horticultura brasileira

Research

SILVA, JR; FERNANDES ACG; VALADARES, NR; ALVES, RA; FARIA, SES; RODRIGUES, CHO; AZEVEDO, AM. Flowering, production and seed quality in sweet potato clones cultivated under staking. *Horticultura Brasileira* v.41, 2023, elocation e2522. DOI: http://dx.doi.org/10.1590/s0102-0536-2023-e2522

Flowering, production and seed quality in sweet potato clones cultivated under staking

Janete R da Silva[1]; Ana Clara G Fernandes[1]; Nermy R Valadares[1]; Rayane A Alves[1]; Sandra Eulália S Faria[1]; Clovis HO Rodrigues[1]; Alcinei M Azevedo[1*]

1Universidade Federal de Minas Gerais (UFMG), Montes Claros-MG, Brasil; janete.ramosdasilva@yahoo.com.br; anaclaragoncalvesfernandes@gmail.com; nermyrv@gmail.com; rayaneaguiaralves@gmail.com; sandraeulalia78@gmail.com; clovis.rod1@gmail.com; alcineimistico@hotmail.com (*author for correspondence).

ABSTRACT

One difficulty in conducting breeding programs in the sweet potato is the low rate of flowering and seed production, which makes genetic recombination difficult. The aim of the present study was to select clones with superior flowering, production, and seed quality, and to verify the best time for crosses and seed harvesting. The study was carried out in the district of Montes Claros in the north of the state of Minas Gerais. Characteristics associated with flowering and seed production were evaluated in a randomized block design of 28 clones. The physiological quality of the seeds was evaluated in a completely randomized design using 11 clones. The data were submitted to analysis of variance and the Scott-Knott test ($p \leq 0.05$). Principal component analysis was carried out and a UPGMA dendrogram was created. July is the most recommended time for carrying out crosses, and August for harvesting the seeds. The UFMG01, LICURI, UFVJM06, UFVJM29, CAMBRAIA, UFVJM25, TCARRO 01, ARRUBA and UFMG02 clones were classified as more precocious for the first floral buds. CAMBRAIA and UFVJM29 were the most dissimilar, with a greater number of flowers and seeds, and should be prioritized as parents.

Keywords: *Ipomea batatas*, genetic breeding, germination, precocity.

RESUMO

Florescimento, produção e qualidade de sementes em clones de batata-doce cultivados sob tutoramento

Uma dificuldade para a condução de programas de melhoramento na cultura da batata-doce é a baixa floração e produção de sementes, o que dificulta a recombinação genética. Assim, objetivou-se selecionar clones superiores para o florescimento, produção e qualidade de sementes, e verificar qual melhor época para cruzamentos e colheita das sementes. O trabalho foi conduzido no munícipio de Montes Claros, localizado na região norte de Minas Gerais. Foram avaliadas características associadas ao florescimento e produção de sementes, no delineamento em blocos casualizados, com 28 clones. A qualidade fisiológica das sementes foi avaliada em delineamento inteiramente casualizado com 11 clones. Os dados foram submetidos à análise de variância e teste de Scott-Knott ($p \leq 0.05$). Foi feita a análise de componentes principais e dendrograma UPGMA. O mês de julho é o período mais recomendado para realização de cruzamentos e agosto para colheita das sementes. Os clones UFMG01, LICURI, UFVJM06, UFVJM29, CAMBRAIA, UFVJM25, TCARRO 01, ARRUBA e UFMG02 foram quantificados como mais precoces para os primeiros botões florais. CAMBRAIA e UFVJM29 foram os mais dissimilares por apresentar maior número de flores e de sementes, devendo ser priorizados como genitores.

Palavras-chave: *Ipomea batatas*, melhoramento genético, germinação, precocidade.

Received on September 6, 2022; accepted on January 6, 2023

The sweet potato (*Ipomoea batatas*) stands out in the agricultural sector due to its short cycle, low cost for planting in the field, and ease of handling (Alves *et al*., 2017). The vegetable can be found on the menu worldwide, particularly because of its high nutritional value. It can be used for both human consumption and animal feeding. In Brazil, it is mostly produced through family farming (Rahajeng *et al*., 2020).

Commercially, the crop is propagated vegetatively using branch segments; it can also be propagated by seeds, which can originate plants of great genetic variability, probably due to the high ploidy level (Silva *et al*., 2012). The species is hexaploid (2n=6x=90) and has hermaphrodite flowers; however, because of self-incompatibility, it carries out cross fertilization to stimulate allogamy, increasing its genetic heterogeneity (Lebot, 2010).

The high genetic heterogeneity that results when growing the sweet potato from seeds reduces its importance for commercial use due to the high variability in root shape and color (Low *et al*., 2017; Brito *et al*., 2021). In addition, the ease of vegetative propagation makes the farmer less dependent on the companies that produce the seeds.

However, obtaining seeds is of great interest to genetic breeding programs, as the seeds remain viable for more than 20 years under controlled conditions (18°C and 50% RH), facilitating conservation

of the germplasm bank (Lebot, 2010). In addition, it allows crosses in order to obtain better individuals than those pre-existing. Nevertheless, sweet potato seeds are difficult to find due to poor flowering. This difficulty may be associated with sporophytic self-incompatibility, temperature and photoperiod.

The crop requires temperatures of 20 to 25°C and a short photoperiod to flower. The use of stakes, together with the above factors, favors flowering by promoting upward plant growth and facilitating insect pollination (Mwanga *et al*., 2017).

Selecting clones that are capable of flowering and producing seeds of good physiological quality is therefore necessary, especially at the start of the breeding program, with a view to selecting characteristics of agronomic interest during the later stages. As such, the aim was to select clones with superior flowering, production, and seed quality, and to verify the best time for crosses and seed harvesting.

