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PERFORMANCE OF EXPERIMENTAL ORANGE-FLESHED SWEET POTATO GENOTYPES IN THE WESTERN REGION OF SÃO PAULO

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Abstract

The orange-fleshed sweet potato has interesting nutritional characteristics, as it has a high concentration of β-carotene, which is a precursor of vitamin A. Vitamin A deficiency is a public health problem and can be avoided by adequate intake of β-carotene-rich foods, like the orange-fleshed sweet potato (OFSP). However, few OFSP genotypes are available to growers. The objective of this study was to evaluate the agronomic performance of OFSP experimental genotypes under the edaphoclimatic conditions of Western São Paulo. The experiment was carried out in the municipality of Álvares Machado-SP in a sweet potato production area on a commercial scale. Planting was carried out in October 2021 using a randomized block design with four replications. Five experimental genotypes of OFSP were evaluated, namely: F-09, F-34, U2-05, U2-19 and C-14. The cultivar Beauregard was adopted as control. At 139 days after planting, the tuberous roots were harvested and the following were assessed: total tuberous root production in Kg ha^{-1}; number of commercial tuberous roots in roots ha^{-1}, production of commercial tuberous roots in Kg ha^{-1}; average mass of commercial tuberous roots in g; dry mass percentage of commercial tuberous roots; length of roots in cm, diameter of roots in cm and soluble solids, in °Brix, appearance of roots using a scale of grades, and resistance to damage caused by insect pests. The commercial yield of the evaluated genotypes ranged from 38,27 t ha^{-1} (Beauregard) to 89,25 t ha^{-1} (F-34). The experimental genotypes present tuberous root quality similar to the commercial control 'Beauregard'. Genotypes F-34 and C-14 have flesh color similar to 'Beauregard', and genotype F-09 has dark orange flesh, a class above the control. All evaluated genotypes can potentially contribute to the increase in yield in Western São Paulo.

Keywords: β-carotene; biofortification; *Ipomoea batatas* (L) Lam.; tuberous roots yield; tuberous roots quality.

DESEMPENHO DE GENÓTIPOS EXPERIMENTAIS DE BATATA-DOCE DE POLPA LARANJA NO OESTE PAULISTA

Resumo

A batata-doce de polpa laranja apresenta características nutricionais interessantes, pois possui alta concentração de β-caroteno, que é um precursor da vitamina A. A deficiência de vitamina A é um problema de saúde pública e pode ser evitada com a ingestão adequada de alimentos ricos em β-caroteno, como a batata-doce de polpa alaranjada (BDPL). No entanto, poucos genótipos da BDPL estão disponíveis para os produtores. O objetivo deste estudo foi avaliar o desempenho agronômico de genótipos experimentais de batata-doce de polpa laranja, nas condições edafoclimáticas do Oeste Paulista. O experimento foi conduzido no município de Álvares Machado-SP em área de produção de batata-doce em escala comercial. O plantio foi realizado em outubro de 2021 em delineamento de blocos casualizados com quatro repetições. Foram avaliados cinco genótipos experimentais de BDPL, a saber: F-09, F-34, U2-05, U2-19 e C-14. A cultivar Beauregard foi adotada como controle. Aos 139 dias após o plantio, as raízes tuberosas foram colhidas e as seguintes avaliações foram realizadas: produção total de raízes tuberosas em Kg ha^{-1}; número de raízes tuberosas comerciais em raízes ha^{-1}, produção de raízes tuberosas comerciais em Kg ha^{-1}; massa média de raízes tuberosas comerciais em g; porcentagem de massa seca de raízes tuberosas comerciais; comprimento das raízes em cm, diâmetro das raízes em cm e sólidos solúveis, em °Brix, aparência das raízes usando uma escala de notas e resistência a danos causados por insetos-praga. A produtividade comercial dos genótipos avaliados variou de 38,27 t ha^{-1} (Beauregard) a 89,25 t ha^{-1} (F-34). Os genótipos experimentais apresentam qualidade de raiz tuberosa semelhante à testemunha comercial 'Beauregard'. Os genótipos F-34 e C-14 possuem cor de polpa semelhante a 'Beauregard', e o genótipo F-09 possui polpa laranja escuro, classe acima do controle. Todos os genótipos avaliados podem potencialmente contribuir para o aumento da produtividade no Oeste Paulista.

