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Research Article

Analysis of agronomic and chemical-nutritional variability of fruits in Amazon germplasm of *Capsicum chinense*

Santina R. SANTANA[1]*, Derly J. H. da SILVA[2], Leonardo L. BHERING[3], Ronaldo S. GOMES[2], Renato D. S. ROSADO[2], Paula C. C. LIMA[2]

[1]*Federal University of Rondônia, Fishery Engineering Department, Presidente Médici, RO, Brazil; santina@unir.br (*corresponding author)*
[2]*Federal University of Viçosa, Department of Agronomy, Viçosa, MG, Brazil; derly@ufv.br; ronaldo.s.gomes@ufv.br; renato.rosado@ufv.br; Paula.c.lima@ufv.br*
[3]*Federal University of Viçosa, Department of General Biology, Viçosa, MG, Brazil; leonardo.bhering@ufv.br*

Abstract

Fruits of *Capsicum chinense*, a native species of Amazon Basin, express high levels of bioactive components such as vitamin C and carotenoids; some of them with pronounced pro-vitamin A activity such as *β*-carotene, which confers high economic potential to this species. The characterization of *C. chinense* germplasm helps in its management and conservation. Therefore, this practice is considered crucial for the identification of genotypes with superior characteristics, especially in relation to agronomic aspects and chemical-nutritional characteristics of fruits. This study aimed to characterize 55 *C. chinense* accessions collected from the Brazilian Amazon in terms of their agronomic and chemical-nutritional descriptors aiming to identify superior genotypes for these traits. The characterization was performed in a completely randomized design with 5 replications in non-heated environment. There was significant difference for all descriptors, confirming the variability among accessions. High heritability estimates for descriptors, such as fruit yield (95.1%) and vitamin C content of fruit (92.4%), was found to be associated with high CVg/CVe ratios of these traits, indicating a favorable condition for the selection of superior genotypes for these characteristics. A considerable part of the accessions expressed averages higher than the checks, notably for the fruit yield and the content of vitamin C. The cluster analysis resulted in the formation of 11 groups, corroborating the high variability of accessions for the agronomic and chemical-nutritional aspects of fruits. The evaluated *C. chinense* germplasm thus expressed high fruit yield and vitamin C content in the fruits, which makes it a promising source for the selection of superior genotypes.

Keywords: characterization; conservation; pepper; breeding; vitamin C

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Introduction

Capsicum spp. peppers belong to the Solanaceae family, and they are much appreciated vegetables worldwide (Rodrigues *et al.*, 2016). According to FAOSTAT (2018), the countries with greater production of capsicum peppers in the world in 2016 included Vietnam (216,432 t), Indonesia (82,167 t), India (55,000 t), Brazil (54,425 t), and Sri Lanka (28,901 t). In Brazil, pepper cultivation is performed in all regions, and the states with the highest production include Minas Gerais, Goiás, Sao Paulo, Ceará, and Rio Grande do Sul (Carvalho *et al.*, 2006). The most appreciated peppers in Brazil are the *C. frutescens*, *C. baccatum*, and the varieties of *C. chinense* (such as the well-known 'Biquinho') (Rufino and Penteado, 2006).

Peppers are one of the most important spices in the world, owing to their intrinsic characteristics such as the aroma and color, in addition to being a source of minerals and vitamins such as vitamins A, C, and (Bosland and Votava, 2000). They are considered as a functional food regarding to their antioxidant properties (Pinto *et al.*, 2013). In food industry, these peppers are used to preparing condiments, sauces, powder products, paprika, vinegar tanning, jellies, and for canning (Chunab e*t al.*, 2011; Pinto *et al.*, 2013; Jäger and Amaya, 2013).

Capsicum chinense, which is native to the Brazilian Amazon, is considered to be the most Brazilian of all species within this genus (Reifschneider, 2000). It expresses great variability in the diversity of its shapes and colors of fruits, which are also very spicy and aromatic (Carvalho *et al.*, 2006); these properties favor the selection of promising parents for breeding programs of the species. The consumption, cultivation, and the conservation of this species in the Amazon region is mainly practiced by the traditional communities such as indigenous, riverside, and small farmers, who have been traditionally trading the fruits of this species in the local markets either in the fresh state or in the form of artisanal preserves.

The characterization study is of great importance as it provides wide information about the germplasm for application in plant breeding programs. According to Burle and Oliveira (2010), it is an essential activity in the management of germplasm collections and involves collecting data to describe, identify, and differentiate accessions. This activity is performed based on the qualitative and quantitative observations of several differentiable characters, such as the morphological descriptors.

The use of multivariate statistical procedures in germplasm characterization studies is important because one can then consider the correlations among the characters, which in turn allows identifying the sources of genetic variability and the importance of each evaluated character in relation to the total genetic divergence (Moura *et al.*, 1999). This strategy is also important to identify promising parents, targeting the attainment of hybrids with higher heterotic vigor (Cruz *et al.*, 2012).

This work had as objectives: a) to characterize 55 accessions of *C. chinense* from the Brazilian Amazon regarding the agronomic characteristics and chemical-nutritional aspects of the fruits, in order to identify promising accessions for these characteristics for use in a breeding program and b) analyze the variability of accessions.

Materials and Methods

Germplasm and origin off collect

We evaluated 55 *C. chinense* accessions (Table 1), collected from the local markets and vegetable gardens from 9 cities of the state of Rondônia which belongs to Brazilian-legal Amazon area. Two of these genotypes are commercially grown and comprise of the varieties 'Biquinho vermelho' and 'Biquinho amarelo'. The collected genotypes were identified with their passport data and introduced in the collection of *C. chinense* maintained by the Vegetable Germplasm Bank of UFV, (BGH-UFV).

The state of Rondônia occupies an area of 237 590, 547 km^2 and is located in the Legal Amazon of the northern Brazil (Figure 1). The prevailing climate in this state throughout the year is humid and warm tropical.