MATERIAL AND METHODS

The experiment was carried out in the experimental area of UFMG, at the Agricultural Institute in Montes Claros in the state of Minas Gerais (16°40'58"S, 43°50'20"W, 646 m altitude). The climate in the region is classified as hot tropical with a dry winter, an average temperature of 22.4ºC, and average annual precipitation of 1025.20 mm. The research period lasted from November 2019 to October 2020.

Twenty-eight elite sweet potato clones were evaluated. These clones were selected from previous experiments conducted by the Universidade Federal dos Vales Jequitinhonha e Mucurí (UFVJM), as follows: BTMAND, BELGARD, CAMBRAIA, LICURI, UFVJM40, UFVJM01, ARRUBA UFVJM06, UFVJM05, UFVJM21, UFVJM41, UFVJM15, UFMG02, UFMG01, UFVJM56, UFVJM44, UFVJM07, CARIRUVERM, UFVJM31, TCARRO01, UFVJM37, PRINCESA, UFVJM54, UFVJM09, UFVJM25, UFVJM29, UFVJM28 and TCARRO02. The stems of the clones were propagated from cuttings in plastic vases, each with a capacity of seven liters, and filled with Vivatto® commercial substrate for vegetables. The cuttings from the branches were approximately twelve cm in length and contained four to five nodes. The seedlings were conditioned in a greenhouse for fifteen days, and then transplanted to the field.

A randomized block design of 28 treatments (clones) was used, with three repetitions. The plots comprised four plants, spaced 0.2 m apart, with 0.9 meters between plots. The soil was prepared by plowing and harrowing, followed by the formation of ridges. The staking and irrigation system were installed before the seedlings were transplanted. The stakes were installed every three meters along the planting row and two lengths of smooth wire were stretched between the posts at a horizontal spacing of 0.40 m, the first of which was 1.40 m above the ground. The ends of the plants were tied by ribbon to the wire strands of the trellis.

Fertilizer was applied based on the soil analysis and recommendations of the Fifth Estimation (5º Aproximação, Alvarez *et al*., 1999), with cropping treatments according to Filgueira (2013). At planting date, 180 kg/ha phosphorus was applied together with 30 kg/ha nitrogen. Topdressing was carried out 30 days after transplanting the seedlings, using 30 kg/ha nitrogen. According to the soil analysis, potassium fertilizer was not required.

The characteristics under evaluation were number of days from planting to the appearance of the first ten floral buds, number of days from planting to anthesis, number of days from anthesis to fruit formation, number of floral buds per plant, number of flowers per plant, number of fruits per plant, and number of seeds per plant. To evaluate the precocity of flowering and fruit production, 10 buds were marked per clone with the aid of colored strings to measure the days elapsed from the appearance of the first floral buds to fruit dehiscence. The floral buds and flowers were counted daily every morning. To avoid any recounting, strings were attached to the buds after each count.

The fruit was harvested when it became dry and brownish in color. Following the final harvest, the total number of seeds per clone were counted, identified, and stored in a cold room at 10°C.

To evaluate the physiological quality of the sweet potato seeds, a completely randomized design was used, with four repetitions and 11 treatments (ARRUBA, CAMBRAIA, CARRO01, LICURI, UFMG02, UFVJM07, UFVJM25, UFVJM29, UFVJM31, UFVJM44 and UFVJM56), each of which had a sufficient number of seeds. Before carrying out the germination test, seed dormancy was overcome by scarifying the seeds with 98% concentrated sulfuric acid for 20 minutes and then washing in running water for 10 minutes, according to the methodology proposed by Rossel *et al*. (2008). The seeds were then treated with Vitavax-tiram® fungicide (75%).

To characterize the physiological quality of the seeds, the following determinations and tests were carried out: 1000 seed weight, using eight repetitions of 50 seeds that were weighed on a precision scale (0.0001 g), with the results expressed in grams. The degree of humidity was obtained by the oven method, at 105ºC, for 24 hours (Brasil, 2009); two repetitions of twenty seeds of each clone were used, and the results were expressed as a mean percentage on a wet basis.

The germination test was conducted in four repetitions of 25 seeds, arranged on two sheets of blotting paper moistened with distilled water at 2.5 times the weight of the substrate, placed in acrylic gerboxes and left in a BOD chamber at a constant temperature of 25°C. The evaluations were carried out on day 7 and day 21, recording the percentage of normal seedlings and non-germinated seeds, dead seeds, and hard seeds at the end of the test (Brasil, 2009). The germination speed index (GSI) was determined by a daily count of normal seedlings (Maguire, 1962). The mean germination speed was also determined together with the germination test, with evaluations every three days from sowing until 21 days after sowing, according to the formula proposed by Edmond & Drapala (1958).

The length of the hypocotyl and root were obtained 21 days after sowing with the aid of a digital caliper. The length of the hypocotyl was taken as the distance between the collar and the point of insertion of the cotyledons. For root length, the measurement was made between the collar and the tip of the largest root. The results were expressed in centimeters (cm).

The fresh and dry weight of the seedlings was determined 21 days after sowing, using the seedlings from the germination test, which were weighed on a 0.0001 g precision balance. The seedlings were then packed in Kraft paper bags and placed in a forced circulation oven at 80ºC for 24 hours, after which the samples were stored in a desiccator containing silica gel and later weighed. The results were expressed in mg/seedling.

The statistical analysis was carried out using the R software (R Core team, 2019). The assumptions of the analysis of variance (ANOVA) were verified using the Shapiro-Wilk and O'Neill-Mathews tests at a level of 5%. A logarithmic transformation of the characteristics, number of floral buds, number of flowers, number of fruits and number of seeds was necessary. ANOVA was then carried out, and when a statistical difference was found between the treatments using the F-test ($p \leq 0.05$) the mean values were grouped by means of the Scott-Knott test ($p \leq 0.05$) using the 'ExpDes.pt' package (Ferreira *et al*., 2021).

