horticultura brasileira

Research

GABRIEL, A; NOGUEIRA, AF; ZEFFA, DM; CONSTANTINO, LV; OLIVEIRA, LVB; FUKUJI, ASS; SANTOS, RL; RESENDE, JTV. 2022. Productivity, physicochemical quality and early flowering resistance of experimental onion hybrids. *Horticultura Brasileira* 40: 197-207. DOI: http://dx.doi.org/10.1590/s0102-0536-20220209

Productivity, physicochemical quality and early flowering resistance of experimental onion hybrids

André Gabriel[1]; Alison F Nogueira[2]; Douglas M Zeffa[3]; Leonel V Constantino[2]; Luiz VB de Oliveira[2]; Aida SS Fukuji[2]; Ricardo L dos Santos[4]; Juliano TV Resende[1,2]

[1]Universidade Estadual do Centro Oeste, (UNICENTRO), Guarapuava-PR, Brasil; andre.gb85@hotmail.com; jvresende@uel.br; [2]Universidade Estadual de Londrina (UEL), Londrina-PR, Brasil; alison.fernando@uel.br; leonel@uel.br; luizvitor.barbosa@uel.br; aidafukuji@gmail.com; [3]Universidade Estadual de Maringá (UEM), Maringá-PR, Brasil; douglas.mz@hotmail.com; [4]Sakata Seed Sudamerica Ltda, Bragança Paulista-SP, Brasil; ricardo.lima@sakata.com.br

ABSTRACT

In order to produce bulbs or seeds, onion plants depend on genotype X environment interaction. Thus, breeders shall select the genotypes based on the climatic conditions of each producing region. This study aimed to evaluate 17 experimental onion hybrids and two commercial genotypes ('Bella Dura' and 'Buccaneer'), based on agronomic, physicochemical attributes of the bulbs and resistance to early flowering under subtropical conditions. Joint analysis of variance and phenotypic divergence estimated through principal component analysis (PCA) and Ward's hierarchical clustering were performed. We observed that the time of transplantation affected the agronomic traits more than the physicochemical traits, not affecting the percentage of early flowering of the genotypes. The first transplant season provided higher bulb productivity, whereas the second season reduced the cycle and productivity. Hybrids H1, H17 and 'Buccaneer' showed flowering rate lower than 3%. Among the experimental hybrids, H2 showed higher productivity when comparing with commercial cultivars, and H1, H12 and H14 were equivalent to them. However, H12 showed the highest early flowering rate (43%). Thus, considering the experimental genotypes evaluated under subtropical conditions, H1, H2, and H14, showed potential for commercial use or as potential parents in advancing the breeding program, as they stood out for presenting good yield, bulb quality and low percentage of early flowering.

Keyword: *Allium cepa*, premature bolting, multivariate analysis, pungency.

RESUMO

Produtividade, qualidade físico-química e resistência ao florescimento precoce de híbridos experimentais de cebola

A cebola para produzir bulbos ou sementes depende da interação do genótipo com o ambiente. Assim, programas de melhoramento genético devem realizar a seleção com base nas condições climáticas de cada região produtora. Neste estudo, objetivou-se avaliar 17 híbridos experimentais de cebola e dois genótipos comercias ('Bella Dura' e 'Buccaneer') com base em atributos agronômicos, físico-químicos dos bulbos e de resistência ao florescimento precoce em condições subtropicais. Foi realizada análise de variância conjunta e a divergência fenotípica estimada por meio de análise de componentes principais (PCA) e agrupamento hierárquico de Ward. Observou-se que a época de transplante afetou mais as características agronômicas do que as características físico-químicas, não afetando a porcentagem de florescimento precoce dos genótipos. O transplantio de primeira época propiciou maiores produtividades de bulbos, enquanto, o transplante na segunda época, reduziu o ciclo e a produtividade. Os híbridos H1, H17 e 'Buccaneer' tiveram taxa de florescimento inferior a 3%. Entre os híbridos experimentais, H2 apresentou produtividade superior às cultivares comercias e, H1, H12 e H14 foram equivalentes a estas. No entanto, o H12 apresentou maior índice de florescimento precoce (43%). Assim, dentre os genótipos experimentais avaliados sob condições subtropicais, H1, H2, e H14, demonstraram potencial de uso comercial ou mesmo como potenciais genitores no avanço do programa de melhoramento, pois se destacaram por apresentar bom rendimento produtivo, qualidade de bulbo e baixo percentual de florescimento precoce.

Palavra-chave: *Allium cepa*, pendoamento precoce, análise multivariada, pungência.

Received on June 23, 2021; accepted on April 26, 2022

Onion production strongly responds to photoperiod and temperature, which limits the recommendation for growing the same cultivar in different locations with a wide range of latitude. Observing the appropriate environment at sowing or transplanting time is quite important, otherwise we verify negative physiological responses of the cultivar in relation to its productive potential (Carline *et al.*, 2017; Sekara *et al.*, 2017).

The South part of Brazil is the largest onion producer, 50% of the national production (FAO 2020). However, it is still the lowest productiveness; one of the main reasons for this situation is that producers do not use hybrids in their crops (Quartiero *et al.*, 2014). The producers prefer to use open-pollinated cultivars (OP), due to the low adaptability of the hybrids available on the market, considering that the crop breeding programs are affected by globalization, not taking into account the climatic particularities of each country or producing region (Resende *et al.*, 2007; Faria *et al.*, 2019). In addition to the lower post-harvest durability of onion hybrids indicated for the subtropical climate regions of Brazil, early flowering also occurs more frequently, resulting in inferior bulbs, and lower market prices (Quartiero *et al.*, 2014; Faria *et al.*, 2019).

In order to express the productivity potential, the onion plant needs mild temperatures (9 to 13ºC) in the beginning of the development and higher temperatures during maturation (Santos *et al.*, 2012). Nevertheless, if the temperature remains too low for prolonged periods, and the genotypes show sensitivity to early flowering, significant yield losses can be noticed (Oliveira *et al.*, 2016). Depending on the time of the crop implantation, the plant may be subjected to higher or lower temperatures at the beginning and the end of the cycle. Thus, link the climatic conditions of the crop location to the physiological responses of the species is fundamental when it comes to genetics improvement, mainly, when developing more adapted and productive hybrids, showing greater post-harvest durability. The breeders shall also take into account the interaction between genotype and growing season when selecting genotypes, mainly considering stability and adaptability to locations and growing seasons (Amalfitano *et al.*, 2019; Ikeda *et al.*, 2019).