Palavras-chave: β-caroteno; biofortificação; *Ipomoea batatas* (L) Lam.; produtividade de raízes tuberosas; qualidade de raízes tuberosas.

Introduction

The sweet potato (*Ipomoea batatas* (L.) Lam.) is a vegetable belonging to the family Convolvulaceae (BRITO *et al*., 2021). Tuberous roots for human consumption are the main product of commercial interest, but the leaves and roots can be used for other purposes, such as animal feed, ethanol production, and the food industry (BACH *et al*., 2020). This vegetable stands out for its rusticity and tolerance to weather conditions, such as heat and water deficit, which facilitates its cultivation and attracts producers (ANDRADE JUNIOR *et al*., 2012). Sweet potato is mostly cultivated by family farming as it is considered a low-demanding crop (PEDROSO *et al*., 2021). However, sweet potato is highly responsive to improvements in the crop system.

Currently, the Western São Paulo is one of the main sweet potato producing regions, but the yield observed is still far from the productive potential. In crops where the technological level is low, the average yield is around 15 t ha^{-1}, however, if technologies are employed, sweet potato has the potential to reach yield above 30 t ha^{-1}, in 4-5 months of cultivation (LEAL *et al*., 2021). Low yields may be associated mainly to the use of obsolete genotypes and viruses-contaminated seedlings. To achieve high yields, it is necessary to use good management and cultural treatments and to seek new genotypes adapted to soil and climate conditions and with greater productive potential (SILVA *et al*., 2015).

Sweet potato is considered a functional food, because in addition to high levels of nutrients, it also has other functional compounds, such as carotenoids, anthocyanins, and phenolic compounds (KATAYAMA *et al*., 2017). The color of sweet potato flesh can vary according to the phenolic compounds and carotenoids present in the roots, and can be predominantly white, yellow, purple or orange, or variations of these colors. Orange-fleshed roots present this color due to the high concentration of carotenoids, mainly β-carotene. β-carotene is a precursor of vitamin A (retinol), which is essential for the proper functioning of the human immune system and cognitive development (LOW *et al*., 2020).

In addition, the nutritional quality of sweet potato can be higher with biofortification, or an increase in the concentration of nutraceutical compounds of interest, as is the case of β-carotene in OFSP. Biofortified foods are the main tool available to combat “hidden hunger”, which is the lack of some nutrients that are not usually available in commercial foods, mainly micronutrients (vitamin A, iron, and zinc), which are essential for the human health (ALVES *et al*., 2012). Interest in the cultivation of colored-fleshed sweet potato is increasing due to its potential related to bioactive and nutritional compounds and its positive impacts on human health (PILON *et al*., 2021).

New sweet potato genotypes that interesting agronomic performance and quality have been developed in the São Paulo Western University. In this sense, a polycross was carried out between local and introduced genotypes to generate genetic variability for future selection of genotypes adapted to local edaphoclimatic conditions. Thus, over three selection cycles, five OFSP genotypes were considered potential for Western São Paulo. For future release to growers, the genotypes should be cultivated in a variety of environments. Thus, the objective of this study was to assess the agronomic performance and quality of OFSP experimental genotypes in a commercial production area in Western São Paulo.

Material and Methods

Experiment installation location

The experiment was installed on October 21, 2021, in the municipality of Álvares Machado – SP, in a commercial crop of rural producers who already cultivate sweet potato. The soil of the area presents sandy characteristics, being classified as argisol. The area comes from degraded pasture where liming was carried out at a rate of 0,970 t ha^{-1}, with the use of dolomitic limestone, and fertilization according to soil analysis (Table 1).

Table 1. Chemical analysis of the soil in the experimental area at a depth of 0 to 20 cm.