According to the Köppen climate classification (1948), Rondônia has an Aw-Tropical Rainy Climate, with average temperatures of >18 °C in the coldest month and a well-defined dry season during the winters. The annual temperature in the state varies between 25 °C to 27 °C, while the maximum temperatures vary between 31 °C to 35 °C, and the minimum temperature between 17 °C to 23 °C (Arruda, 2012). The typical vegetation in the state of Rondônia consists of the Amazon rainforest with some savanna patches.

Table 1. The origin of *C. chinense* genotypes collected and introduced at BGH-UFV, Viçosa, 2019

Accessions	Place of collect	Coordinates	Accessions	Place of collect	Coordinates
BGH 8287	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8322	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8288	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8324	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8290	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8325	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8291	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8326	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8292	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8327	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8293	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8328	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8296	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8329	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O
BGH 8297	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8330	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O
BGH 8298	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8333	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O
BGH 8299	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8338	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8300	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8339	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O
BGH 8301	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8289	Cacoal	11° 26' 46.38" S 61° 26' 53.35" O
BGH 8302	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8314	São Fco do Guaporé	12° 03' 57.14" S 63° 34' 10.48" O
BGH 8303	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8335	Novo Horizonte D'Oeste	11° 43' 28.60" S 62° 02' 32.02" O
BGH 8304	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8336	Novo Horizonte D'Oeste	11° 43' 28.60" S 62° 02' 32.02" O
BGH 8305	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8295	Novo Horizonte D'Oeste	11° 43' 28.60" S 62° 02' 32.02" O
BGH 8306	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8315	Novo Horizonte D'Oeste	11° 43' 26.71" S 61° 59' 55.04" O
BGH 8307	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8316	Novo Horizonte D'Oeste	11° 43' 26.71" S 61° 59' 55.04" O
BGH 8308	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8317	Novo Horizonte D'Oeste	11° 43' 26.71" S 61° 59' 55.04" O
BGH 8309	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8294	Novo Horizonte D'Oeste	11° 43' 28.60" S 62° 02' 32.02" O
BGH 8310	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8295	Novo Horizonte D'Oeste	11° 43' 28.60" S 62° 02' 32.02" O
BGH 8311	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8318	Rolim de Moura	11° 43' 39.95" S 61° 47' 47.38" O
BGH 8312	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8323	Feira- Presidente Médici	11° 10' 5.96" S 61° 54' 14.23" O
BGH 8313	Feira-Cacoal	11° 25' 59.71" S 61° 27' 50.97" O	BGH 8331	Feira- Pimenta Bueno	11° 41' 07.78" S 61° 10' 07.93" O
BGH 8319	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8332	Feira- Ji-Paraná	10° 52' 37.38" S 61° 57' 07.47" O
BGH 8320	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8334	Mercado- Porto Velho	8° 45' 54.14" S 63° 54' 34.30" O
BGH 8321	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8337	Mercado- Porto Velho	8° 45' 54.14" S 63° 54' 34.30" O
BGH 8340	Feira-Cacoal	11° 26' 27.20" S 61° 26' 41.03" O	BGH 8341	Presidente Médici	11° 18' 15.87" S 61° 46' 59.54" O

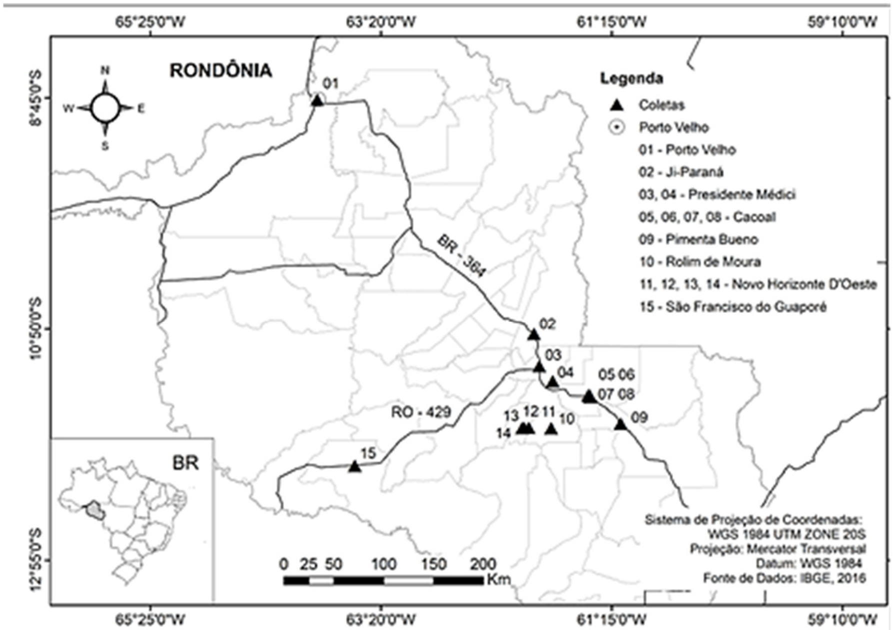

Figure 1. The location of the state of Rondônia in northern Brazil (left); cities of the state where the *C. chinense* genotypes were collected

Experimental design and characteristics evaluated

The seeds of the genotypes were obtained from the samples of fully ripe fruits weighing 250-500 g of fruits. After extraction of the seed samples, they were subjected to drying, identification, and storage at 4 °C until sowing.

The experiment was grown between July 2017 and September 2018 at the Experimental Unit "Horta Velha", in the Department of Plant Science, Federal University of Viçosa, Viçosa-MG (latitude: 20°45'S, longitude: 42°54'W; elevation: 648 m).

The seedlings were produced in a 128-cell polyethylene tray filled with a commercial substrate, which were transplanted to pots after 60 days, where they remained in a protected environment thereafter.