Given the above, the aim of this study was to evaluate onion experimental genotypes, based on physicochemical agronomic attributes of the bulbs and resistance to early flowering under subtropical conditions.

MATERIAL AND METHODS

Plant material and growing conditions

We evaluated 19 onion genotypes, 17 experimental hybrids and two commercial hybrids ('Bella Dura' and 'Buccaneer'), from Sakata Seed Sudamerica and Top Seed Agristar companies, respectively.

The experiments were carried out in geographical coordinates 25°23'00''S, 51°29'38''W, altitude 1100 m. The soil is classified as Typical Bruno Dystroferric Orison. According to Köppen, the climate is mesothermic, wet subtropical, type Cfb, without a well-defined dry season, with hot summers and mild winters, frequent frosts and sporadic occurrence of snow.

Sowings were performed on April 15, 2016 and May 15, 2016 for the first and second seasons, respectively, in furrows, at 0.5 to 1.0 cm depth, in seedbeds density 4 g-seeds m^{-2}. Afterwards, the furrows were covered using a mixture of sieved soil, commercial substrate Plantmax® and vermiculite at a ratio of 3:1:0.5. The seedbeds were covered with a low tunnel (100 µm film), 1.0 m ceiling height and 1.0 m wide. The sides of the low tunnels were raised during the day for a better ventilation and covered during the night to avoid leaf wetness and keep the temperature. Micro-sprinkling irrigation was performed daily and, after the plant emergence, we applied fertilizer Yogen® (30% N; 10% P_2O_5; 10% K_2O; 0.10% MgO; 0.05% B_2O_3; 0.10% MnO and 0.05% Zn) weekly, up to transplanting day. Liming was not necessary. Preventive fungal applications were performed every 10 days after emergence using Iprodione at a dose of 100 mL p.c. 100 L of solution ha^{-1}.

The bare-root seedlings were transplanted on July 01, 2016 and August 01, 2016 for the first and second seasons, respectively, in 1.20 m-wide and 0.25 m-high seedbeds.

The experimental design used was randomized blocks, with three replicates. Each plot consisted of a useful area of 1.5 m^2 (1.0 m wide X 1.5 m long) with 90 plants distributed in six lines, spacing 0.17 m between lines and 0.10 m between plants, with population of 600 thousand plants ha^{-1} (Baier *et al.*, 2009).

Planting fertilization was performed based on soil analysis, using 400 kg ha^{-1} of formula 04-14-08 (NPK). For the top-dressing fertilization, we used 200 kg ha^{-1} N in urea form, splitted in two applications, at 30 and 60 days after transplanting.

Preventive maintenance was carried out for disease control, alternating applications of fungicides, Iprodione 150 mL (Rovral SC®), Captan 240 g (Orthocide 500®), Mancozeb 2.5 kg ha^{-1} (Dithane NT®), Cymoxanil + Famoxadone 60 g (Equation®), Azoxystrobin + Difenoconazole 300 mL ha^{-1} (Amistar Top®), Famoxadone + Mancozeb 120 g (Midas BR®) and Metalaxil -M + Mancozeb 2.5 kg ha^{-1} (Ridomil Gold®), adding an adjuvant (25% solution), with a solution volume of 150 L of water ha^{-1}, with an interval of seven days between applications.

Preventive maintenance was also carried out for pest control, alternating the insecticides, Thiamethoxam + Lambda-Cyhalothrin 250 mL ha^{-1} (Engeo Pleno S®) and Imidacloprid 200 mL ha^{-1} (Imidacloprid 350 SC®), adding an adjuvant (25% solution), with a solution volume of 150 L of water ha^{-1}, and an interval of 15 days between applications.

Weeds were controlled by hand hoeing; the sprinkler irrigation was performed (using tape Santeno®pró). The irrigations were performed according to the crop necessity, being suspended 15 to 25 days before harvest.

Evaluated traits

At 90 days after transplanting, we evaluated in 10 random plants in the plot the following traits: plant height (PH) in cm, with the aid of a graduated ruler, number of leaves (NL), haulm diameter (DP) in mm using a digital caliper, leaf area (LAI) in cm^2 (Licor-LI3100C). At the end of the cycle, the percentage of plants which emitted floral haulms (CF) was evaluated, using the total number of living plants in the plot in relation to the number of flowering plants, according to the expression %CF=(PF/PV) x100, in which CF=% of flowering plants, PF= number of flowering plants in the plot and, PV = number of living plants in the plot, this trait was evaluated only in the first season.

The plants were pulled out manually after reaching 80% leaf collapse, physiological maturity, characterized as the cycle (in terms of days) from transplant up to harvest (CI). After being pulled out, the plants were still kept in the field for five days, then, they were stored in a shed to complete the "curing" process for 21 days. Afterwards, the toilet of the bulbs was performed, by removing the shoot and the root systems; later, the bulbs were classified. The bulbs, which showed diameter greater than 36 mm, were considered "marketable". Then, the authors estimated the productivity of the marketable bulbs (YIE) in t ha^{-1} and the average mass of these marketable bulbs (ABM) in grams.

The authors quantified the dry mass (DB) by weighing about 100 g of the sample taken from three bulbs of each plot, dried in an oven with forced air at 65°C for 48 hours; later, the bulbs were weighed again in order to calculate the percentage of the bulb dry mass. Titratable acidity (TA) was determined using three bulbs from each plot, crushed in a blender and homogenized. We used the methodology proposed by AOAC (2006), in which the values are expressed in percentage of TA in the sample. Three bulbs from each plot were cut and homogenized in a blender for measuring the soluble solid content (SS). The mass obtained was pressed to extract the liquid, and the soluble solids were determined using a digital refractometer ATAGO (°Brix). The pyruvic acid content (TAP) was measured using the samples of four bulbs of each genotype. These bulbs were homogenized in a blender, after having their skin removed. Then, the bulb pungency was evaluated using the methodology proposed by Schwimmer & Weston (1961), to quantify the TAP in micromoles of pyruvic acid per gram of onion. The onions were classified based on pungency as low pungency/sweet (<3.0 µmol g^{-1}), medium pungency (3.1-7.0 µmol g^{-1}), and high pungency (>7 µmol g^{-1}) (Dhumal *et al.*, 2007). The analyzes were performed in triplicate.

