutral cultivars.

The twelve hybrid populations were described by Dov (♀ parent) x Aro (♂ parent) - MDA (progeny code); Oso x Aro - MOGA; Cam x Aro - MCA; Dov x Swt - MDSC; Oso x Tud - MOGT; Fes x Swt - MFSC; Swt x Aro - MSCA; Tud x Aro - MTA; Tud x Swt - MTSC; Cam x Swt - MCSC; Fes x Aro - MFA; Oso x Swt – MOGSC.

Hybridization (April to July 2012) was carried out according to the procedures recommended by University of Florida (Chandler et al., 2012). The achenes were extracted from fully ripe pseudo-fruits using a blender to extract the seeds (Osterizer Mod.4655). The achenes were dried at room temperature and were later stored in a desiccator (25°C). To overcome achene dormancy, acid scarification was performed by immersion in H_2SO_4 (98%) (Galvão et al., 2014). After these treatments, the achenes were transferred to in vitro culture in MS medium (Murashige & Skoog, 1962) solidified with agar (0.6%) and supplemented with sucrose (3%).

After 60 days of in vitro growth, seedlings with 4 or 5 leaves were transplanted to 72-cell trays filled with Plantmax® substrate and were kept in a greenhouse with fogging and a controlled temperature for acclimation. To assist in their initial growth, the seedlings were transferred (February

2013) to polyethylene cups (5 cm diameter × 10 cm height) filled with Plantmax® substrate and were kept in a greenhouse with fogging for the second stage of acclimation.

The soil of the experimental area is classified as a typical dystroferric Red Latosol (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2006) and presents a clay texture, with 33% sand, 18% silt and 49% clay content. Soil preparation in the greenhouse was carried out a month before the seedlings were transplanted into the beds (0.20 × 1.20 m) through plowing followed by liming and disking. Limestone in the amount of 2.5 t ha^{-1} (PRNT 92%), which was calculated based on a chemical analysis of the soil, was used for liming. Basic fertilization was carried out five days before transplanting with 1,650 kg ha^{-1} simple superphosphate, 250 kg ha^{-1} potassium chlorate, and 295 kg ha^{-1} urea. Irrigation was carried out using driplines with drips that were 0.3 cm apart. Two driplines were used in each bed. The beds were covered by black polyethylene film (mulching), 30 μm thick.

After 60 days of growth in the second acclimation stage (March 25th, 2013), the seedlings received *toilets* and a Bordeaux mixture treatment and were immediately transplanted into the greenhouse beds with 0.30 × 0.40 m spacing, forming two lines per bed, with each plant next to a dripping point.

The experimental design was augmented blocks (Federer, 1956). This design was chosen due to the lack of genotype replication because the focus of the study was the F_1 generation with only one plant per genotype. Therefore, the common treatments were the parental cultivars (witnesses) and the regular treatments were the 42 experimental F_1 hybrids of each breeding (42 hybrids x 12 populations = 504 hybrids), where each breeding was arranged in a block, forming 12 blocks.

Covering manure was applied every 30 days. Each application was a compound of 60 kg ha^{-1} ammonium sulfate, 11.5 kg ha^{-1} potassium sulfate, and 14.5 kg ha^{-1} potassium chlorate. Pest and disease control was performed according to culture recommendations.

The total fruit mass (TFM) was determined over 29 harvests. Harvesting started on May 4th, 2013, and was subsequently performed every 3 days. The initial harvest occurred on different dates due to the distinct development patterns of each genotype. Fruits presenting at least 75% dark red color were harvested and measured. Fruits were classified as either noncommercial (≤ 35 mm) or commercial (> 35 mm) according to (Programa brasileiro para a modernização da horticultura e produção integrada de morango [PBMH-PIM], 2015). The end of the commercial production period was determined when an evaluated plant produced more than 70% noncommercial fruits. Using the harvest data, we calculated the total fruit mass (TFM g $plant^{-1}$), the commercial fruit mass (CFM g $plant^{-1}$), the noncommercial fruit mass (NFM g $plant^{-1}$) and the average fruit mass (AFM g $fruit^{-1}$).