The experimental design used to evaluate the germplasm was completely randomized and as per the following statistical model:

$$Yij = Ti + \mu + \varepsilon ij$$

Where,

Yij corresponds to the observed value for a variable under study regarding the *i*th treatment in the ith repetition;

T_i corresponds to the effect of the ith treatment, which is considered as a random effect;

μ corresponds to the general average and;

ε_{ij} corresponds to the effect of the random error associated with the observation of order ij.

Each treatment consisted of 5 repetitions; each plot consisted of a plant kept in a 10-l pot with soil.

For the characterization and evaluation of the accessions, we used 26 descriptors, as recommended by the IPGRI (1995) in the current Biodiversity International. The descriptors comprised the following agronomic and chemical-nutritional descriptors:

<u>Agronomic</u>

Plant height (PH cm); canopy diameter (CD, cm); leaf length (LL, cm); leaf width (LW, cm); number of flowers per axilla (NFA); corolla length (CL, mm); anther length (AL, mm); fruit length and diameter (FL and FD, mm); fruit peduncle length (FPL, mm); pericarp thickness (PT, mm); number of fruit locules (NFL);

number of seeds per fruit (NSF); weight of 1000 seeds (WTS, g); total fruit production (TFP, g); number of fruits per plant (NFP).

Chemical-nutritional

The color determination of ripe fruits, performed at the commercial harvesting point, was performed using the Color Reader CR-10 Konica Minolta colorimeter. The results were interpreted by the CIELAB System using the coordinates L*, a*, and b*. From the mean values of a* and b*, we calculated, according to the following equations, the estimates of saturation (Chroma, C*) and angle Hue (chromatic h*) (Itle and Kabelka, 2009):

$C^* = \sqrt{a^{*2}+b^{*2}}$

$H\text{ue} = tan-1(b^*/a^*)$

Nutritional-chemical analyzes were performed from ripe fruit samples. For titratable acidity (TA) analysis, 5 g of ground fruit pulp was added to a 100-ml-volumetric flask containing distilled water, and 10 ml of this solution was pipetted into an Erlenmeyer flask, to which 2 drops of 1% phenolphthalein were added. The mixture was titrated with 0.005 mol NaOH l^{-1}, according to the Adolfo Lutz Institute (2008), and the results were expressed as % citric acid.

The pH was determined through direct reading using a digital pedometer (DIGIMED model DM 22) previously calibrated with pH-6.86 buffer solutions and then with a pH-4.01 buffer solution at 25 ^{O}C. For this analysis, we used 200 g of the ground fruit pulp.

The analysis of soluble solids (°Brix) was performed using a sample of fruit juice obtained via maceration. This sample was placed on the luminous surface of a digital refractometer for reading, and the values were expressed in Brix degree. The estimation of the ratio was obtained from the relationship between soluble solids values and titratable acidity (SS/TA) according to the Adolfo Lutz Institute Analytical Standards (2008), and the results were expressed in absolute numbers.

For the analysis of vitamin C (CV) content, samples of 1 g seedless fruits were weighed on a 1200-g analytical balance with 0.1-g precision (Bel Engineering M1003). These samples were subsequently triturated in 20 ml of 1% oxalic acid (Sigma-Aldrich Missouri USA) using polytron until complete homogenization. For the quantification, 1 ml of the sample was added to an Erlenmeyer flask containing 25 ml of 1% oxalic acid. Ascorbic acid content was determined using the modified Tillmans method by titrating 2,6-dichlorophenolindophenol sodium (DFI; 0.02%; Sigma-Aldrich, Missouri, USA) (AOAC, 2012). For titration, L-ascorbic acid PA (Sigma-Aldrich Missouri, USA) was used as the standard, and the results of vitamin C contents (expressed in mg ascorbic acid 100 g^{-1} sample) according to the formula proposed by the Ministry of Agriculture Livestock and Supply (MAPA, 2013).

Statistical analysis

For data analysis, a univariate analysis was initially performed to obtain the estimate and significance of the mean squares of the evaluated characteristics as well as to obtain the genetic-statistical parameters of the same characteristics. For the mean test, we adopted the Dunnet test at 5% probability, aiming at comparing the means of accessions with the checks.

Genetic diversity among the accessions was analyzed by Unweighted Pair-group Method Using Arithmetic Averages (UPGMA) based on the generalized distance of Mahalanobis, as presented by Cruz *et al.* (2011).

The ideal number of groups formed in the UPGMA hierarchical method was determined according to the Mojena's criterion (Mojena, 1977). This procedure is based on the relative size of merger levels in the dendogram, which is used to select the number of groups in stage j that first satisfies the following inequality: $\alpha j > \theta k$, where αj is the value of distances from the fusion levels corresponding to stage j (j = 1, 2, ..., n) and θk is the cut off reference value, expressed as $\theta k = \alpha\hat{} + k\sigma\hat{}\alpha$, where α and $\alpha\sigma\hat{}\alpha$ are, respectively, non-biased estimates of the mean and standard deviation of α values and k is a constant. For the definition of the number of groups to be formed, the cutoff point based on the criterion k = 1.0 was used according to the methodology of Milligan and Cooper (1985).

To verify the fit between the dissimilarity matrix and the dendogram, the cofenetic correlation coefficient (CCC) was obtained. Singh's method (1981) was used to evaluate the relative importance of the descriptors in relation to genetic divergence among the studied accessions. Statistical analyzes and diversity studies were performed using the Genes software (Cruz, 2013).

Results

Mean squares, means, and genetic-statistical parameters

In this study, we will highlight only the descriptors of greater agronomic and nutritional importance. The estimates for the mean squares of the evaluated characteristics ranged from 985.08 to 0.01 for the characteristics number of fruits per plant and titratable acidity of the fruit pulp, respectively (Table 2). The results obtained through analysis of variance (ANOVA) also revealed, through the F test, a significant difference for all the descriptors (Table 2).