Statistical analyses

After verifying normality and homogeneity of variances, the data were submitted to the analysis of variance (ANOVA) for all the evaluated traits and the averages were grouped using the Scott & Knott test, at 5% probability, using Genes software (Cruz, 2016). The 19 genotypes were analyzed in different experiments, season 1 and season 2, and afterwards they were analyzed together.

The relationship between the traits was verified using Pearson's linear correlation analysis, applying a correlation network approach. The phenotypic divergence between the treatments was verified using the analysis of principal components (PCA) and Ward hierarchical grouping, based on standardized average Euclidean distance. The optimum number of groups formed in the dendrograms was established using Mojena method (1977). The authors used R software (https://www.r-project.org/), packages 'Exp.Des' (Ferreira, 2014), 'ggplot2' (Wickham *et al.*, 2016), 'factoextra' (Kassambara & Mundt, 2017), 'pheatmap' (Kolde & Kolde, 2015) and 'qgraph' (Epskamp *et al.*, 2012).

RESULTS AND DISCUSSION

Agronomic and physicochemical traits

The results of the analysis of variance showed differences among the genotypes for all evaluated traits, except for DP (haulm diameter). The growing season interfered negatively in NL (number of leaves), PH (plant height), CI (growing cycle), YIE (yield), ABM (average bulb mass) and SS (soluble solids). A significant interaction only between genotypes and environment for LAI (leaf area index) was verified. In relation to early flowering, a difference between the genotypes was noticed (Table 1). The pyruvic acid content (PA) was significant only between the genotypes, no effect of growing season was verified, though. Bulb dry mass (DB) and titratable acidity was significant among the genotypes only in the second growing season, however, a difference between seasons was observed: higher accumulation of DB and TA in the first season. For pungency, no differences among the genotypes in relation to growing seasons and between these seasons was verified (Table 1), since all the genotypes kept the same average values (3.1-7.0 µmol g^{-1}) (Dhumal *et al.*, 2007).

The genotypes did not differ in relation to haulm diameter (DP), considering the growing seasons. Nevertheless, the hybrid H8 showed higher DP in the second growing season. No difference for number of leaves per plant (NL) considering growing seasons was also verified. The hybrids H1, H2

Table 1. Joint analysis of variance related to 19 onion genotypes in two growing seasons in subtropical region. Guarapuava, UNICENTRO, 2016.

FV	DP (mm)	NL	PH (cm)	LAI (cm^2)	CI (days)	YIE (t ha^{-1})	ABM (g)	PA (%)	SS (°Brix)	DB (%)	TA (µmol g^{-1})	PG (µmol g^{-1})	CF (%)
Genotype (G)	ns	*	**	**	**	**	**	**	**	**	**	ns	**
Season (E)	ns	*	*	ns	**	**	**	ns	*	ns	ns	ns	x
G x E	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	x
General Average	12.53	7.95	47.78	210.33	140.35	50.79	9199	5.84	8.55	8.82	0.27	4.3	12.51
CV (%)	9.12	8.50	7.65	16.49	3.32	10.13	10.63	13.36	12.49	18.41	14.87	11.24	4.11

**Significant at 1% probability by F test (P≤0.01). *Significant at 5% probability by F test (P≤0.05). ns = non significant. DP = haulm diameter, NL = number of leaves, PH = plant height, LAI = leaf area, CI = cycle from transplant to harvest, YIE = productivity of marketable bulbs, ABM = average mass of marketable bulbs, PA = pyruvic acid content, DB = percentage of dry mass, SS = total soluble solid content, TA = titratable acidity, PG = pungency, CF = early flowering.

Table 2. Average comparison test for agronomic and physicochemical traits of onion genotypes evaluated in two transplant seasons in subtropical conditions. Guarapuava, UNICENTRO, 2016.

Genotype	DP (cm)		NL		PH (cm)	
	Season I	Season II	Season I	Season II	Season I	Season II
H1	12.77 A	12.12 A	7.94 B	9.60 A	41.69Bb	49.07bA
H2	12.83 A	14.00 A	7.63 B	9.47 A	38.83Bb	48.50bA
H3	12.95 A	13.96 A	7.57 A	8.44 A	50.49Ab	58.31aA
H4	12.68 A	13.15 A	7.47 A	7.70 A	45.92aB	53.13aA
H5	12.45 A	12.11 A	8.12 A	8.70 A	46.28aB	52.83aA
H6	11.66 A	11.47 A	7.43 A	7.68 A	39.27bB	45.69bA
H7	12.69 A	12.08 A	8.19 A	8.18 A	44.28aB	50.68bA
H8	10.99 B	13.03 A	7.06 B	8.57 A	42.61bB	54.40aA
H9	12.21 A	13.11 A	7.30 A	8.23 A	42.58bB	50.17bA
H10	12.11 A	13.21 A	7.40 A	8.01 A	42.40bB	51.84bA
H11	11.92 A	13.17 A	7.43 A	8.30 A	47.07aA	51.81bA
H12	13.01 A	11.90 A	8.20 A	8.62 A	48.04aA	49.90bA
H13	11.27 A	13.14 A	7.37 A	8.43 A	38;27bB	45.40bA
H14	12.87 A	13.43 A	7.77 A	8.70 A	40;80bB	50.70bA
H15	11.94 A	12.26 A	7.33 A	7.73 A	44.83aB	52.77aA
H16	12.24 A	12.82 A	7.43 A	8.06 A	46.17aA	51.99bA
H17	11.49 A	12.78 A	7.13 A	7.97 A	41.43bB	49.93bA
Bella Dura	12.68 A	11.85 A	7.67 A	7.85 A	45.07aB	56.67aA
Buccaneer	13.55 A	12.30 A	7.31 A	8.42 A	48.77aB	57.23aA
Genotype	**LAI (cm^2)**		**CI (days)**		**YIE (t/ha)**	
	Season I	**Season II**	**Season I**	**Season II**	**Season I**	**Season II**
H1	216bA	201bA	148.00 A	125.33bB	70.75bA	40.01bB
H2	220bB	278aA	151.33 A	136.67aB	79.91aA	52.05aB
H3	190bB	317aA	153.33 A	135.67aB	59;87cA	37.03bB
H4	310aA	216bB	148.00 A	126.00bB	64.40cA	37.75bB
H5	238aA	212bA	142.00 A	123.67bB	51.77cA	31.64bB
H6	222bA	175bA	147;67 A	125.00bB	57.76cA	30.79bB
H7	309bA	175bA	148.00 A	129.67bB	59.61cA	32.16bB
H8	122cB	189bA	153.00 A	136.33aB	36,48cA	35.33bB
H9	184bA	158bA	145.00 A	129.00bB	66.29bA	35.19bB
H10	197bA	188bA	153.00 A	137.33aB	60.84cA	35.47bB
H11	256aA	191bB	148.67 A	135.00aB	67.67bA	34.30bB
H12	282aA	196bB	153.00 A	135.33aB	75.50aA	41.23bB
H13	144cA	137bA	149.00 A	126.33bB	56.93cA	35.31bB
H14	177bA	199bA	148.00 A	129.00bB	71.78bA	46.46aB
H15	260aA	182bB	149.00 A	129.33bB	54.53cA	28.88bB
H16	206bA	184bA	147.33 A	132.00aB	59.81cA	40.25bB
H17	238aA	197bA	148.33 A	129.33bB	58.96cA	32.80bB
Bella Dura	223bA	211bA	153.3 A	138.67aB	62.37cA	47.47aB
Buccaneer	258aA	233bA	152.00 A	135.67aB	67.60bA	53.10Ab
Genotype	**ABM (g)**		**PA (µmol/g)**		**SS (^{0}Brix)**	
	Season I	**Season II**	**Season I**	**Season II**	**Season I**	**Season II**
H1	131.59aA	72.09aB	9.87 a	8.87 a	9.87 a	8.87 a
H2	146.70aA	91.73aB	10.43 a	9.30 a	10.43 a	9.30 a
H3	110.73bA	66.50bB	10.43 a	10.17 a	10.43 a	10.17 a