Prof. (cm)	**Ph**	**M.O.**	**P**	**Al3+**	**H+Al**	**K**	**Ca**	**Mg**	**SB**	**CTC**	**V**
	($CaCl^2$)	**-(g dm^{-3})-**					**(mmolc dm^{-3})**				**%**
0 - 20	4.6	17	3	1	18	1,5	9	4	15	33	45

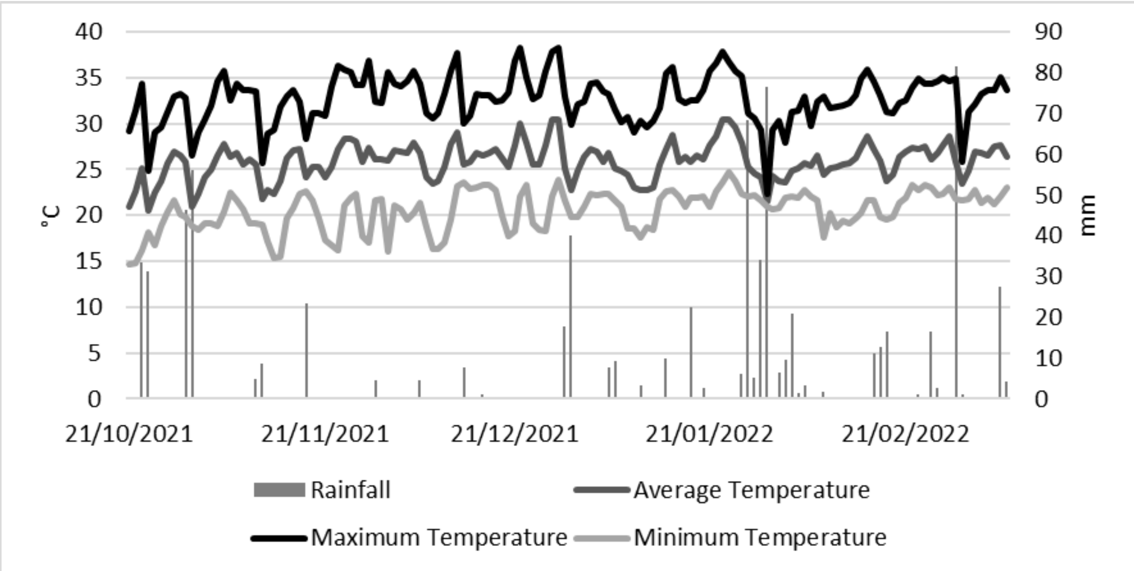

Figure 1. Climatic data of the region during the experiment.

Source: Meteorological Station – Universidade do Oeste Paulista (Unoeste), Experimental Farm, Presidente Bernardes – SP.

Genotypes and experimental design

Five experimental genotypes developed in the São Paulo Western University were evaluated: F-09, F-34, U2-05, U2-19, and C-14. These experimental genotypes were selected based on agronomic performance and tuberous roots quality. Additionally, as a commercial control, the cultivar Beauregard was used. A randomized block design was adopted, with four replications. Each plot consisted of seven plants, with the three central plants of each plot considered as useful area for the evaluation.

Experimental installation and management

Soil preparation was carried out in a conventional manner, with four heavy harrowing using a harrow and one using a leveling harrow. After the harrowing, limestone was applied according to soil analysis, with subsequent incorporation by means of heavy harrowing. The average plant population was 15.384 plants ha^{-1}.

On the day of planting, windrows with approximately 40 cm in height were built with the aid of a windrowing implement. Concomitant with the construction of the windrows, the planting fertilization was carried out as recommended for the culture and soil analysis (ECHER *et al*., 2015), i.e. 743 kg ha $^{-1}$ of the commercial formula 06-30-10 (NPK) was applied. The spacing used in the experiment was 0, 50 m between plants and 1,30 m between windrows, totaling an average of 15.384 plants ha^{-1}.

The vines were collected from a maintenance block, with a total of 13 buds. The lower eight buds were buried, and the upper five buds were kept above ground. The experiment was carried out in a rainfed system taking advantage of the harvest period and simulating the average local sweet potato grower conditions. During the conduction of the experiment, the phytosanitary control was carried out based on the literature (ECHER *et al*., 2015).