The monthly data on flowering were normalized to vary between -1 and +1, using the 'Normatiza' function of the Multivariate Analysis package (Azevedo, 2021). This was then represented on a color scale with the help of the 'ggcorrplot' package (Kassambara, 2019). The relationships between clones were investigated by principal component analysis (PCA). A dendrogram was obtained from estimates of Mahalanobis dissimilarity, using the UPGMA algorithm to the determination of the number of groups used the Mojena's method (1977).

RESULTS AND DISCUSSION

Among the 28 clones under evaluation, only four did not flower, namely: UFVJM40, UFVJM01, UFVJM21 and UFVJM54. By quantifying the days from planting to emission of the first floral buds, two groups were formed, 'A' (late clones) and 'B' (early clones) using the Scott-Knott test (Table 1). The UFVJM07, UFMG01, LICURI, UFVJM06, UFVJM29, CAMBRAIA, UFVJM25, TCARRO 01, ARRUBA and UFMG02 clones showed greater precocity for emergence of the first floral buds, particularly the last two clones (Table 1).

The onset of the first floral buds in clones considered to be the most precocious ranged from 149 to 176 days after planting, with the first recorded during May, and later clones varying between 186 to 242 days, recorded during June and July (Table 1). The temperature during this period ranged from 20 to 26°C (Brito *et al*., 2021). When evaluating flowering and production in sweet potato seeds at the Federal University of Lavras, in Minas Gerais (UFLA), it was found that flowering occurred during the first weeks of August in all clones, approximately 125 days after planting. Climate conditions during the flowering period coincided with more moderate temperatures, around 20.4°C. In another study of the sweet potato in Nigeria, flowering was recorded during September, 56 days after planting for the early clones, and 152 days for the later clones, with an average temperature of 21.5°C during the winter (Mwanga *et al*., 2015).

This variation in flowering time is associated with the climate conditions of each region, since flowering and fruiting in the sweet potato occur at milder temperatures, between 20 and 25°C (Rossel *et al*., 2008). In addition, the differences seen in flowering time, floral intensity and seed production in the sweet potato are strongly influenced by genotype, photoperiod and environmental stress (Mwanga *et al*., 2017). As such, plants tend to flower during the autumn and winter, when the days shorten to below the critical length (Lincoln *et al*., 2017).

For the number of days from planting to anthesis, the clones were grouped into three groups, Group A (late), B (intermediate) and C (early). Clone UFVJM09 (289 days) showed late anthesis, while the clones with intermediate anthesis presented an interval of 248 to 215 days. As for the earliest group, there was variation between clones UFMG02 (179 days) and UFVJM28 (213 days) (Table 1). The time between the flowers opening and fruit dehiscence ranged from 28 to 47 days in the clones under evaluation. It can be inferred, therefore, that the sweet potato takes an average of six weeks from fertilization of the flower to fruit dehiscence (Filgueira, 2013).

There was significant variation in terms of flowering capacity among the sweet potato clones, where CAMBRAIA and UFVJM29 had the highest number of flowers, with 1902.42 and 1142.67, and 1968.42 and 1166.33 floral buds, respectively. The clones, UFMG01, ARRUBA, TCARRO01, UFVJM07, UFVJM05, UFVJM44 and UFVJM25 showed intermediate results for the number of floral buds (145.67, 228.63, 164.17, 110.25, 384.88, 106.58, 76 and 83, respectively), while the other treatments showed less flowering. The lowest rate of flowering was seen in clones UFVJM41 and UFVJM09 (Table 1).

Low flower production and the time of flowering limits the number of crosses that can be made in the crop (Ngailo *et al*., 2016). The CAMBRAIA and UFVJM29 clones showed greater flowering and can be used in the initial stages of breeding as parents to obtain progeny that produce a greater number of seeds for later selection of the attributes of agronomic interest.

The CAMBRAIA and UFVJM29 clones had the highest fruit and seed production, with 291.5 fruits and 322.50 seeds, and 272.50 fruits and 354.17 seeds, respectively. The clones, UFMG02, LICURI, UFVJM05 and UFVJM25 showed intermediate fruit production. The remaining treatments

had lower production. The treatments with a smaller number of fruits and seeds ranged from around 0.5 to 17.63 fruits and from 0.5 to 25.63 seeds (Table 1). In a similar study, evaluated from July to October at UFLA-MG, 35% of the genotypes under study presented an overall mean of 340.05 seeds per plant, with 65% of the genotypes ranging from 4 to 68 seeds. This implies a large variation between the genotypes (Brito *et al*., 2021).

The crop began to flower in May (Figure 1A). From the graphic representation (Figure 1C), it was found that the ARRUBA clone presented the greatest flowering intensity during May, while in June, only UFVJM41, UFVJM15 and UFVJM09 did not flower (Figure 1A). The CAMBRAIA clone stood out with the highest number of flowers (Figure 1C). In July, flowering synchronized among all the clones that flowered, and during this period, the clones presented a high number of flowers (Figure 1A). This characteristic is of great importance in breeding programs, as it allows the planning of genetic recombinations, facilitating the process of obtaining a new cultivar. The region of this study therefore offers great potential for setting up breeding programs for the sweet potato.

A high rate of flowering was seen in the CAMBRAIA clone, whereas UFVJM06, UFMG02, UFVJM07, TCARRO 01 and UFVJM29 showed a moderate rate, while treatments UFVJM41, UFVJM15 and UFVJM09 presented a smaller number of flowers (Figure 1C). There was a reduction in the number of flowers in almost all clones during August, with only UFVJM41, CARIRUVERMELHO and UFVJM09 presenting no flowers (Figure 1A). The

Table 1. Number of days from planting to the first floral buds (DPFB), number of days from planting to anthesis (DPA), number of floral buds (NFB), number of flowers (NFL), number of fruits (NFR), and number of seeds (NSE) in 24 clones of the sweet potato grown using stakes. Montes Claros, UFMG, 2019-2020.