Table 2. Continuation

H4	119.57aA	67.23bB	9.40 a	9.17 a	9.40 a	9.17 a
H5	96.52bA	55.23bB	8.93 a	8.17 a	8.93 a	8.17 a
H6	105.62bA	55.62bB	7.25 c	6.83 b	7.25 c	6.83 b
H7	108.82bA	58.87bB	6.73 c	6.47 b	6.73 c	6.47 b
H8	102.62bA	62.82bB	8.97 a	9.00 a	8.97 a	9.00 a
H9	120.53aA	62.73bB	8.10 b	7.70 b	8.10 b	7.70 b
H10	108.52bA	62.83bB	5.93 c	5.67 b	5.93 c	5.67 b
H11	121.76aA	60.62bB	6.53 c	6.00 b	6.53 c	6.00 b
H12	134.19aA	76.15aB	8.17 b	7.53 b	8.17 b	7.53 b
H13	101.42bA	63.75bB	8.30 b	7.77 b	8.30 b	7.77 b
H14	131.03aA	83.26aB	10.10 a	9.07 a	10.10 a	9.07 a
H15	97.02bA	52.20bB	9.23 a	9.10 a		
H16	107.71bA	72.95aB	10.63 a	10.50 a	10.63 a	10.50 a
H17	107.40bA	59.71bB	10.37 a	9.77 a	10.37 a	9.77 a
Bella Dura	128.97aA	76.70aB	9.47 a	8.67 a	9.47 a	8.67 a
Buccaneer	135.20aA	78.81aB	8.67 a	7.70 b	8.67 a	7.70 b

Genotype	DB (%)		TA (% pyruvic acid)		CF (%)
	Season I	Season II	Season I	Season II	
H1	9.62 A	8.86aA	0.31 A	0.30aA	1.41 e
H2	9.85 A	10.99aA	0.32 A	0.28aA	4,70 e
H3	10.65 A	11.85aA	0.27 A	0.31aA	9.47 c
H4	10.55 A	10.65aA	0.29 A	0.28aA	16.95 b
H5	9.32 A	8.05bA	0.28 A	0.24bA	8.45 d
H6	7.72 A	7.48bA	0.23 A	0.25bA	2.86 e
H7	10.95 A	6.26bB	0.33 A	0.23bB	12.03 c
H8	8.95 A	9.26aA	0.32 A	0.29aA	10.30 c
H9	8.26 A	7.13bA	0.26 A	0.26bA	8.42 c
H10	6.50 A	6.43bA	0.23 A	0.21bA	23.02 b
H11	7.45 A	6.06bA	0.21 A	0.22bA	20.18 b
H12	8.79 A	7.53bA	0.29 A	0.26bA	43.55 a
H13	7.78 A	4.96bB	0.26 A	0.25bA	8.76 c
H14	9.50 A	8.85aA	0.29 A	0.29aA	15.03 b
H15	10.36 A	8.97aA	0.30 A	0.30aA	8.87 c
H16	9.40 A	9.25aA	0.31 A	0.29aA	20.49 b
H17	10.19 A	10.64aA	0.27 A	0.27aA	2.58 e
Bella Dura	9.75 A	8.85aA	0.29 A	0.26aA	19.00 b
Buccaneer	9.07 A	8.52aA	0.26 A	0.23aA	2.13 e

*Averages followed by the same lowercase letter in the column belong to the same group, by Scott & Knott test at 5% probability ($P \leq 0.05$). DP = haulm diameter, NL = number of leaves, PH = plant height, LAI = leaf area, CI = cycle from transplant to harvest, YIE = productivity of marketable bulbs, ABM = average mass of marketable bulbs, PA = pyruvic acid content, DB = percentage of dry mass, SS = total soluble solid content, TA = titratable acidity, CF = early flowering.

and H8 showed the lowest number of leaves in the first season, though (Table 2). PH ranged within and between the two growing seasons. In the first season, the hybrids H3, H4, H5, H7, H11, H12, H15 and H16, and also the cultivars Bella Dura and Buccaneer, showed higher plants. In the second growing season, the highest values for plant height were observed for the hybrids H3, H4, H5, H8 and H15 and the marketable cultivars used as controls. The hybrids H11, H12 and H16 did not differ for PH considering the growing seasons (Table 2).

For the growing cycle of onion genotypes (CI), no variations in the first season were noticed. In the second, the earliest hybrids were H1, H4, H5, H6, H7, H9, H13, H14, H15 and H17. The marketable cultivars showed longer cycles (Table 2). Comparing the seasons, the authors observed that plants in the second season were earlier than in the first, for all evaluated genotypes (Table 2).