To analyze the results, we used a statistical model suitable for the experimental design of augmented blocks (Federer, 1956):

$$Y_{ij} = \mu + \tau_i + B_j + \varepsilon_{ij}$$

The results were subjected to variance analysis, where the mean square expected values were obtained from the Type I sums of squares using the SAS software. For the analysis, we employed general linear model (GLM) procedures in SAS (SAS/STAT, 2002). Witness averages and the experimental hybrid results were subjected to Dunnett's test ($p \leq 0.05$ and ≤ 0.01) for comparison with two controls (Control 1 - Aromas, the worst-performing cultivar, and Control 7 – Camarosa, although not presenting the best results for every characteristic, considered the best-performing cultivar under these study conditions). Hybrid selection for TFM, AFM, CFM and NFM was based on comparisons with cultivar Camarosa. The averages from populations and witnesses were subjected to heterosis calculation based on the parental averages according to the formula $h = (F1 - (P1 + P2) / 2) * 100$ for each tested hybrid population.

Results and discussion

There was a significant effect of all the characteristics, as detected through variance analysis and Dunnett's test.

Regarding heterosis (Table 1), among the evaluated hybrid populations, the observed values ranged from 24.61 to -46.85 for total fruit mass (TFM), from 9.83 to -33.37 for average fruit mass (AFM), from 52.97 to -64.80 for commercial fruit mass (CFM) and from 51.33 to -53.02 for noncommercial fruit mass (NFM).

With a heterotic effect of -53.02 for noncommercial fruit mass, the breeding of Tudla x Aromas stood out (Table 1). According to Morales et al. (2011), this breeding presents 48% genetic similarity, as the cultivars were allocated into different groups and are from different breeding programs. The noncommercial fruit mass may have been influenced by this genetic interaction, which provided this high heterotic effect.

Table 1. Heterosis in terms of total fruit mass (TFM), average fruit mass (AFM), commercial fruit mass (CFM), and noncommercial fruit mass (NFM) based on the results from the adjusted averages of the 12 breedings.

Cultivars	TFM ($g\ plant^{-1}$)	AFM ($g\ fruit^{-1}$)	CFM ($g\ plant^{-1}$)	NFM ($g\ plant^{-1}$)
Aromas	519.17*	8.89*	213.50*	305.67*
Camarosa	909.08	8.24	282.06	391.36
Dover	925.08	6.92	218.14	706.94
Festival	802.71	9.81	389.00	420.41
Oso Grande	673.42	9.52	237.73	360.36
Sweet Charlie	562.17	6.78	141.76	413.71
Tudla	598.08	8.94	355.67	553.41
Breedings	Heterose regarding parental average (%)			
Dov x Aro	24.61	-33.37	-31.97	48.72
Oso x Aro	-0.55	-21.31	-15.26	20.67
Cam x Aro	12.65	-11.69	11.81	51.33
Dov x Swt	2.81	-14.29	-6.54	6.43
Oso x Tud	-19.16	-9.02	-43.56	-24.17
Fes x Swt	-17.83	-7.26	-31.01	-9.44
Swt x Aro	-0.66	-21.11	-20.45	10.05
Tud x Aro	-45.95	-20.35	-64.80	-53.02
Tud x Swt	3.22	-4.87	-21.34	-16.63
Cam x Swt	-46.85	-16.27	-62.40	-22.67
Fes x Aro	4.37	-2.97	-0.57	7.51
Oso x Swt	12.24	9.83	52.97	4.16

* Columns with averages adjusted by Dunnett's test ($p < 0.05$). ARO: Aromas; CAM: Camarosa; DOV: Dover; FES: Festival; OSO: Oso Grande; SWT: Sweet Charlie; TUD: Tudla. Lavras, Minas Gerais State, Brazil, 2013.