Clone	DPFB	DPA	NFB*	NFL*	NFR*	NSE*
Arruba	157.00 b	185.00 c	5.34 (228.63) b	5.24 (1200.38) b	3.55 (35.00) b	3.75 (42.88) b
Belgard	199.00 a	215.00 b	2.68 (16.50) c	2.46(12.88) c	1.85 (7.25) c	2.19 (11.63) c
Btmand	202.00 a	238.00 b	3.18 (45.92) c	2.84 (29.00) c	1.47 (5.50) c	1.57 (6.50) c
Cambraia	166.00 b	194.00 c	7.49 (1968.42) a	7.44 (1902.42) a	5.61 (291.5) a	5.70 (322.50) a
Cariruvermelho	204.00 a	229.00 b	3.65 (37.50) c	2.69 (13.75) c	0.56 (0.75) c	0.56 (0.75) c
Licuri	171.00 b	205.00 c	3.87 (49.63) c	3.42 (37.38) c	2.91 (18.50) b	2.93 (19.63) c
Princesa	199.00 a	223.00 b	1.72 (9.92) c	1.71 (8.42) c	1.71 (2.00) c	1.1 (2.58) c
TCARRO01	161.00 b	191.00 c	4.35 (164.17) b	3.74 (144.50) b	1.69 (12.42) c	1.69 (13.25) c
TCARRO02	199.00 a	222.00 b	5.1 (8.75) c	1.55 (3.75) c	1.1 (2.17) c	1.33 (3.08) c
UFMG01	173.00 b	210.00 c	4.75 (145.67) b	4.55 (137.33) b	(8.16) 12.25 c	2.20 (11.17) c
UFMG02	149.00 b	179.00 c	3.42 (34.92) c	2.57 (15.67) c	0.82 (2.00) c	0.86 (2.00) c
UFVJM05	195.00 a	222.00 b	5.1 (384.88) b	5.10 (355.88) b	3.12 (129.13) b	3.12 (141.88) b
UFVJM06	170.00 b	198.00 c	2.72 (21.42) c	2.25 (17.25) c	0.81 (2.25) c	0.82 (2.33) c
UFVJM07	176.00 b	192.00 c	4.35 (110.25) b	3.88 (82.33) c	1.67 (8.17) c	1.65 (7.33) c
UFVJM09	242.00 a	289.00 a	2.62 (12.75) c	1.45 (3.25) c	0.41 (0.50) c	0.41 (0.50) c
UFVJM15	222.00 a	248.00 b	1.9 (9.33) c	1.74 (7.00) c	1.03 (2.42) c	1.23 (3.17) c
UFVJM25	162.00 b	196.00 c	4.19 (76.83) b	3.98 (58.67) c	2.91 (23.17) b	3.11 (26.75) b
UFVJM28	187.00 a	213.00 c	3.94 (54.42) c	3.27 (32.67) c	1.99 (6.83) c	2.29 (9.08) c
UFVJM29	168.00 b	189.00 c	7.04 (1166.33) a	7.04 (1142.67) a	5.55 (272.50) a	5.79 (354.17) a
UFVJM31	204.00 a	227.00 b	2.97 (37.88) c	2.92 (37.38) c	2.23 (17.63) c	2.64 (25.63) c
UFVJM37	208.00 a	230.00 b	2.29 (10.92) c	1.89 (6.00) c	1.02 (1.83) c	1.19 (2.42) c
UFVJM41	205.00 a	228.00 b	1.79 (5.00) c	0.81 (1.25) c	0.41 (0.50) c	0.41 (0.50) c
UFVJM44	191.00 a	221.00 b	3.31 (106.58) b	3.08 (74.00) c	2.58 (14.67) c	2.47 (12.58) c
UFVJM56	186.00 a	222.00 b	3.19 (34.50) c	2.90 (26.75) c	2.21 (14.08) c	2.47 (9.75) c
CV (%)	11.26	9.09	49.59	53.24	67.91	65.72

Mean values followed by the same letter in a column belong to the same group by the Scott-Knott test at a level of 5%. CV= coefficient of variation. *Transformed mean values: Y transformed=log (Y observed) with the original value in parentheses.

CAMBRAIA and UFVJM29 clones showed the most flowering during this period. The crop showed a reduction in flowering during September, with the greatest number of flowers recorded for UFVJM29 (Figure 1C).

October saw the end of the reproductive period, when only CAMBRAIA, ARRUBA, UFMG02, UFVJM44 and UFVJM29 presented flowers (Figure 1A). In studies on flowering in *I. carnea* subsp. *fistulosa*, flowering was recorded for each month under evaluation, with no sharp peaks, where it can be seen that external factors such as rain, temperature and photoperiod had no effect on flowering in this species (Paz *et al*., 2013). The sweet potato has a high ploidy level which, based on the assumption that this factor is related to the duration and intensity of the reproductive period and to spore self-incompatibility, can compromise fertility and lead to partial or total sterility (Shin *et al*., 2011; Mwanga *et al*., 2017).