The results obtained in this study showed a wide variation in the average evaluated characteristics, especially for the production (PF) and number of fruits (NFP), as well as for the vitamin C (VC) content of the fruit pulp (Table 2). The average for TFP ranged from 69.45 to 1.275.27g for BGH-8339 and BGH-8319 accessions, respectively, with an overall average of 629.9 g. The overall average for NFP was 308.2, and the highest average for this treat corresponded to BGH-8290 access (721.00) and the lowest to BGH8296 access (97.00). The overall mean for the fruit pulp vitamin C content was 1107.41 mg/100 g and the averages for this trait ranged from 734.37 mg/100 g for BGH8335to 1509.81 mg/100 g for BGH-8328.

The average for plant height (PH), was 81.2 cm, and the lowest mean for this trait corresponded to the BGH-8318 (53.6 cm) and the highest to the BGH-8310 (124.2 cm). The descriptors length, diameter, and thickness of the fruit also expressed variation, especially the first one, ranging from 7.8 (BGH-8318) to 85.4 mm (BGH-8331). The averages for the descriptor (Cra *), corresponding to the contribution of red in fruit color, ranged from 7.8 (BGH-8288) to 59.7 (BGH-8325), and the overall mean for this trait was 43.5. The chemical descriptors of soluble solid of fruit pulp (SS), pH, titratable acidity (TA), and the soluble solids/titratable acidity ratio (SS/TA) expressed variation, especially SS, which ranged from 5.7 to 13, 8 for accessions BGH-8312 and BGH-8311, respectively (Table 2).

The evaluated characteristics expressed different estimates of phenotypic variance, and the highest estimates for this parameter corresponded to the descriptors PF, VC, and NFP. The lowest phenotypic variances corresponded to the chemical descriptors of fruits TA, pH, SS/AT, and SS. The heritability estimates ranged from 21.6 to 98.6 for the SS/AT and CF descriptors, respectively. These estimates were considered high (>70.0) for all descriptors, except for pH (55.8) and SS/TA (21.6) (Table 2).

Regarding the coefficient of genetic variation (CVg %), the descriptors DF (64.8) and FL (63.9) expressed the highest values for this parameter. The CVg/CVe ratio was >1 unit for all descriptors, except for pH. As observed in Table 2, most of the descriptors had low coefficients of variation, and slightly higher values for this parameter were observed only for FD, PF, and NFP.

Table 2. Summary of analysis of variance and genetic-statistical parameters for the 13 agronomic descriptors and chemical-nutritional aspects of fruits used to characterize *C. chinense* germplasm from the Amazon region. UFV, Viçosa, 2019

Mean squares													
VF	**PH**	**CD**	**FL**	**FD**	**PT**	**PF**	**NFP**	**Cra***	**VC**	**SS**	**pH**	**TA**	**SS/TA**
Genotypes	927.0**	504.0**	1.7**	179.3**	0.74**	361.3**	985.08**	905.0**	117.1**	9.3**	0.1*	0,01*	3.7**
Parameters													
Range	53,0 - 124,2	35,33- 97,75	7,8- 85,4	7,1- 32,5	0.8- 2,6	69.4- 1.275,2	97- 721	7,8- 59,7	734,3- 1.509,8	5,7- 13,8	4,6- 5,3	0,1- 0,3	38,02- 99,27
M	81.2	72.8	31.0	15.9	1.7	629.9	308.2	43.5	1107	9,3	4.9	0.2	60.6
σ_p	217.1	15.9	403.5	28.6	0.2	84646.5	23080.1	212.1	27444.3	2.2	0.03	0.00	0.9
h^2	92.6	86.5	98.6	90.3	90.4	95.1	95.9	95.5	92.4	93.1	55.8	94.6	91.6
CVg %	17.3	13.8	63.9	64.8	22.8	44.9	48.7	32.2	14.4	15.4	2.6	28.07	24.7
CVg/CVe	1.7	1.2	4.1	1.5	1.5	2.1	2.3	2.2	1.7	1.8	0.5	2.03	1.6
CV (%)	10.2	11.3	15.8	44.3	15.3	21.0	20.6	14.7	8.5	8.7	4.8	13.8	6.8

VF: variation factor; PH: plant height (cm); CD: canopy diameter (cm); FL: fruit Length (mm); FD: fruit diameter (mm); PT: pericarp thickness (mm); PF: total production of fruits production; NFP: number of fruits per plant; Colorimetric parameter Cra *: contribution of red; VC: vitamin C; SS: soluble solids; pH: hydrogen potential; TA: titratable acidity and SS/AT: ration between soluble solid and titratable acidity. µ: overall mean; σ_p: phenotypic variance h^2: heritability; CVg%: genotypic coefficient of variance; CVg/CVe: relation of the genotypic coefficient of variance and the environmental variance coefficient; CV (%): coefficient of variation. **, * Significant at 1 and 5% probability, respectively, by the F test.

Average test

By comparing the averages by Dunnett's test at 5% of probability (Table 3), it was found that the average of most accessions differed from the average of the checks (Table 3).