The total fruit mass (TFM) ranged from 0 to 2,050 g $plant^{-1}$ among the hybrids, from 302.0 to 899.8 g $plant^{-1}$ among the breeding averages (Table 2), and from 519.17 to 925.08 g $plant^{-1}$ among the cultivars (Table 1). The breedings of Dover x Aromas and Camarosa x Aromas presented 28.6% of the hybrids with higher TFM than Aromas and were 9.5 and 14.3% higher than Camarosa, respectively.

Studies focused on cultivar evaluation that have been carried out in Brazil have reported productivities of 607 g $plant^{-1}$ (Calvete et al., 2008) and 840 g $plant^{-1}$ (Resende et al., 2010) for cultivar Camarosa, 549 g $plant^{-1}$ (Calvete et al., 2008) and 653 g $plant^{-1}$ (Resende et al., 2010) for cultivar Dover, and 708 g $plant^{-1}$ (Oliveira & Scivittaro, 2011) for cultivar Aromas, showing the high performance of these cultivars, as also evidenced by the original breeding programs (Camarosa: Voth, Shaw, & Bringhurst, 1994; Dover: Howard & Albregts, 1980, Aromas: Shaw, 1998). The existence of hybrids with production that is higher than the production shown by the cultivars in this trial and reported in the quoted literature indicates that at least some of the studied hybrid combinations have high productive potential.

Hybrids were found with a total fruit mass that was higher than that of the cultivar Aromas in every breeding in which this cultivar was one of the parents, except when combined with the cultivar Tudla. The genetic diversity between genitor cultivars (Morales et al., 2011) resulted in some superior progenies. The short day Aromas cultivar shows favorable combinations with most of the other short day cultivars. Progenies that have the Aromas cultivar as one of their genitors resulted in more adaptability to local environment conditions. Thus, this could lead to higher vegetative and reproductive vitality, which results in better strawberry fruit production.

The characteristics of average fruit mass (AFM), commercial fruit mass (CFM) and noncommercial fruit mass (NFM) were used to assert hybrid quality standards. None of the cultivars had an AFM above the "commercial standard" (≥ 35 mm, approximately 10 g; PBMH-PIM, 2015) (Table 2); thus, the low adaptability of these cultivars to the local environmental conditions is evident. In contrast, 8.5% of the hybrids produced fruits with an AFM ≥ 10 g, which makes them interesting because this mass is considered as the standard for commercial fruits. The breedings of Oso Grande x Aromas, Oso Grande x Tudla and Oso Grande x Sweet Charlie presented 2.4% of the hybrids that were superior to both controls (Aromas and Camarosa). The highest AFM was observed in a hybrid from the breeding Oso Grande x Aromas (15.1 g $fruit^{-1}$), however this breeding had the highest mass range (from 1.5 to 15.1 g $fruit^{-1}$) among the three best results. The three breedings that stood out as being superior to the controls have the cultivar Oso Grande as one of the parents. According to Voth and Bringhurst (1989), this cultivar produces large fruits, which is confirmed by the mass (16.1 g $fruit^{-1}$) reported by Resende et al. (2010). In addition, the cultivar Oso Grande is one of the parents of the cultivar Festival (Chandler, Legard, Dunigan, Crocker & Sims, 2000), which is also known for producing large fruits. Thus, the existence of genes leading to fruits of larger size is evident in the cultivar Oso Grande. Obtaining hybrids that produce large fruits is of utmost importance because this characteristic makes harvesting and packing easier, increases the value of the products and consequently results in higher earnings for the farmers.

From the Camarosa x Aromas breeding, 4.8% of the new hybrids resulted in superior values in commercial fruit mass compared to Camarosa (Table 3). From the Festival x Aromas, Oso Grande x Aromas and Oso Grande x Sweet Charlie breedings, 2.4% of the new hybrids from each breeding showed superior values of commercial fruit mass compared to Camarosa.

Table 2. The total fruit mass (TFM) and the average fruit mass (AFM) of seven cultivars and 12 strawberry breedings and their respective numbers and percentage of hybrids that were superior to the cultivars Aromas (C1) and Camarosa (C7).