Fruiting of the sweet potato began in May, with the presence of fruit in the TCARRO01 clone, while in June, fruit was seen in ARRUBA, UFVJM06, UFMG02, UFVJM07, TCARRO01, UFVJM25 and UFJM29 (Figure 1B). During this period, the ARRUBA clone stood out for production (Figure 1D). During July, no fruit was seen in UFVJM41, UFVJM15, CARIRUVERMELHO, UFVJM31, UFVJM37 and UFVJM09. During August, fruiting occurred in all treatments, with CAMBRAIA and UFVJM29 recording the highest number of flowers and fruit during this period

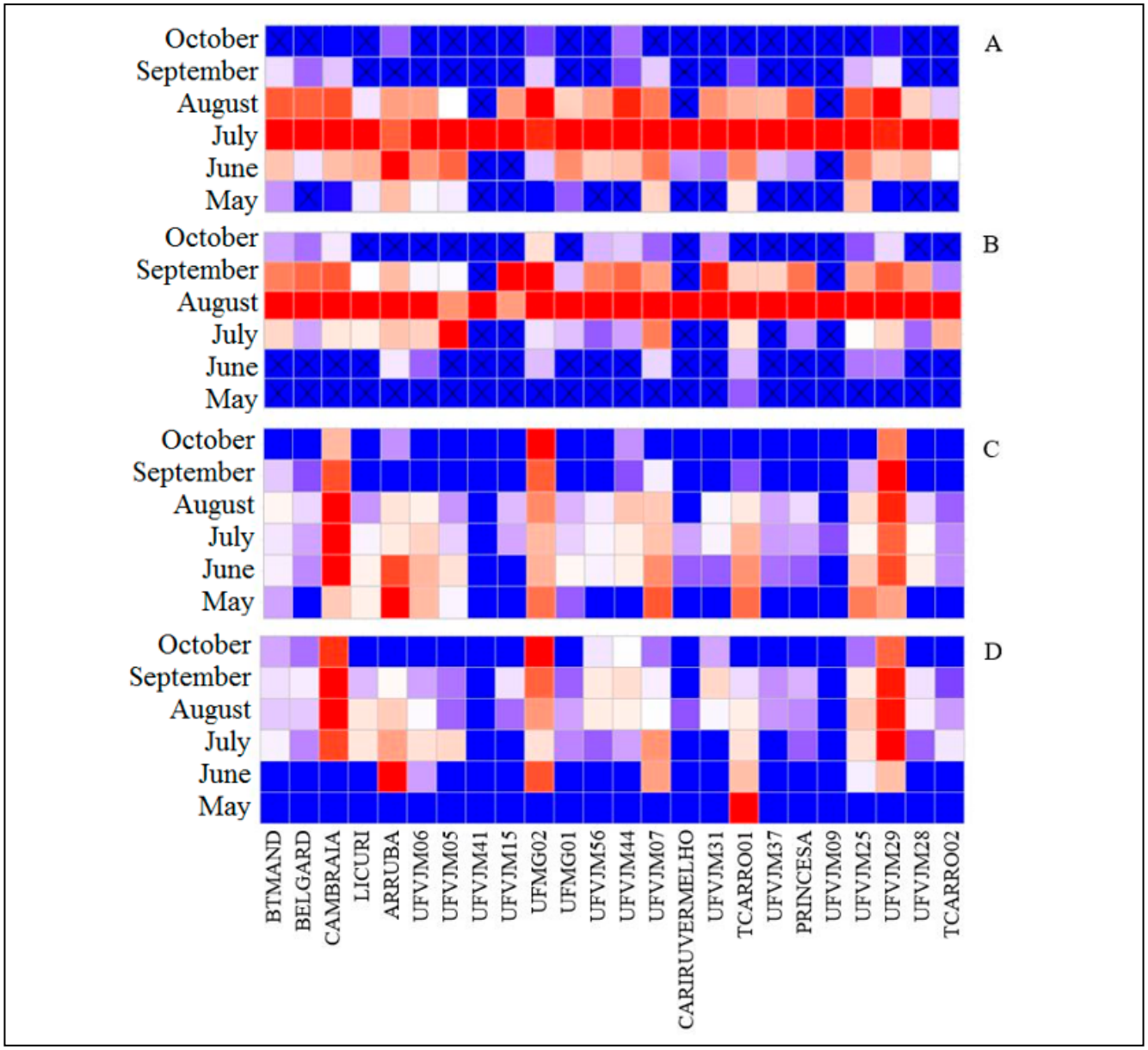

Figure 1. Graphical representation, with dark red colors indicating the month with the highest number of flowers (A) and fruits (B) for each of the sweet potato clones, and the highest number of flowers (C) and fruits (D) in each month. Dark blue colors indicate the lowest number. 'X' indicates the absence of flowers or fruits. Montes Claros, UFMG, 2019-2020.

(Figures 1B and 1D).

Fruit was present on most clones in September, with the CAMBRAIA and UFVJM29 clones showing the most fruit, and UFVJM41, CARIRUVERMELHO and UFVJM09 bearing no fruit during this time (Figure 1B and 1D). October ended fruit production, when the UFVJM02 clone stood out with the greatest number of fruits (Figure 1D). The flower/fruit/seed ratio is very low in the sweet potato, which may be associated with factors that affect flowering, and even fertilization and fruit development (Mwanga *et al*., 2017).

A scatterplot was created based on Principal Components 1 (PC1) and 2 (PC2) to illustrate the dissimilarity between the sweet potato clones for flowering and seed production (Figure 2A). The first two principal components explained 85.74% of the total variation in the data set.

The first principal component analysis (PC1) explains 50.82% of the total data variance, while the second (PC2) explains 34.92% (Figure 2A). In addition, the number of floral buds, number of flowers, number of fruits and number of seeds were seen to overlap. The same was found for the variables, number of days from planting to the first floral buds and number of days from planting to anthesis. Only the number of days from planting to the first floral buds and number of days from planting to anthesis showed a low correlation estimate with the principal components (Figure 2A).