Table 3. Dunnett's mean test between the 53 accessions of *C. chinense* from the Amazon region and the 2 checks for agronomic descriptors and chemical-nutritional aspects of fruits. UFV, Viçosa, 2019

Treatments	PH	CD	FL	FD	PT EP	NFP	PF	Cra*	VC	SS	pH	TA	SS/TA
BGH 8287	63.0b	68.0ab	53.2	16.5ab	2.0ab	352.0ab	1191.0	24.2	1066.0ab	7.5ab	4.9ab	0.12ª	64.3ab
BGH 8288	112.0	63.0b	45.1	22.1	1.8ab	133.0	657.0ab	7.8	1113.0ab	7.1b	4.7ab	0.15ab	48.5ab
BGH 8289	68.0b	66.0ab	32.4a	16.6ab	1.8ab	323.0ab	849.0	42.8b	1264.0b	8.5ab	4.8ab	0.17ab	50.1ab
BGH 8290	70.0b	63.0b	12.9	9.5ab	1.1	721.0	387.0	59.4a	1200.0ab	9.5ab	5.0ab	0.22	42.9ab
BGH 8291	69.0b	59.0b	15.2b	15.1ab	1.5ab	312.0ab	404.0ab	51.1ab	1111.0ab	8.5ab	4.7ab	0.22	39.8ab
BGH 8292	62.0b	61.0b	23.1ab	13.4ab	1.3	356.0ab	309.0	58.8a	1260.0b	13.9	5.0ab	0.15ab	91.1
BGH 8293	70.0b	70.0ab	22.9ab	12.6ab	1.3	300.0ab	383.0ab	57.8a	1223.0b	10.9	5.1ab	0.11	95.0
BGH 8294	76.0a	71.0ab	54.6	17.6ab	2.0ab	232.0	1148.0	43.7b	888.0a	8.9ab	4.9ab	0.11	77.9
BGH 8295	82.0a	68.0ab	18.0ab	20.7a	2.7	225.0	741.0a	49.4ab	1214.0ab	8.0ab	5.0ab	0.12ª	67.4a
BGH 8296	64.0b	68.0ab	31.7a	32.6	1.9ab	97.0	1032.0ab	40.6b	1013.0ab	7.2b	5.0ab	0.13ab	52.4ab
BGH 8297	86.0a	73.0ab	14.9b	10.6ab	1.1	513.0b	395.0ab	20.7	1152.0ab	9.6a	5.0ab	0.12ab	67.2a
BGH 8298	87.0a	80.0a	39.8	19.8ab	1.9ab	183.0	749.0ab	49.2ab	1004.0ab	8.9ab	5.0ab	0.11	85.3
BGH 8299	85.0a	79.0a	63.6	21.8	1.8ab	185.0	865.0a	44.9ab	1063.0ab	8.7ab	5.0ab	0.11	69.5a
BGH 8300	83.0a	83.0a	36.1	25.5	1.8ab	190.0	1027.0	46.5ab	901.0a	6.5	4.7ab	0.15ab	43.1ab
BGH 8301	70.0b	79.0a	20.2ab	14.2ab	2.0ab	408.0ab	680.0ab	54.0a	900.0a	8.4ab	4.7ab	0.22	38.8b
BGH 8302	78.0a	75.0ab	21.0ab	17.4ab	2.4	357.0ab	773.0ab	19.7	1084.0ab	9.4ab	4.9ab	0.13ab	71.2a
BGH 8303	77.0a	68.0ab	11.5	10.4ab	1.7ab	440.0ab	278.0	55.0a	839.0	9.9a	4.7ab	0.24	40.0ab
BGH 8304	85.0a	81.0a	14.2b	11.6ab	1.3b	665.0	610.0ab	52.7a	1049.0ab	9.6a	4.6ab	0.19ab	50.1ab
BGH 8305	78.0a	75.0ab	8.8	7.8ab	2.1ab	376.0ab	267.0	57.2a	1089.0ab	9.5ab	4.7ab	0.23	40.6ab
BGH 8306	99.0a	81.0a	10.3	9.0ab	1.8ab	466.0ab	309.0	59.7a	987.0ab	10.8	4.8ab	0.2ab	54.0ab
BGH 8307	77.0a	76.0ab	18.7ab	13.0ab	1.9ab	344.0ab	313.0	54.8a	1162.0ab	9.6ab	4.7ab	0.17ab	55.6ab
BGH 8308	72.0a	72.0ab	36.0	24.4	1.8ab	113.0	563.0ab	43.7b	1113.0ab	7.5ab	4.7ab	0.16ab	49.2ab
BGH 8309	79.0a	49.0b	15.8b	10.8ab	1.4b	353.0ab	315.0	54.4a	1219.0b	10.2a	5.2b	0.17ab	58.2ab