Parameters explored

The harvest was performed manually at 139 days after planting. The parameters evaluated were: total yield of tuberous roots (PTRT) in kg ha^{-1}; number of commercial tuberous roots (NTRC), in roots ha^{-1}; yield of commercial tuberous roots (PRTC), in kg ha^{-1}. To estimate the total and commercial root yield, the average of the three plants harvested per plot of the experiment was considered and this average multiplied by the total number of plants per hectare. Average mass of commercial tuberous roots (MMRC), in g; percentage of dry mass of commercial tuberous roots (MSRTC), for this evaluation, a sample of commercial tuberous roots was collected and taken to the oven for seven days until reaching constant mass. Tuberous roots with more than eighty (80) g were considered commercial. From a sample of PRTC, the parameters root length (RL) in cm, root diameter (RD) in cm and soluble solids (SS) in °Brix were evaluated through homogenized and filtered flesh and analyzed in a portable digital refractometer (Instrutherm/ Mod. RTD-95).

By means of a sample of the PTRT, per plot, the appearance (AP) of the roots was evaluated using the grade scale proposed by Andrade Júnior *et al*. (2012): 5- non- standard, with very irregular shape, presence of large veins and deep cracks, 4- very uneven, with presence of large veins and cracks: 3- non-uniform, with large veins and cracks, 2- slightly non-uniform with the presence of veins, and 1- regular fusiform, without veins or cracks. Resistance to insect pest damage was also evaluated using a rating scale: 1- free of insect damage, 2- rare damage, 3- few commercial roots damaged, 4- most damaged commercial roots, and 5- unacceptable commercial roots for human and animal consumption. Using the same PTRT sample, per plot, bark thickness (EP), number of perforations by insects (NP), bark color (CC) and flesh color (FC). The bark color was visually determined using a grade scale, where 1= White; 2= cream; 3= yellow; 4= orange; 5= orange brown; 6= pink; 7= red; 8= purplish red, and 9= dark purple. Flesh color (CP) was visually determined using a scale adapted from Moulin *et al*. (2014), where 1= light orange; 2= intermediate orange; 3= dark orange.

Data analysis

The data of the productive and qualitative characteristics evaluated were tested for normality of errors by the Shapiro-Wilk test and homogeneity of variances by the Levene test. Data were transformed according to the Box-Cox methodology proposed by Hawkins; Weisberg (2017). Means were compared by Tukey's test at 5% probability. The analyzes were performed using the statistical program AgroEstat (BARBOSA; MALDONADO JÚNIOR, 2015).

Results and Discussion

Among the yield parameters, only the characteristic total production of tuberous roots (PTRT) showed a significant difference between the evaluated genotypes, at 5% probability (Table 2). The experimental genotypes showed PTRT values numerically higher than the control, but not all of them are statistically different (Table 2). F-34 and C-14 showed superior performance to the commercial control 'Beauregard' regarding the PTRT, with 105,96 and 87,54 t ha^{-1}, respectively (Table 2). However, C-14 did not differ from the other genotypes, which in turn, did not differ from 'Beauregard'. It is worth mentioning that all experimental genotypes, for all characteristics related to tuberous root production, presented numerically higher values than the control, but did not differ statistically (Table 2). This numerical superiority is of great importance for producers because it brings profitability and greater financial return.

Table 2. Summary of analysis of variance and comparison of experimental genotypes of orange-fleshed sweet potato in terms of production parameters of tuberous roots obtained from commercial crops in Western São Paulo.

Genotype	PTRT ($t\ ha^{-1}$)	PRTC ($t\ ha^{-1}$)	NRTC	MMRC	MSRTC	CRP
F-09	59,10 ab	48,79	167,50	290,18	21,64	7,79
F-34	105,96 a	89,25	189,50	306,70	16,53	5,25
U2-05	66,30 ab	49,23	200,00	265,13	13,44	6,76
U2-19	66,02 ab	55,49	182,50	306,88	9,42	3,58
C-14	87,54 ab	57,90	177,50	337,60	10,46	3,81
Beauregard	46,35 b	38,27	140,00	284,90	9,43	2,65
Mean	70,77	55,17	176,52	298,56	13,48	4,97
Test F	4,04*	$1,53^{ns}$	$0,52^{ns}$	$0,55^{ns}$	$1,93^{ns}$	$2,65^{ns}$
P-valor	0,0177	0,2421	0,7579	0,7369	0,1487	0,0657
CV (%)	0,74	3,29	6,15	9,06	15,33	22,54