Higher bulb productivity was verified for hybrids H2, H12 in the first season, surpassing even the marketable cultivars. In the second season, the genotypes H2, H14, 'Bella Dura' and 'Buccaneer' stood out, highlighting that the hybrid H2 stood out in the two growing seasons for the evaluated trait (Table 2). Comparing the two growing seasons, higher bulb productivity was observed in the first growing season, for all evaluated genotypes (Table 2).

Higher bulb mass was verified in the first season, for all genotypes, in hybrids H1, H2, H4, H9, H11, H12, H14 and in the cultivars used as control; In the second season, ABM was higher in genotypes H1, H2, H12, H14, H16, 'Buccaneer' and 'Bella Dura' (Table 2).

In relation to pyruvic acid content (PA), no difference was noticed between the growing seasons of the evaluated genotypes, as well as to soluble solids content (SS). Considering the first season, the highest values for PA and SS were found in hybrids H1, H2, H3, H4, H5, H8, H14, H15, H16, H17 and in the marketable cultivars. In the second season, the highest values for PA and SS were observed in the same genotypes of the first season, except for the cultivar Buccaneer (Table 1).

Higher dry mass accumulated in bulbs (DB) and higher values for titratable acidity (TA) occurred in the genotypes H1, H2, H3, H4, H8, H14, H15, H16, H17 and in the marketable cultivars in the second growing season. In the first season, no differences among the tested genotypes for both traits were noticed. However, comparing the genotypes between the growing seasons, we concluded that H7 and H13 accumulated higher percentage of dry mass in the first season. Evaluating TA in the two growing seasons, we verified that only H7 showed difference, accumulating higher content in the bulb in the first season (Table 2).

The lowest flowering percentage occurred in the genotypes H1, H2, H6, H17 and 'Buccaneer'. H12 showed 43% flowering during the cycle, which makes its cultivation under this climatic condition unfeasible, despite the good productive performance.

In relation to leaf area index (LAI), an interaction between genotype and growing season was verified. In the first season, greater leaf area was obtained in genotypes H4, H5, H11, H12, H15, H16, 'Buccaneer' and 'Bella Dura'. In the second season, H2 and H3 showed greater leaf area, surpassing even the marketable cultivars (Table 2). In relation to interaction, we highlight that H2, H3, H8 showed the lowest leaf area in the first growing season and greater in the second season (Table 2). H4, H11, H12 and H15 had the smallest leaf area at season 2 and the largest at season 1 (Table 2).

The number of leaves is an important trait, as it increases the photosynthetic potential of the onion plants (Nunes *et al.*, 2014), mainly in subtropical regions, in which, the intensity of radiation is low. As the plant presents cylindrical and tubular leaves with low self-shading capacity, this trait shall be taken into account for selection. Some experimental hybrids were characterized for showing greater number of leaves when compared with the controls. Some studies report genetic variability for number of leaves (NL) in onions (Nunes *et al.*, 2014). The NL verified in this study is in accordance with the results obtained by Bettoni *et al.* (2013), who evaluated onion cultivars under Brazilian subtropical conditions, showing a number ranging from six to nine leaves per plant. The number of leaves is a trait which is influenced by the environment, which explains the difference between the average number between the first (8.35) and the second

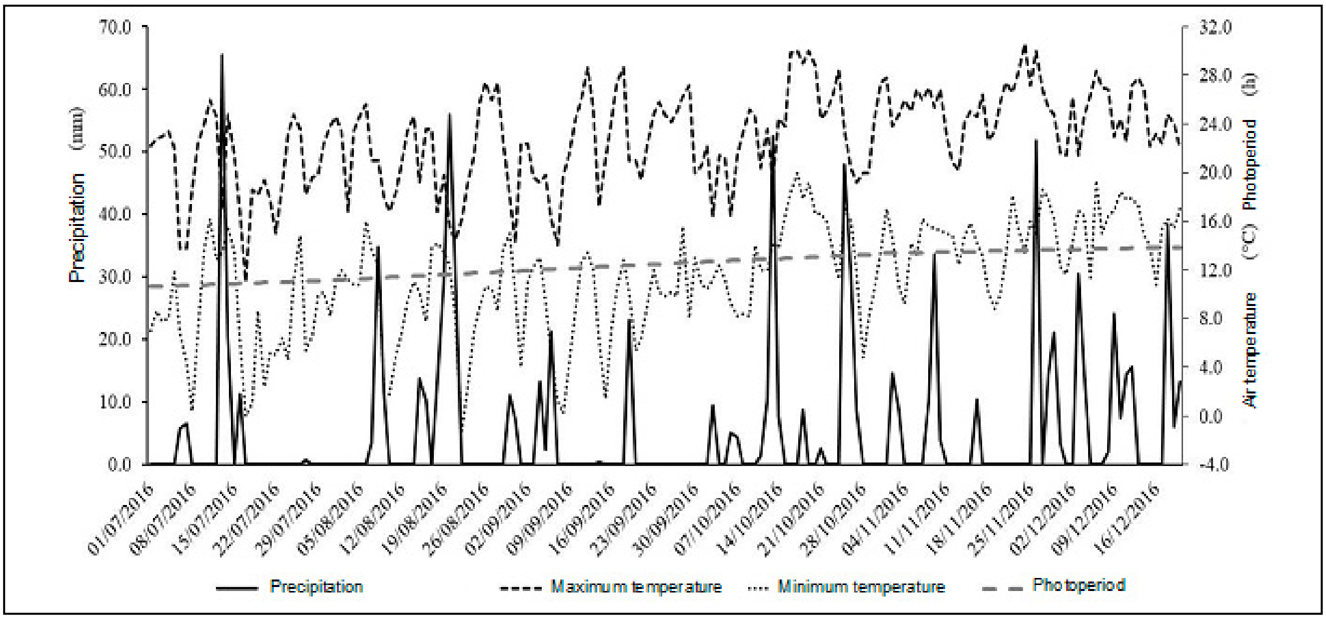

Figure 1. Values of rainfall (mm), maximum and minimum temperatures (°C) and photoperiod (hour day^{-1}) in two onion sowing seasons. Guarapuava, UNICENTRO, 2016.

growing season (8.56), as decribed by Baier *et al.* (2009).