The UFVJM29 and CAMBRAIA clones presented lower estimates for PC1, indicating higher estimates for the number of floral buds, number of flowers, number of fruits and number of seeds. Regarding the estimated 'scores' of the second principal component (PC2), lower estimates were found for TCARRO02, UFVJM37 and UFVJM41. This suggests higher values for the number of days to the first floral buds and number of days from planting to anthesis (Figure 2A).

The dendrogram obtained from the dissimilarity matrix generated by the Mahalanobis distance between the 24 sweet potato clones, based on eight flowering characteristics of the crop, showed a cophenetic correlation of 0.74% (Figure 2B). The clones were grouped into three clusters based on the Mojena criterion, with a cutoff point of 20.76. The first cluster was formed by the UFVJM41 clone, while the second cluster consisted of the CAMBRAIA and UFVJM29 clones; the third cluster was formed from the remaining clones.

The CAMBRAIA and UFVJM29 clones were grouped together in Cluster 2 as they presented higher estimates for fruit and seed production (Figure 2B). The UFVJM41 clone, on the other hand, formed Cluster 1 by itself, and was considered the most different of all the treatments, standing out for having fewer floral buds and fewer flowers (Figure 2B).

In the multivariate analysis, the UFVJM29 and CAMBRAIA clones were dissimilar to the others as they had a greater number of flowers, fruits, and seeds. This indicates that these treatments can be used during pre-breeding to increase the reproductive propagation capacity of the clones. Another dissimilar clone was UFVJM41, which stood out for being the latest and having fewer seeds and fruits. The other treatments showed intermediate values for these characteristics.

The highest percentage germination (%G) was obtained with the ARRUBA, CARRO01, UFVJM07, UFVJM25, UFVJM29 and UFVJM31 clones, the other treatments presenting a low percentage with germination varying between 5% and 54.7% (Table 2). The sweet potato seed has a hard, thick coat, which contributes to slow and irregular germination (Jorge *et al*., 2020). Scarification with sulfuric acid is considered one of the most effective methods for increasing germination in seeds with a hard coat. Overcoming dormancy with sulfuric acid is efficient in germinating sweet potato seeds but may vary with the period of each treatment (Nair *et al*., 2017), resulting in the large variation in percentage germination seen in the clones under evaluation.

Only the UFMG02, UFVJM07 and UFVJM44 clones had a low GSI, which implies less seed vigor. The higher the germination speed index, the more vigorous the seed (Marcos Filho, 2015). The LICURI, UFMG02, UFVJM07, UFVJM44 and UFVJM56 clones had a higher percentage of hard seeds. The highest percentage of dead seeds

Table 2. Germination (% G), germination speed index (GSI), hard seeds (HS), and dead seeds (DS). Montes Claros, UFMG, 2019-2020.

Clone	G (%)	GSI	HS (%)	DS (%)
Arruba	47.00 a	3.30 a	14.00 b	17.00 b
Cambraia	20.0 b	3.80 a	14.00 b	39.00 a
CARRO01	54.70 a	3.80 a	10.70 b	18.70 b
Licuri	25.30 b	2.80 a	24.00 a	29.30 b
UFMG02	5.00 b	1.40 b	26.00 a	46.00 a
UFVJM07	36.00 a	2.40 b	29.30 a	18.70 b
UFVJM25	34.00 a	3.90 a	15.00 b	25.00 b
UFVJM29	47.00 a	4.10 a	4.00 b	22.00 b
UFVJM31	39.00 a	3.30 a	10.00 b	36.00 a
UFVJM44	17.30 b	1.70 b	48.00 a	18.70 b
UFVJM56	29.00 b	3.60 a	32.00 a	16.00 b
CV(%)	38.36	29.98	63.79	42.78

Mean values followed by the same letter in a column belong to the same group by the Scott-Knott test at a level of 5%. CV= coefficient of residual variation.