Cultivars/	TFM (g plant^{-1})		% ofHybrids		AFM (g fruit^{-1})		% ofHybrids	
Breedings	Mean	Range	> C1	>C7	Mean	Range	> C1	>C7
Dov x Aro	899.8^x	45 - 1605★	28.6	9.5	5.27^x	1.3 - 10.3★	0	0
Oso x Aro	593.0	44 - 1142	7.0	0	7.24	1.5 - 15.1	2.4	2.4
Cam x Aro	804.7	120 - 2050	28.6	14.3	7.56	3.3 - 11.5	0	0
Dov x Swt	764.5	189 - 1515	7.0	2.4	5.87	3.5 - 8.8	0	0
Oso x Tud	513.9^x	76 - 962*	0	0	8.41	4.2 - 13.1*	2.4	2.4
Fes x Swt	560.8	48 - 1002	0	0	7.69	4.6 - 10.9	0	0
Swt x Aro	537.1	25 - 1371	4.8	0	6.18	3.1 - 11.3	0	0
Tud x Aro	302.0	0.0 - 696	0	0	7.12	4.1 - 10.6	0	0
Tud x Swt	598.9	167 - 1219	4.8	0	7.48	3.0 - 9.8	0	0
Cam x Swt	391.0	0.0 - 840	0	0	6.29	4.2 - 9.2	0	0
Fes x Aro	689.8	130 - 1873	11.9	2.4	9.07	5.3 - 11.5	0	0
Oso x Swt	693.4	184 - 1412	14.3	0	8.95	4.1 - 13.0	2.4	2.4

^{x} Columns with averages adjusted by Dunnett's test ($p < 0.05$). ★ Range of the data in terms of the adjusted averages of the 42 hybrids in each breeding. ARO: Aromas; CAM: Camarosa; DOV: Dover; FES: Festival; OSO: Oso Grande; SWT: Sweet Charlie; TUD: Tudla. Lavras, Minas Gerais State, Brazil, 2013.

Table 3. Commercial fruit mass (CFM) and noncommercial fruit mass (NFM) of seven cultivars and twelve breedings and their respective numbers and percentage of hybrids that were superior to the cultivars Aromas (C1) and Camarosa (C7).

Cultivars/	CFM (g plant^{-1})		% ofHybrids		NFM (g plant^{-1})		% ofHybrids	
Breedings	Media	Variação	> C1	>C7	Media	Variação	> C1	>C7
Dov x Aro	135.7^x	0 - 504★	0	0	621.3^x	158 - 1435★	52.4	26.2
Oso x Aro	167.7	0 - 728	7.1	2.4	323.3	65 - 885	2.4	0
Cam x Aro	242.7	0 - 827	11.9	4.8	457.7	80 - 1222	28.6	7.2
Dov x Swt	135.4	42 - 447	0	0	458.7	146 - 1067	19.0	7.2
Oso x Tud	138.9^x	28 - 455*	0	0	306.9^x	47 - 578*	0	0
Fes x Swt	157.6	0 - 473	0	0	326.9	70 - 721	4.8	0
Swt x Aro	115.3	36 - 485	0	0	331.1	0.0 - 980	16.7	4.8
Tud x Aro	83.2	13 - 337	0	0	176.0	0.0 - 485	0	0
Tud x Swt	169.3	63 - 593	2.4	0	337.7	81 - 794	4.8	0
Cam x Swt	66.8	0 - 324	0	0	247.2	4 - 667	0	0
Fes x Aro	245.3	95 - 1141	9.5	2.4	336.5	35 - 779	7.1	0
Oso x Swt	236.3	49 - 752	7.1	2.4	337.0	53 - 934	14.3	0

^{x} Columns with averages adjusted through Dunnett's test ($p < 0.05$). ★ Range of the data in terms of the adjusted averages of the 42 hybrids in each breeding. ARO: Aromas; CAM: Camarosa; DOV: Dover; FES: Festival; OSO: Oso Grande; SWT: Sweet Charlie; TUD: Tudla. Lavras, Minas Gerais State, Brazil, 2013.