*Significant at 5% probability. PTRT= total productivity of tuberous roots ($t\ ha^{-1}$), PRTC= productivity of commercial tuberous roots ($t\ ha^{-1}$), NRTC= number of commercial roots, MMRC= mean mass of commercial tuberous roots (g), MSRTC= percentage dry mass of commercial tuberous roots, CRP= length of main branch (cm). The averages presented are those observed, but the statistics come from data that were transformed according to the Box- Cox methodology proposed by Hawkins; Weisberg (2017).

When comparing the control 'Beauregard' with studies in the literature (CAVALCANTE *et al*., 2010; AMARO *et al*., 2017), it is observed that, in general, commercial yield was higher in the present work, which, among other factors, may be linked to the favorable soil and climate conditions of Western São Paulo for the cultivation of sweet potato. The region presents high temperatures practically throughout the year, and its sandy soil facilitates the full development of tuberous roots, as well as results in better root quality because it causes less damage at harvesting. For example, Amaro *et al*. (2017) reported 20,69 $t\ ha^{-1}$ of commercial yield for Beauregard cultivar in Alto da Paraíba – MG, whereas it was observed 38,27 $t\ ha^{-1}$ in the present study.

The PTRT and PRTC variables presented values higher than expected, compared to the local average commercial yield, ranging from 46,35 to 105,96 $t\ ha^{-1}$ and 38,27 to 89,25 $t\ ha^{-1}$, respectively. In a similar study conducted in Vitória da Conquista – BA by Cardoso *et al*. (2005), using sweet potato clones, obtained root production numbers of 33,5 $t\ ha^{-1}$, which is lower than that observed in this study.

Total yield includes all types of tuberous roots, whether or not they meet the commercial standard. It is worth mentioning that the frequency of defects or roots that do not have a minimum average mass to be classified as commercial may vary according to several factors and is not necessarily exclusively linked to genetics.

Although it is an important producer, the average sweet potato yield in Western São Paulo is far below what is possible to obtain. It is attributed to this aspect the low technological level adopted by the sweet potato growers, use of obsolete genotypes, and planting with viruses-contaminated propagation material. Thus, the development of productive genotypes adapted to soil and climate conditions can contribute to increase production and profitability. In this sense, it is noteworthy that the commercial yield of the evaluated genotypes are higher than the current average for the region, which ranges from 11 to 15 t ha^{-1}.

The average mass of commercial roots was within the expected pattern, varying between 265,13 and 337,60 g. The observed values are higher than those obtained by Leonardo *et al*. (2014) who reported a maximum value of 233,6 g, in an experiment that tested the response of sweet potato to different doses of N. The ideal to export for table market is that the tuberous roots have between 250 and 400 g of mass.

Regarding the quality parameters of tuberous roots, only the bark thickness characteristic showed a significant difference between the evaluated genotypes, at 5% probability (Table 3). Aiming at greater use of the root, whether culinary or industrial, tuberous roots with a thinner bark are sought. Thus, the U2-05 genotype, with 0,18 cm, presented the lowest value of bark thickness, although it did not differ from most genotypes (Table 3).

Table 3. Summary of analysis of variance and comparison of experimental genotypes of orange – fleshed sweet potato regarding quality parameters of tuberous roots obtained from commercial crops in West São Paulo.

Genotypes	**EP (cm)**	**COMP (cm)**	**DIAN (cm)**	**NP**	**DI**	**SS (°Brix)**	**AP**
F-09	0,37 ab	21,88	6,42	7,00	1,75	10,22	2,25
F-34	0,30 ab	23,20	5,85	11,28	2,00	9,70	3,00
U2-05	0,18 b	18,87	5,73	5,75	1,50	9,40	2,25
U2-19	0,40 a	25,45	5,67	7,75	1,25	9,27	1,25
C-14	0,37 ab	23,10	5,75	1,50	1,75	9,47	2,25
Beauregard	0,20 ab	28,00	4,77	0,75	1,00	10,15	1,00
General avarage	0,30	23,41	5,70	5,00	1,54	9,70	2,00
Teste F	4,32*	$2,39^{ns}$	$1,53^{ns}$	$1,39^{ns}$	$1,43^{ns}$	$0,25^{ns}$	$2,25^{ns}$
P-valor	0,0123	0,0870	0,2394	0,2835	0,2701	0,9346	0,1032
CV (%)	20,09	3,60	7,13	17,06	19,80	1,42	25,03