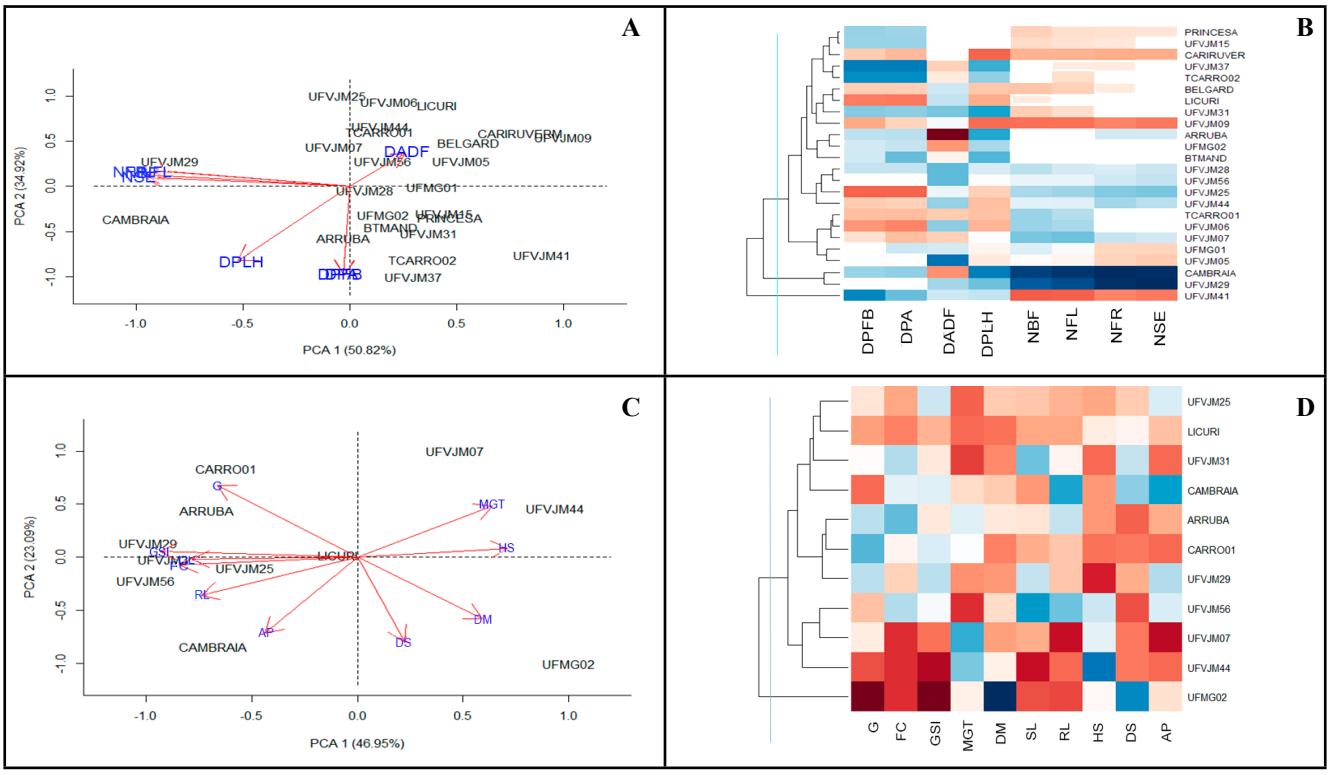

Figure 2. Scatterplot of the principal components (A and B) and (C and D), with dendrograms obtained using the UPGMA algorithm in a study of the following variables: number of floral buds (NFB), number of flowers (NFL), number of fruits (NFR), number of seeds (NSE), number of days to the first floral buds (DPFB); number of days from planting to anthesis (DPA); number of days from anthesis to fruit dehiscence (DADF); number of days from planting to the last harvest (DPLH), first count (%FC), germination (%G), germination speed index (GSI), mean germination time (MGT), dry matter (DM), shoot length (SL), root length (RL), hard seeds (HS), dead seeds (DS), abnormal plants (AP). Montes Claros, UFMG, 2019-2020.

was seen in CAMBRAIA, UFMG02, UFVJM31 (Table 2).

A variation of between 7.33% and 13.14% was seen in the seed water content, with the highest percentage in the UFVJM56 clone. The 1000 seed weight ranged from 11.96 g (UFMG02) to 22.89 g (ARRUBA).

In the principal component analysis, the first two components explained 70.04% of the total variability of the data (Figure 2C). Principal Component 1 (PC1) and Principal Component 2 (PC2) explained the variation in the data, with values of 46.95% and 23.09%, respectively. PC1 was correlated mainly with the percentage of hard seeds and mean germination time, while percentage germination was the most representative variable in the PC2 analysis. The scatterplot showed considerable variability in the physiological quality of the sweet potato seeds (Figure 2C). It can be seen that, with the two principal components, the CAMBRAIA clone showed a low estimate, suggesting a high estimate for the percentage of abnormal seedlings. The UFVJM56, UFVJM31, UFVJM29 and ARRUBA clones had the lowest estimate with Principal Component 1, indicating greater root length, percentage first count, shoot length and GSI. The overlap of these characteristics indicates that they were highly correlated. The CARRO01 clone presented a high estimate with Principal Component 2, indicating high percentage germination.

UFMG02 had a high 'score' for PC1, indicating a high percentage of dead seeds and dry matter; whereas UFVJM44 and UFVM07 had positive 'scores' with Principal Components 1 and 2, which suggests a high percentage of hard seeds and a longer mean germination time. The LICURI clone was positioned close to the origin of the principal components, showing this clone to have intermediate values for each of the characteristics (Figure 2C).

To identify how the clones were grouped based on the ten characteristics relating to the physiological quality of the seeds, a dendrogram was produced from the dissimilarity matrix using the Mahalanobis distance, showing a cophenetic correlation coefficient (CCC) of r=0.75 using the UPGMA method (Figure 2D). Two clusters were formed based on the Mojena criterion, where to determine the number of clusters, the cutoff point was 36.8. The first cluster was formed by the UFMG02 clone, with the second cluster formed by the remaining treatments (Figure 2D).

UFMG02 was the only clone grouped in Cluster 1, as it had a lower germination percentage, lower germination speed index and greater dry matter weight. The second cluster comprised the other treatments, presenting intermediate values for the characteristics under

evaluation (Figure 2D). With the multivariate analysis, the UFVJM56, UFVJM31, UFVJM29, ARRUBA and CARRO01 clones showed advantageous characteristics as selection criteria, with high percentage germination, high percentage first count, high GSI and greater shoot and root length.

The UFMG02 clone was the most dissimilar of all the treatments, as it had low percentage germination, a low germination speed index, a high percentage of dry matter and a high percentage of dead seeds. UFVJM44 and UFVJM07 showed the greatest dissimilarity, with a lower estimate for first count and a longer mean germination time. These treatments present undesirable characteristics for selection as parents to increase flowering capacity and seed production.

It is concluded that the clones are dissimilar in terms of flowering and seed production. The UFVJM29 and CAMBRAIA clones should be prioritized as parents in breeding programs due to their high rate of flowering, high production, and greater seed vigor. July is the most recommended period for carrying out crosses, and August for harvesting seeds.

ACKNOWLEDGEMENTS

The authors thank CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, code 001), FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for the support of this study.

REFERENCES

ALVAREZ, VVH; RIBEIRO, AC. 1999. Calagem. In: RIBEIRO, AC; GUIMARÃES, PTG; ALVAREZ, VVH (eds). *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação*. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais, p.43-60.

ALVES, RP; BLANK, AF; OLIVEIRA, AMS; SANTANA, ADD; PINTO, VS; ANDRADE, TM. 2017. Morpho-agronomic characterization of sweet potato germplasm. *Horticultura Brasileira* 35: 525-541. DOI - http://dx.doi.org/10.1590/S0102-053620170410.