Among the four breedings with the highest results, Oso Grande x Aromas was the third best and the one with the highest AFM (Table 2). However, of these four breedings (Table 3), the Aromas cultivar was a parent in three, showing that combinations with this cultivar as a parent produces hybrids with good agronomical results. Among the cultivars, Festival presented the best performance (389 g plant^{-1}). The high performance of the cultivars Camarosa, Oso Grande, Festival and Aromas in terms of commercial fruit mass was also observed by Pereira et al. (2013), in which 543, 594, 672, and 582 g plant^{-1}, respectively, was reported.

With an inferior value compared to the other populations, Tudla x Aromas resulted in plants with an average of 176 g plant^{-1} of noncommercial fruit mass, a value lower than other populations (Table 3). New hybrids with low values of noncommercial fruit mass produce large fruits.

The highest noncommercial fruit mass (NFM) was observed in the breeding Dover x Aromas, with more than 50 and 25% of hybrids having higher values than Controls 1 and 7, respectively (Table 3). These results corroborate those of Calvete et al. (2008) and Resend et al. (2010), which both report cultivar Dover producing the highest number of noncommercial fruits, directly influencing the NFM. According to Howard and Albregts (1980) and Santos (2009), the cultivar Dover is known for producing small fruits and is therefore presumed to have genes related to smaller fruit size, with some degree of dominance. However, genotypes producing a large number of noncommercial fruits are not always unwelcome, considering that small fruits can processed for use in prepared foods such as preserves, fruit juice, pies or ice creams.

Among the 504 studied hybrids, 33 were selected for presenting good productive potential; however, the results are presented for only 17 (Table 4). The hybrids MCA12-93, MFA12-443 and MCA12-89 stood out the most due to superior total fruit mass and noncommercial fruit mass values compared to the cultivar Camarosa. These three hybrids presented superior results compared to all of the cultivars in terms of production characteristics. It is therefore clear that these hybrids are productive both in terms of CFM and NFM and have an AFM within the standard expected of a good cultivar (≥ 10 g) (PBMH-PIM, 2015), which makes them important as study subjects for the continuity of the breeding program.

Table 4. Selected hybrids superior to the best-performing cultivar (Camarosa) for the characteristics of total fruit mass (TFM), average fruit mass (AFM), commercial fruit mass (CFM), and noncommercial fruit mass (NFM).

Hybrids	TFM	AFM	CFM	NFM
	g plant^{-1}			
Camarosa	909.08	8.24	355.67	553.41
MCA12-93	2049.96**	8.49ns	1140.61**	1222.74**
MFA12-443	1873.24**	11.48ns	827.21**	732.64ns
MCA12-89	1479.96*	11.46ns	777.75*	702.20ns
MCA12-112	1455.96*	9.32ns	643.29ns	812.66ns
MOGSC12-495	1411.96*	9.00ns	477.82ns	934.14ns
MCA12-86	1355.96*	9.01ns	622.32ns	733.63ns
MOGSC12-468	1332.96ns	9.49ns	557.37ns	775.59ns
MFA12-423	1308.24ns	10.32ns	669.60ns	638.65ns
MFA12-461	1259.24ns	10.03ns	540.35ns	718.90ns
MTSC12-343	1218.82ns	9.53ns	593.43ns	625.38ns
MCA12-105	1157.96ns	9.99ns	532.59ns	625.36ns
MOGA12-58	1141.67ns	10.99ns	727.79*	413.89ns
MOGSC12-475	1119.96ns	10.28ns	497.26ns	622.70ns
MOGSC12-501	1093.96ns	13.00*	751.82ns	342.14ns
MOGA12-75	1089.67ns	9.85ns	537.65ns	552.03ns
MOGSC12-477	1030.96ns	9.27ns	483.59ns	547.37ns
MOGSC12-483	968.96ns	12.23ns	625.74ns	343.22ns

**,* – significant values at $p < 0.01$ and $p < 0.05$, respectively, compared to cultivar Camarosa. ns – not significant through the minimum square method. Lavras, – Minas Gerais State, Brazil, 2013.