*Significant at 5% probability. ^{ns}not significant at 5% probability. EP=bark thickness (cm), was the only variable to present significance, where the other estimates do not present relevant variations: COMP= length (cm), DIAN= root diameter (cm), NP= number of perforations per root, DI= damage to half integrity defect in roots by means of soluble solid media (°Brix), AP= by notes (ANDRADE JUNIOR *et al*., 2012). The proposed averages are considered to be evaluated, but organizations have been transformed into Box-Cox compliance. By Hawkins; Weisberg (2017).

The visual appearance of tuberous roots is an important qualitative parameter for the consumer (SILVA *et al*., 2015). Thus, genotypes with better appearance scores and fewer perforations and insect damage are sought. In this sense, no experimental genotypes differed statistically from the commercial control 'Beauregard', which is positive, as it is a commercial standard with high market acceptance. However, the F-34 genotype had an average of 11,28 perforations and a score of 3 for appearance. The soluble solids content ranged from 9,27 to 10,22 °Brix values higher than some studies found in the literature (ALI *et al*., 2015; CORRÊA *et al*., 2016).

The color of the bark and flesh of the tuberous roots was visually evaluated using a grade scale. The genotypes presented cream (F-09 and F-34), purplish red (U2-05 and U2-19), yellow (C-14) or orange (Beauregard) skin (Table 4). Orange flesh-color intensity is positively correlated with β-carotene content (WU *et al*., 2018). Thus, as a preliminary strategy, the genotypes were classified with light, intermediate or dark orange pulp. The cultivar 'Beauregard' presented intermediate orange flesh, with the same result observed for genotypes F-34 and C-14. The F-09 genotype showed a darker orange tone than the control, indicating a probable higher concentration of β-carotene. However, it should be considered that quantitative analyzes must be carried out to confirm the concentration of β-carotene, and the results of the present study provide information to define which genotypes have the greatest potential.

The cultivar 'Beauregard' was developed by the Louisiana Agricultural Experiment Station in the early 1980s and was introduced in Brazil through Embrapa. This genotype presents, on average, 115 mg/Kg of β-carotene root, a value much higher than that observed in roots with white and cream flesh, which present around 10 mg Kg^{-1} of root of this compound (FERNANDES *et al*., 2014).

Table 4. Characterization of skin and pulp color of experimental genotypes of orange-fleshed sweet potato cultivated in commercial farming in West São Paulo.

Genotypes	**Shell color**	**Pulp color**
F-09	Cream	Dark orange
F-34	Cream	Intermediate orange
U2-05	Red purple	Light orange
U2-19	Red purple	Light orange
C-14	Yellow	Intermediate orange
Beauregard	Orange	Intermediate Orange

Orange-fleshed sweet potato has a high concentration of β-carotene, which is a precursor of vitamin A. Vitamin A deficiency is a public health problem that mainly affects pregnant women and children in a situation of socioeconomic vulnerability (QUEIROZ *et al*., 2013). For this reason, there is an incentive for the development of biofortified genotypes that present higher concentrations of nutrients and strategic compounds, which increases the need for productive, adapted cultivars with high biological value.

The cultivation of orange or purple- fleshed sweet potato is still small in Brazil, as the greatest domestic demand is for white or cream-fleshed tuberous roots. However, some sweet potato importing countries prefer color-fleshed due to their high nutraceutical value. Thus, obtaining colored-flesh genotypes can serve foreign markets and boost the export of tuberous roots, which would invariably contribute to the sweet potato agribusiness.

Conclusions

Thus, the experimental genotypes are promising four cultivation in Western São Paulo or regions with similar edaphoclimatic conditions.

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