Usually, the number of leaves is correlated with the haulm diameter, since this is formed by overlapping sheaths. However, these results were not observed in this study (Table 2). The highest haulm diameter is a parameter which evidences the possible development of unproductive plants and may be associated with climatic factors, such as high temperature and long photoperiod. (Manfron *et al.*, 1992).

Among some target traits for breeding programs, earliness production stands out, because the earlier the crop is, the better the use of area, increasing, consequently, the profitability to the farmer. Especially for the farmers in the south part of the country, who face great competition with onions imported from Argentina. Most experimental hybrids (H1, H4, H5, H6, H7, H9, H13, H14, H15 and H17) showed production cycle shorter than the marketable controls, with an amplitude of 13 days between the earliest hybrid (H5) and the cultivar Bella Dura, which was the latest. The genotypes which were transplanted after 30 days (season 2), showed a cycle reduced in 11.20%, which may be related to an increase in the photoperiod, which induces early onset of bulbing, as well as higher temperatures, accelerate bulb maturation. The authors verified that the average temperature and photoperiod in the first growing season during sowing, in April, were 18°C and 11.5 h daylength and, in November, during harvest time, were 19°C and 13.4 h daylength, respectively. For the second growing season, in May, the temperature was 14°C, and 10.9 h daylength and, in December, were 20°C and 13.7 h daylength (Weatherspark, 2022). The increase in photoperiod stimulates greater photosynthetic activity in plants, providing a greater amount of photoassimilates which are destined for the growth and development of shoot and root, and greater accumulation of reserves in the bulb, which represents agronomic yield and precocity (Tesfay *et al.*, 2011). Faria *et al.* (2012) reported that a cycle extension in onion genotypes cultivated under mild temperatures and short photoperiod can be noticed.

To start the bulb filling process, the cultivars need a minimum number of dailylight hours, known as the

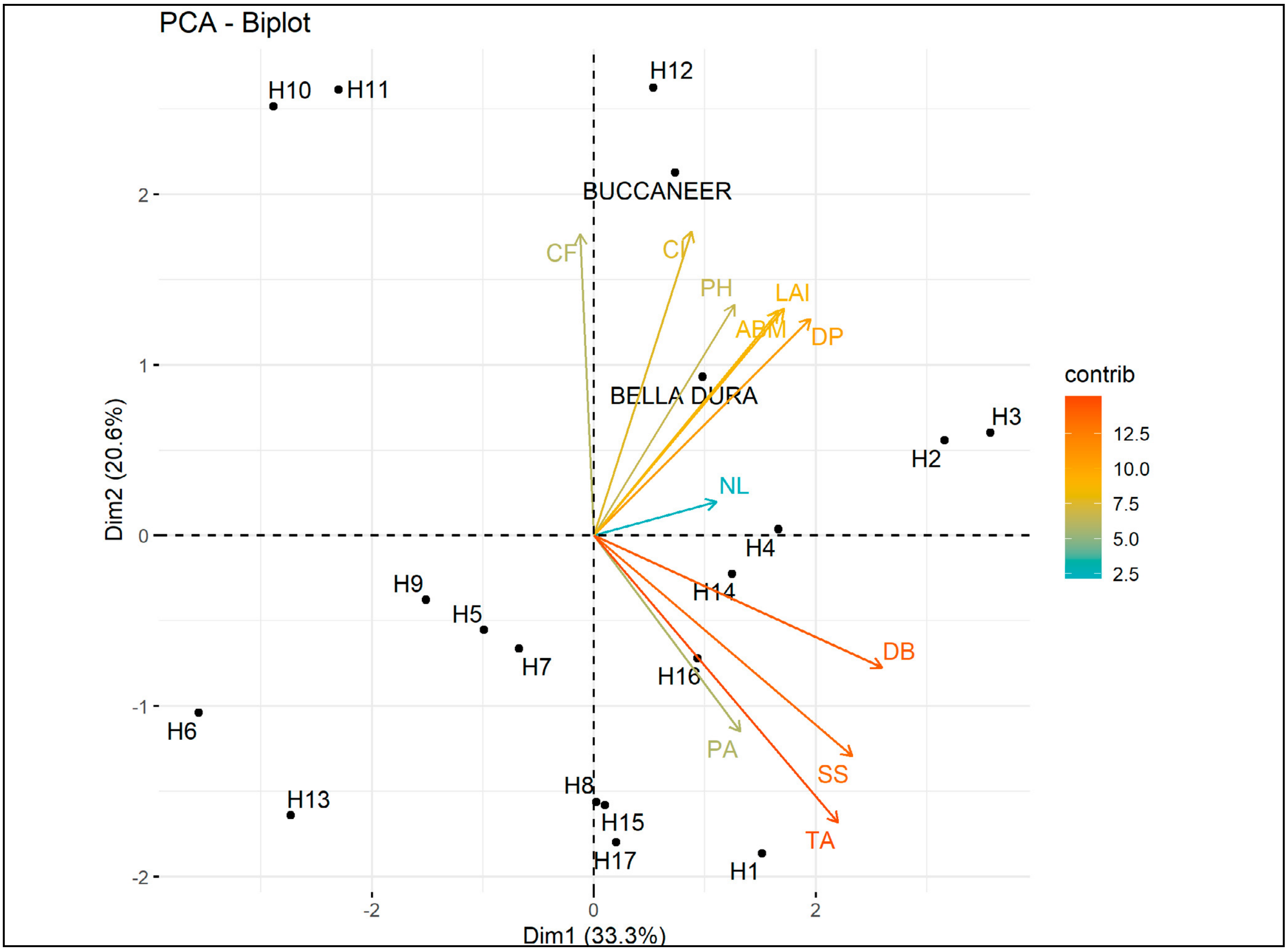

Figure 2. Analysis of principal components (PCA) of 19 onion genotypes (*Allium cepa*) evaluated for agronomic traits: PH = plant height in cm, NL = number of leaves, DP = haulm diameter in cm, LAI = leaf area in cm^2, CI = cycle from transplant to harvest in days, YIE = productivity of marketable bulbs in t ha^{-1} ABM = average mass of marketable bulbs in g; DB = percentage of dry mass, TA = titratable acidity, SS = soluble solid content (°Brix), PA = pyruvic acid content. Guarapuava, UNICENTRO, 2016.