AZEVEDO, AM. 2021. Multivariate analysis: pacote para analise multivariada. R package version *0.4.4.*

BRASIL. 2009. Ministério da Agricultura, Pecuária e Abastecimento. *Regras para análise de sementes*. 398p.

BRITO, OG; ANDRADE JÚNIOR, VC; LOPES, TK; SILVA, JCO; FIRME, TD; SILVA, EA; AZEVEDO, SM. 2021. Capacidade de floração e semente botânica produção de genótipos de batata-doce. *Horticultura Brasileira* 39: 369-375.

EDMOND, JB; DRAPALA, WJ. 1958. The effects of temperature, sand and soil, and acetone on germination of okra seed. *Proceedings of the American Society Horticutural Science* 71: 428-434.

FERREIRA, EB; CAVALCANTI, PP; NOGUEIRA; DA. 2021. ExpDes.pt: Pacote experimental *designs* (Portugues). R package version 1.2.2. https://CRAN.R-project.org/package=ExpDes.pt.

FILGUEIRA, FAR. 2013. *Novo manual de olericultura:* agrotecnologia moderna na produção e comercialização de hortaliças. 4ª ed. Viçosa: UFV, 421p.

JORGE, MHA; MELO, RAC; BERNARDES, IB; VENDRAME, LPC. 2020. Quebra de dormência em sementes botânicas de batata-doce utilizando diferentes compostos químicos. Brasília, DF: *Embrapa Hortaliças* (Boletim de pesquisa e desenvolvimento).

KASSAMBARA, A. 2019. ggcorrplot: *Visualization of a correlation matrix using 'ggplot2'*. R package version 0.1.3.https://CRAN.R-project.org/package=ggcorrplot.

LEBOT, V. 2010. Sweet potato. In: Bradshaw J (ed). Root and tuber crops. Handbook of Plant Breeding, vol 7. *Springer, New York*, NY 97-125.

LINCOLN, T; ZEIGER, E; MOLLER, IM; MURPHY. 2017. *A Fisiologia e desenvolvimento vegetal*, 6 ed. Porto Alegre: *Artmed,* 888p.

LOW, JW; ANDRADE, MM; CAREYD, E; BALL, AM. 2017. Tackling vitamin a deficiency with biofortified sweetpotato in sub-Sahan Africa. *Global Food Security* 14: 23-30.

MAGUIRE, JD. 1962. Speed of germination - aid in selection an devaluation for seed lingemergence and vigour. *Crop Science* 2: 176-177.

MARCOS FILHO, J. 2015. *Fisiologia de sementes de plantas cultivadas*. 2 ed., Piracicaba: FEALQ (Biblioteca de Ciências Agrárias Luiz de Queiroz), 495p.

MOJENA, R. 1977. Hierarchical grouping methods and stopping rules: an evaluation. *The Computer Journal* 20: 359-363.

MWANGA, ROM; Andrade, MI; CAREY, EE; LOW, JW; YENCHO, GC; GRUNEBERG, WJ. 2017. Sweetpotato (*Ipomoea batatas* L.). *Genetic Improvement of Tropical Crops* 181-218p.

MWANJA, YP; WUYEP, SZ; GOLER, EE. 2015. Clonal assessment of sweet potato (Ipomoea batatas (L.) lam.) lines for flower and seed characteristics in Jos-Plateau, Nigeria. *International Journal of Plant Breeding and Genetics* 9: 136-142.

NAIR, AGH; VIDYA, P; SREEKUMAR, J; MOHAN, C. 2017. Effect of seed pre-sowing treatment on germination of sweet potato. *International Journal of Applied and Pure Science and Agriculture* 3: 69-75.

PAZ, JRL; GIMENES, M; PIGOZZO, CM. 2013. Floral biology of the morning glory *Ipomoea carnea* subsp. *fistulosa* (Mart. ex Choisy) DF. Austin (Convolvulaceae) in an anthropic area of the semiarid region of Brazil, with emphasis on diurnal and nocturnal pollination. *Flora* 208: 138-146.

R CORE TEAM. 2019. R: A language and environment for statistical computing. R *Foundation for Statistical Computing*, Vienna, Austria.

RAHAJENG, W; RESTUONO, J; INDRIANI, FC; PURWONO, P. 2020. Genetic parameters of agronomic traits in sweetpotato accessions. *Biosaintifika: Journal of Biology & Biology Education* 12: 240-246.

ROSSEL G; ESPINOZA C; JAVIER M; TAY, D. 2008. Directrizes de regeneração: batata-doce. In: DULLOO, ME; THORMANN, I; JORGE, MA; HANSON, J (eds). *Crop specific regeneration guidelines* [CD-ROM]. CGIAR System-wide Genetic Resource Programme (SGRP), Rome, Italy. 9pp.

SHIN, JM; KIM, BK; SEO, SG; JEON, SB; KIM, JS; JUN, B; KANG, SY; LEE, JS; CHUNG, MN; KIM, SH. 2011. Criação de mutação de batata-doce por radiação de raios gama. *African Journal of Agricultural Research* 6: 1447-1454.

SILVA, GO; PONIJALEKI, R; SUINAGA, FA. 2012. Genetic divergence among sweet potato accessions based on root traits. *Horticultura Brasileira* 30: 595-599. DOI: https://doi.org/10.1590/S0102-05362012000400006.

NGAILO, S; SHIMELIS, H; SIBIYA, J; MTUNDA, K. 2016. Screening of Tanzanian sweet potato germplasm for yield and related traits and resistance to sweet potato virus disease. *Acta Agriculturae Scandinavica* Section B, *Soil & Plant Science* 66: 52-66.