BGH 8310	124.0	75.0ab	14.9b	14.3ab	1.7ab	344.0ab	365.0b	44.8ab	1154.0ab	11.0	4.8ab	0.15ab	72.3a
BGH 8311	91.0a	65.0ab	18.8ab	18.2ab	1.4b	343.0ab	582.0ab	40.1b	1225.0b	1.3	4.7ab	0.14ab	94.9
BGH 8312	83.0a	70.0ab	12.1	12.2ab	1.4b	476.0ab	503.0ab	53.9a	1371.0	5.8	4.8ab	0.11	49.0ab
BGH 8313	81.0a	68.0ab	11.8	10.9ab	1.6ab	414.0ab	328.0b	59.5a	1338.0	10.1a	5.0ab	0.24	46.7ab
BGH 8314	76.0a	65.0b	66.0	24.9	1.6ab	136.0	1217.0	21.6	1213.0ab	7.7ab	4.9ab	0.12[a]	61.8ab
BGH 8315	89.0a	68.0ab	26.0ab	15.6ab	2.5	243.0	708.0ab	50.3ab	1305.0	9.7a	5.1ab	0.14ab	67.2a
BGH 8316	75.0a	73.0ab	40.1	16.3ab	1.8ab	122.0	340.0b	54.3a	1137.0ab	11.2	4.8ab	0.20b	56.4ab
BGH 8317	82.0a	71.0ab	22.3ab	14.7ab	2.4a	140.0	334.0	58.2a	994.0	9.7	5.0ab	0.24	40.1
BGH 8318	54.0b	48.0b	7.9	8.4ab	13.0b	485.0ab	361.0b	59.7a	1205.0ab	10.6	4.7ab	0.26	40.2a
BGH 8319	81.0a	89.0a	40.1	26.3	2.2ab	184.0	1275.0	45.9ab	962.0ab	8.2ab	4.8ab	0.16ab	50.2ab
BGH 8320	88.0a	81.0a	30.4ab	15.7ab	1.6ab	241.0	642.0ab	49.5ab	1119.0ab	11.6	4.8ab	0.15ab	76.9
BGH 8321	80.0a	72.0ab	54.6	13.9ab	1.6ab	190.0	744.0ab	49.5ab	1117.0ab	11.0	5.0ab	0.14[a]	89.1
BGH 8322	86.0a	73.0ab	65.1	15.5ab	1.6ab	160.0	690.0ab	25.8	1341.0	10.6	5.1ab	0.12[a]	79.9
BGH 8323	103.0	89.0a	15.6b	16.1ab	1.3b	361.0ab	426.0ab	15.3	783.0	9.8a	4.9ab	0.17[a]	57.9ab
BGH 8324	77.0a	70.0ab	8.4	9.8ab	1.4b	541.0	244.0	38.5b	1205.0ab	12.3	4.7ab	0.32	38.3b
BGH 8325	68.0b	70.0ab	20.3ab	12.2ab	1.1	413.0ab	388.0ab	59.8a	875.0a	9.9a	4.9ab	0.19ab	52.8ab
BGH 8326	119.0	92.0a	34.2a	17.3ab	1.5ab	254.0	549.0ab	41.1b	1147.0ab	9.1ab	4.9ab	0.17ab	52.5ab
BGH 8327	103.0	94.0a	19.1ab	15.6ab	2.4a	285.0ab	798.0ab	48.2ab	1328.0	8.6ab	5.0ab	0.15ab	57.6ab
BGH 8328	84.0a	81.0a	16.0b	14.8ab	1.9ab	180.0	351.0b	44.3ab	1510.0	10.9	5.0ab	0.11	100.0
BGH 8329	70.0b	91.0a	33.8a	21.7a	2.5	329.0ab	1142.0	46.6ab	969.0ab	8.4ab	4.7ab	0.13ab	64.9a
BGH 8330	70.0b	86.0a	38.8	7.2ab	0.8	618.0	718.0ab	14.5	1200.0ab	9.3ab	5.3ab	0.14ab	66.4a
BGH 8331	88.0a	73.0ab	85.5	13.2ab	1.6ab	163.0	635.0ab	56.3a	1199.0ab	9.7[a]	5.0ab	0.12[a]	79.5
BGH 8332	95.0a	76.0ab	64.6	17.6ab	2.2ab	115.0	785.0ab	51.2ab	1143.0ab	9.0ab	5.0ab	0.13[a]	69.4a
BGH 8333	84.0a	75.0ab	49.8	18.3ab	1.8ab	209.0	853.0a	34.3b	956.0ab	8.4ab	4.8ab	0.12[a]	67.0a
BGH 8334	53.0b	63.0b	13.8b	12.3ab	1.4b	594.0	431.0ab	55.5a	1023.0ab	8.0ab	5.1ab	0.13ab	60.4ab
BGH 8335	101.0a	73.0ab	12.5	14.2ab	1.8ab	335.0ab	384.0ab	56.2a	734.0	8.9ab	5.1ab	0.15ab	56.9ab
BGH 8336	112.0	98.0	18.2ab	19.5ab	2.1ab	369.0ab	885.0	29.5b	844.0	8.1ab	4.8ab	0.14ab	58.1ab
BGH 8337	72.0a	81.0a	78.6	13.7ab	1.9ab	160.0	653.0ab	13.0	1331.0	8.7ab	4.5ab	0.15ab	56.3ab
BGH 8338	74.0a	35.0	16.8b	11.1ab	1.3	370.0ab	334.0b	56.6a	1119.0ab	10.7	5.1ab	0.19ab	55.6ab
BGH 8339	110.0	63.0b	17.6ab	9.1ab	1.0	186.0	69.0	41.3b	1312.0	11.6	5.0ab	0.16ab	63.7ab
Checks													
BGH 8340	87.0a	80.0a	26.0a	15.4a	1.9a	378.0a	627.0a	56.1a	1041.0a	9.0a	4.7a	0.16[a]	56.3[a]
BGH 8341	55.0b	62.0b	22.2b	13.4b	1.8b	416.0b	569.0b	39.8b	1112.0b	8.1b	4.9b	0.17b	47.3b

PH: plant height (cm); CD: canopy diameter (cm); FL: fruit Length (mm); FD: fruit diameter (mm); PT: pericarp thickness (mm); NFP: number of fruits per plant; PF: total production of fruits production; Cra *colorimetric parameter: contribution of red; VC: vitamin C; SS: soluble solids; pH: hydrogen potential; TA: titratable acidity and SS/AT: ration between soluble solid and titratable acidity. The averages followed by the same letters of the checks in the column do not differ from these at the 5% probability level

For the PH descriptor, 33 of the 53 accessions did not differ from the check BGH 8340 (commercially named as 'Biquinho vermelho') (87.0 cm), and 13 accessions did not differ from the other check BGH 8341 (commercially named as 'Biquinho amarelo') (55.0 cm). The accessions BGH-8288, BGH-8310, BGH-8323, BGH-8326, BGH-8327, BGH-8336, and BGH-8339 expressed the highest PHs, averaging higher than the both checks. For the descriptor canopy diameter (CD), most of the accessions did not differ from the checks, except for BGH-8336 (98.0 cm) accession, which was higher than the 2 checks, and for the BGH-8338 accession (35, 0 cm) with a lower average than that of the checks (Table 3).

Regarding the FL (Fruit Length) descriptor, 14 accessions did not differ from the average of both the checks, which expressed an average of 24.1 mm. On the other hand, 17 accessions expressed averages higher than the check of highest average, 'Biquinho vermelho' (26.0 mm). Regarding the FD descriptor, most of the accessions (n = 43), did not differ from both the checks that expressed a mean DF of 14.4 mm, while only 6 accessions expressed averages higher than the check of the highest average for this characteristic, 'Biquinho vermelho' (15.4 mm). Thirty-one accessions did not differ from the average of both the checks (1.85 mm) in relation to the PT descriptor. On the other hand, accessions BGH-8295, BGH-8302, BGH-8315, and BGH-8329 outperformed the average of both the checks with respect to PT (Table 3).