The highest percent contributions of clones with the highest TFM of all the selected hybrids were from the breedings of Dover x Aromas (33.33%) and Camarosa x Aromas (27.27%) (Table 5). Opposite the cultivar Aromas, the cultivars Camarosa and Dover had the highest results for TFM (Table 2). Therefore, it can be assumed that these high percentages are a consequence of the additive genetic effects of the alleles present in Camarosa and Dover.

Table 5. Contribution of each breeding to the selected hybrids for the characteristics of total fruit mass (TFM), average fruit mass (AFM), commercial fruit mass (CFM), and noncommercial fruit mass (NFM).

Breeding	TFM	AFM	CFM	NFM
	% oftheselectedhybrids			
Dov x Aro	33.33	3.03	3.03	0
Oso x Aro	0	9.09	15.15	12.12
Cam x Aro	27.27	6.06	21.21	6.06
Dov x Swt	9.09	0	3.03	3.03
Oso x Tud	0	3.03	3.03	15.15
Fes x Swt	0	6.06	3.03	9.09
Swt x Aro	6.06	3.03	3.03	9.09
Tud x Aro	0	6.06	0	6.06
Tud x Swt	3.03	0	3.03	6.06
Cam x Swt	0	0	0	15.15
Fes x Aro	15.15	27.27	21.21	15.15
Oso x Swt	6.06	36.36	24.24	3.03

ARO: Aromas; CAM: Camarosa; DOV: Dover; FES: Festival; OSO: Oso Grande; SWT: Sweet Charlie;TUD: Tudla. Lavras – Minas Gerais State, Brazil, 2013.

The breedings Dover x Aromas and Camarosa x Aromas also provided the highest average heterosis for TFM (24.61 and 12.65%, respectively) (Table 1). According to Morales et al. (2011), even though they have common ancestors, the cultivars Camarosa and Dover were allocated into genetic similarity groups that were different from that of cultivar Aromas, what increases the probability of a heterotic effect.

The breeding of Oso Grande x Sweet Charlie represented the highest participation among the selected hybrids of genotypes with the highest AFM (36.36%) and CFM (24.24%) (Table 5). This breeding presents a genetic similarity of 48% between the parental cultivars (Morales et al., 2011); however, this wasn't among the lowest reported by these authors. Nevertheless, this was the only breeding that presented a positive heterosis for AFM (9.83%) and had the highest heterosis for CFM (52.97%) because the cultivar Oso Grande is from the breeding program at the University of California and Sweet Charlie is from the breeding program at the University of Florida. Therefore, we suggest the use of this breeding and Camarosa x Aromas as a result of their high performance in terms of the TFM (27.27%) and CFM (21.21%) (Table 5) and the positive heterosis for CFM (11.81%) (Table 1) in programs aiming to identify hybrids with high commercial fruit number and higher fruit mass.

Although the breeding of Dover x Aromas obtained the highest average TFM, no hybrid from this breeding was present among those selected with low NFM (Table 5). In Brazil's market, fruits that do not reach the commercial standard can be directed for processing; therefore, genotypes with a high NFM should not be immediately discarded. Despite not reaching good results when combined with the other cultivars, the Dover cultivar is widely grown and presents high productivity and good post-harvest preservation (Santos, 2009).

Conclusion

Breeding between the cultivars Camarosa and Aromas resulted in hybrids with high productivity and higher commercial fruit mass.

Breeding between the cultivars Dover x Aromas resulted in hybrids with high productivity and with high noncommercial fruit mass.

Breeding between the cultivars Oso Grande x Sweet Charlie resulted in hybrids with high average fruit mass.

The hybrids MCA12-93, MFA12-443 and MCA12-89 have high productive potential and can be used as parental plants in strawberry breeding programs.

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