critical photoperiod, and when the plant reaches this point, the photoassimilates accumulated in the shoot are sent to the bulb, where they are stored (Manfron *et al.*, 1992). The highest production per unit area and average bulb mass were obtained with the experimental hybrid H2 (65.98 t ha^{-1}, 119 g/bulb), differing from the other treatments, including the marketable controls (Table 2). Transplant season effect was noticed, showing that this season interferes in the onion bulb production, as it was reported by Quartiero *et al.* (2014) and Carline *et al.* (2017). Despite the productivity achieved in this study being relatively high, depending on the technological level adopted, these values are in agreement with those observed by May *et al.* (2007), who obtained yields of 71 t ha^{-1} and 64.8 t ha^{-1} with the hybrids Superex and Optima, respectively, and Baier *et al.* (2009) who obtained yields up to 92.20 t ha^{-1} with Buccaneer hybrid at high population density. The highest production of bulbs in season 1 is linked to the response of the genotypes to the climate conditions, in which variations were observed for each season during the cycle (Figure 1), variations in temperature and photoperiod. As the aim of this study was to identify promising genotypes for being grown under subtropical conditions, the results found in relation to higher yields in the first season highlight the genotypic constitution of the parents to better adapt to this condition. In addition, longer photoperiod and hotter temperature observed in the second season (Figure 1) explain the lower productivity observed.

In relation to average bulb mass, the results showed that the values obtained are in accordance with the ideal averages in order to meet consumer preference. Faria *et al.* (2012) observed average bulb mass, in experimental and marketable hybrids, ranging from 92.0 to 178.5 g/bulb. Resende *et al.* (2007) evaluated onion genotypes in Central-South region of Paraná and also observed values ranging from 52.13 and 159 g/bulb.

The highest percentage of plants showing early flowering was obtained in hybrids H12 (43.55), H10 (23.02), H11 (20.18) and H16 (20.49) and cultivar Bella Dura (19.0). The marketable hybrid Buccaneer (2.13) and the experimental hybrids H1 (1.41), H2

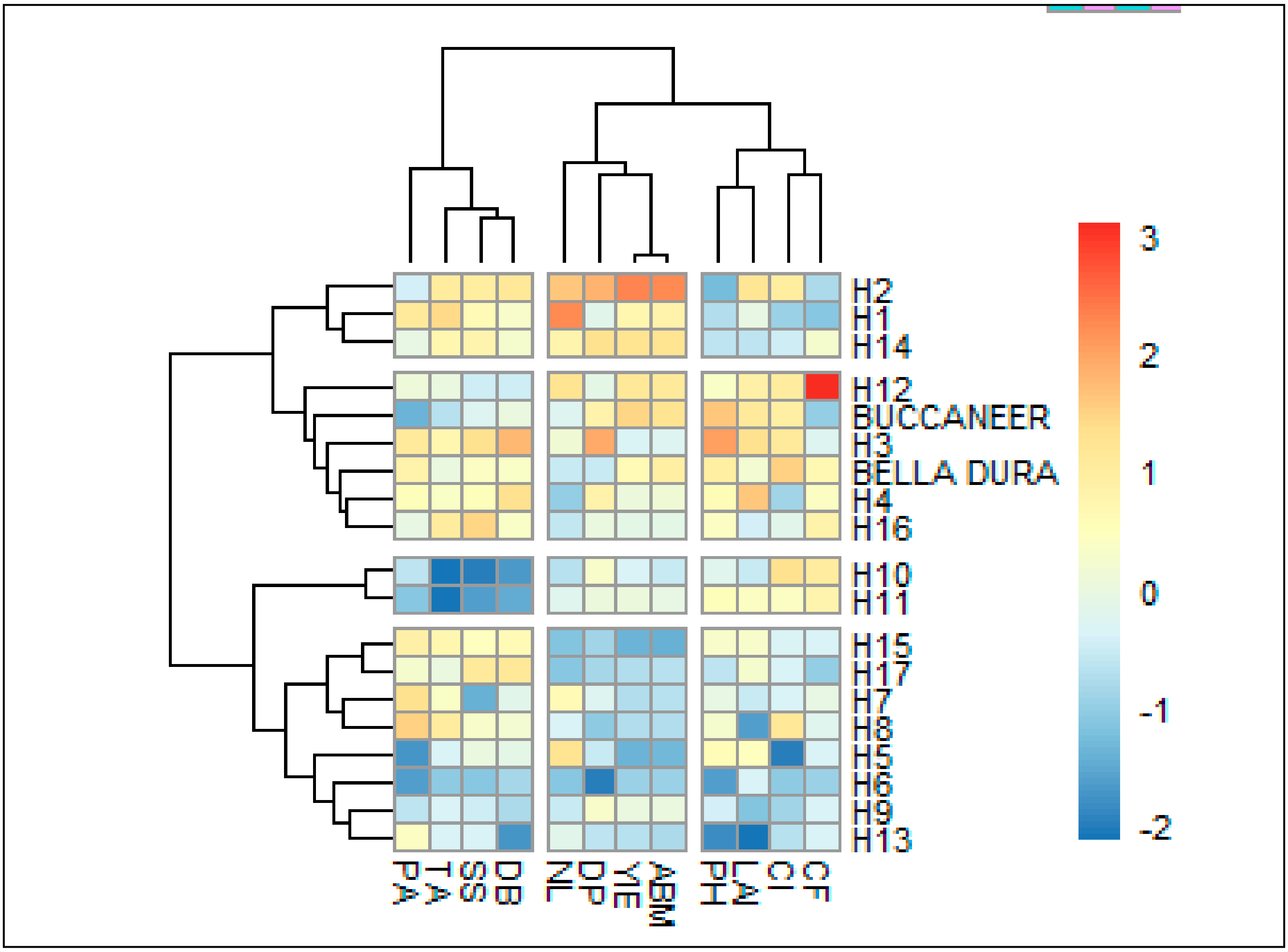

Figure 3. Dendrogram obtained using Ward's method of 19 onion genotypes (*Allium cepa*) evaluated for PH = plant height in cm, NL = number of leaves, DP = haulm diameter in cm, LAI = leaf area in cm^2, CI = cycle from transplant to harvest in days, CF = percentage of early flowering, YIE = productivity of marketable bulbs in t ha^{-1}, ABM = average mass of marketable bulbs in g, DB = percentage of dry mass, TA = titratable acidity, SS = soluble solids content (°Brix), PA = pyruvic acid content. Guarapuava, UNICENTRO, 2016.

(4.70), H6 (2.86) and H17 (2.58), showed the lowest percentages of early flowering (CF) (Table 1).