Analyzing NFP (Number of fruits per plant) descriptor, it was observed that the accessions BGH-8290, BGH-8304, BGH-8324, BGH 8330, and BGH-8334 expressed averages higher than both of checks' average (397 fruits per plant), with an emphasis on BGH- 8290 (721 fruits per plant). In addition, regarding this descriptor, a considerable part of the accessions (n = 24), did not differ from both the checks, who expressed a mean NFP of 397 (Table 3). Regarding the FP, it was observed that the accessions BGH-8287, BGH-BGH-8289, BGH-8294, BGH-8314, BGH-8319, BGH-8329, and BGH-8336 expressed averages higher than the checks (598 g), highlighting accession BGH-8314 with an average of 1,217.0 g. Twenty-six of the 53 accessions did not differ from both the checks that expressed a PF mean of 598 g (Table 3).

For the Cra* descriptor, which corresponds to the numerical values for colors between green (-a*) and red (+a*), most accessions expressed means equal to the check highest average for this characteristic, Biquinho Vermelho (56.1). For VC (Vitamin C), the accessions BGH-8312, BGH-8313, BGH-8315, BGH-8322, BGH-8327, BGH-8328, BGH-8337, and BGH-8339 (on average) expressed content of VC 25% higher than the average of the checks (1,076.5 mg.100 g-1). On the other hand, most of the accessions (n = 31) did not differ from the average of both the checks in relation to VC (Table 3). It was observed that 12 accessions expressed higher means than the checks (8.55) in relation to the SS descriptor. On the other hand, 25 of the accessions did not differ from the average of the witnesses in relation to the SS descriptor.

The accession variation associated with pH, most accessions did not differ from the average of the checks (4, 8). For the AT descriptor, 27 of the 53 accessions did not differ from the average of the witnesses (0.16), and 6 accessions expressed lower averages than the checks with the lowest average for this characteristic, 'Biquinho vermelho' (0.16). For the SS/AT ratio, BGH-8292, BGH-8293, BGH-8294, BGH-8298, GGH-8311, BGH-8320, BGH-8321, BGH-8328, and BGH- 8331 expressed averages higher than those of the checks (51.8), and most of the accessions (n = 29) did not differ from the checks' average (Table 3).

Variability analysis based on agronomic characteristics and chemical-nutritional aspects of fruits

The clustering of the genotypes based on the UPGMA method resulted in the formation of 11 groups (Figure 2). Group I clustered the following 12 accessions: BGH 8332, BGH 8294, BGH 8333, BGH 8298, BGH 8299, BGH 8321, BGH 8287, BGH 8146, BGH 8329, BGH 8300, and BGH 8319. Group II and group V gathered 14 accessions, and these 2 were the largest groups. Group II clustered accessions BGH 8297 and BGH 8330. Group IV, VI, IX, X, and XI clustered only one accession BGH 8324, BGH 8341, BGH 8288, BGH 8223, and BGH 8325, respectively. Group VII clustered the accessions BGH 8327, BGH 8328, BGH 8311, BGH 8310, and BGH 8339, and in group VIII the accessions BGH 8331, BGH 8322, and BGH 8337. Group VII identified the BGH-8328 accession-the one found with the highest vitamin C content (1510.0 mg 100 g^{-1}) (Figure 2).

The cophenetic correlation coefficient obtained between the dendrogram and the genetic distance matrix was 0.63.

Contribution of the descriptors to the divergence among accessions

By the method of Singh (1981), it was observed that the descriptors that most contributed to the genetic divergence among accessions were the FL - fruit length (22.3%), with an average of 7.8-85.4 mm (Table 4). The NFP - number of fruits per plant contributed with (10.0%), with values of 97-721 fruits per plant, and the PF - total production of fruits contributed with (8.2%), with values of 69.45-1,275 g (Table 4).

Descriptors with the smallest contribution to genetic variability included the CD - canopy diameter, FD - fruit diameter, PT - pericarp thickness, and the NSF - number of seeds per fruit, with an average contribution of 2.0% (Table 4).