These results showed a genetic variability among the evaluated genotypes, suggesting expectations of selecting promising hybrids with higher flowering tolerance under low temperature conditions. Other studies in literature report genetic variability among onion genotypes concerning early flowering (Wamser *et al.*, 2012; Ncayiyana *et al.*, 2017). This percentage of flowering in the production field can be increase when favorable climatic conditions and nitrogen fertilization are associated, as reported for cultivar Bola Precoce (Menezes Júnior & Kurtz, 2016) and Mata Hari (Ncayiyana *et al.*, 2017). However, the temperature is the environmental factor which most influences in differing the vegetative and reproductive phase in onion and that temperatures below 13˚C promote early flowering (Khokhar, 2009). From transplant until harvest, the authors observed that 65.35% of the days presented minimum temperatures below 13°C (Figure 1), which predisposes the ideal condition for the evaluated genotypes, especially the most sensitive ones, express their genetic potential for early flowering. Although the long photoperiod has no effect on the onset of flowering, it accelerates inflorescence development (Ami *et al.*, 2013).

For physicochemical traits, percentage of dry mass (DB), titratable acidity (TA), soluble solids content (SS) (°Brix) and pyruvic acid content (PA), some differences were noticed among the treatments: the first season was better for the evaluated traits, except for pyruvic acid which did not change in seasons 1 and 2. Higher accumulation of dry mass in onion bulbs were obtained in genotypes H3 (10.67%), H8 (9.83%), H9 (10.96%), H11 (12.14%), H12 (10.37%) and H14 (9.88%), differing from the marketable controls. The highest accumulation of soluble solids was obtained in the bulbs of the hybrids H2 (9.87), H3 (10.30), H16 (10.57) and H17 (10.07), differing from the others, including the controls 'Bella Dura' and 'Buccaneer' which accumulated 9.7 and 8.18ºBrix, respectively (Table 2).

Higher titratable acidity was determined in the bulbs of the experimental hybrids H1 (0.31), H2 (0.30), H3 (0.29), H4 (0.28), H7 (0.28), H8 (0.30), H12 (0.27), H14 (0.29), H15 (0.29), H16 (0.30), H17 (0.27) and control 'Bella Dura'. Pyruvic acid, which mediates bulb pungency, was obtained at higher rates in hybrids H1 (6.40), H3 (6.40), H4 (6.09), H7 (6.50), H8 (6.62), H12 (5.87), H13 (6.05), H14 (5.80), H15 (6.30), H16 (5.80), H17 (5.95) and control 'Bella Dura' (6.27). However, when it comes to classify pungency levels, all genotypes were classified as medium pungency, with pyruvic acid contents above 3 μmol g^{-1} and below 7 μmol g^{-1} (Dhumal *et al.*, 2007).

The content of pyruvic acid (TA), PA and DB showed a significant effect only for genotype, thus, the averages were analyzed individually for each sowing season, which indicates the behavior of the hybrids. Chemical traits were not influenced by the transplant season. The difference among the genotypes, showed a genetic variability for this trait and the possibility of selecting genotypes with high and low pyruvic acid content, being able to allocate production according to the market demand. Other studies reported equivalent results (Muniz *et al.*, 2012).

Multivariate analysis

Ward clustering and principal component analysis (PCA) of the agronomic and physicochemical traits evaluated in this study are presented in Figures 2 and 3. The dendrogram separated the genotypes into four groups. Group 1 was formed by the experimental hybrids H1, H2 and H14; group 2 was formed by the marketable controls and hybrids H12, H3, H4 and H16, group 3 by the genotypes H10 and H11; the last group was formed by H15, H17, H8, H5, H6, H9 and H13.

The two first main components explained 53.9% of the variation observed between the treatments for the evaluated traits. PCA biplot (Figure 2) allowed to infer that the experimental hybrids H16, H14, H1, H17 and H15 stood out, as they presented better post-harvest parameters (PA, TA, SS and DB), whereas the hybrids H3, H12, H2 and the marketable controls 'Buccaneer' and 'Bella Dura', stood out for presenting higher values for biometric traits (LAI, NL and DP), agronomic traits (YIE and ABM), earliness (CI) and flowering (CF). Post-harvest traits showed positive correlations among each other, in which, dry mass, soluble solids, pyruvic acid and titratable acidity are correlated (Figure 2). Production and biometric traits are also correlated among each other.

In general, the results were similar to the ones observed in the dendrogram, since a significant difference was noticed among the formed groups, as well as for the average tests. The results obtained using PCA showed correlations among the agronomic and biochemical traits. Higher productivity and average bulb mass are associated with greater leaf area and number of leaves, which is related to a higher photosynthetic rate and greater accumulation of photoassimilates, providing greater reserve in the bulb; as the soluble solid content (SS) is directly associated to dry mass and pyruvic acid contents. Typically, bulbs with higher dry mass and pyruvic acid content provide longer shelf life and storage (Chope *et al.*, 2006).

Onion productivity is affected by temperature and photoperiod which limits the recommendation for growing the same cultivar in different locations with a wide range of latitude. In order to obtain a successful cultivation of onions, a combination between temperature and photoperiod is essential, otherwise, we may verify productivity losses (Menezes Júnior & Vieira Neto, 2012). Therefore, breeders shall be careful when selecting the best genotypes to be grown under climatic conditions of the producing regions. Most companies which improve and sell seeds have their programs centered in countries with a climate different from the Brazilian regions of production. Thus, the genotypes shall be evaluated, taking into account the characteristics of each growing site. In this study, a significant effect of the environment was verified for almost all the evaluated traits, highlighting that onion hybrid cultivation is affected by climatic factors, as reported in studies already mentioned.

The tested genotypes presented good productive yield and bulbs with excellent commercial standard, being superior for some traits to the marketable genotypes used as control. Some hybrids stood out for presenting a reduction in the growing cycle and, mainly, with less emission of floral tassel, when submitted to a cultivation under low temperatures, showing release potential for these regions.

Onion transplant season affects agronomic traits significantly, physicochemical traits are less affected, though. Planting season did not influence early flowering, however the genotypes responded to this trait differently: less flowering for some experimental hybrids and the hybrid Buccaneer. Of the 17 evaluated experimental hybrids, H1, H2 and H14 stood out for showing an excellent productive potential, bulb quality and greater resistance to early flowering when growing under subtropical regions.

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