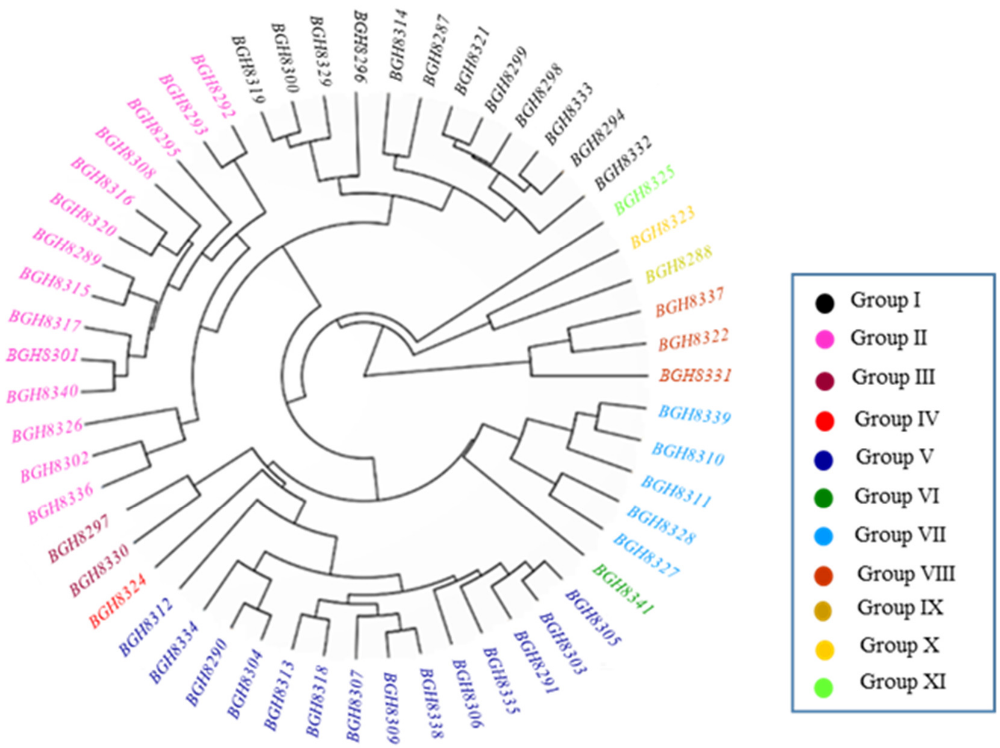

Figure 2. Dendogram obtained based on the data from agronomic descriptors and chemical-nutritional aspects of fruits of 55 accessions of *C. chinense*

Table 4. Relative contribution of agronomic and chemical-nutritional descriptors to the divergence of 55 accessions of *C. chinense*

Traits	Contribution %	Traits	Contribution %
PH	5.1	NSF	3.4
CD	2.4	PF	8.2
NFA	3.6	NFP	10.0
CL	5.9	a*	6.6
AL	4.2	b*	7.6
FL	22.3	VC	4.6
FD	2.0	SS	5.2
PT	3.0	TA	6.1

PH: plant height; CD: canopy diameter; NFA: number of flowers per armpit; CL: corolla length; AL: anther length; FL: fruit length; FD: fruit diameter; PT: pericarp thickness; NSF: number of seeds per fruit; PF: total fuit production; NFP: number of fruits per plant; a*: contribution of red color, b*: contribution of yellow color; VC: vitamin C; SS: soluble solids; TA: titratable acidity

Discussion

ANOVA analysis confirmed the wide genetic variability among the accessions. This was confirmed by the high estimates of phenotypic and genotypic variances for the descriptors, including PH, fruit length, color parameter a *, total production of fruit, number of fruits per plant, and the vitamin C content. These results were expected, since these accessions had not been submitted to any selection process, suggesting that the *C.*

chinense germplasm found in the Amazon region is a promising source for the improvement of this species' characteristics.

In the same direction, some studies have highlighted that the genetic variability present in a population is an essential condition for the beginning of a breeding program and should be explored to obtain genotypes with desirable characteristics (Santos *et al.*, 2008; Galate *et al.*, 2014). The average for the total fruit production obtained in this study (629.9 g) was slightly higher than the values reported elsewhere in the literature. When evaluating *C. chinense* accessions maintained at the Campinas Agronomic Institute, Domenico *et al.* (2012) reported an average value for this characteristic of 500 g, while Lopes e*t al.* (2016) reported an average value of 300 g in the evaluation of *C. baccatum* accessions.

The heritability estimates in this study were similar to those reported by Lannes (2005), who reported heritability estimates for FL, FD, and VC of 92.1, 95.8 and 78.2%, respectively. Moreira *et al.* (2010) found values for NFP, FL and FD of 91.1, 89.1, and 93.6%, respectively. On the other hand, Neto *et al.* (2014) found heritability estimate for PH of 92.9%.

According to Rigon *et al.* (2012), the estimates of heritability, genotypic coefficient of variation, and the relationship between the genotypic and environmental coefficient of variation are important information in elucidating the genetic variability of a given population. Thus, parameters such as the genotypic coefficient of variation of a given trait informs the gain proportionality to the average in the case of selection, thus constituting an important parameter when determining the potential of a given population for breeding purposes. The relationship between the coefficient of genotypic variation and the coefficient of environmental variation with a value >1 unit indicates a favorable condition for selection. Thus, the selection processes can be successfully conducted in the germplasm evaluated in this study for traits such as PH, CD, FL, FD, PT, PF, Cra *, VC, and SS.

As for the coefficients of experimental variation, the results for total number of fruits per plant and the total fruit production found in this study were similar to those obtained by Moreira *et al.* (2010), who reported CV values for these characteristics of 20.5 and 23.0%, respectively. In evaluating *C. frutescens* accessions, Rabelo *et al.* (2013) reported CV estimates of 12.9; 4.5; 10.7; and 14.8% for the characteristic's vitamin C content, soluble solids, titratable acidity, and soluble solids/titratable acidity ratio, respectively. On the other hand, Neto *et al.* (2014) reported lower CV values for PH (7.7%) and canopy diameter (3.8%) than those found in the present study.

Averages test

The mean results observed for PH were similar to those recorded by Di Prado (2013), who reported amplitude for this characteristic of 53.3-95.04 cm. PH is an important feature in defining the use classification of pepper cultivars, that is to determine whether the cultivars are best suited for landscape, ornamental, or production purposes. As per Rego *et al.* (2011), production gains in pepper can be achieved by cultivating tall plants.

For canopy diameter, values above and below the average of the two checks were observed only for accessions BGH 8336 and BGH 8338, respectively. According to Bento *et al.* (2007), canopy diameter is an important feature for growers in planning pepper cultivation, as this descriptor directly influences the determination of spacing to be used in planting.

The descriptors FL and FD are associated with the fruit quality of peppers when marketed freshly or preserved (Paulus *et al.*, 2015). According to Lopes *et al.* (2016), larger fruits facilitate harvesting and increased productivity. Our results for FL were corroborated by Barroca *et al.* (2015) when evaluating the production of *C. chinense* (70.83 mm) and *C. baccatum* (61.1 mm). For the descriptor FD, these authors found the mean values of 13.2 and 17.2 mm for these 2 species, respectively. Ulhoa *et al.* (2017) estimated averages for this characteristic of 16.0-28.0 mm.

The descriptor PT is of commercial importance, mainly in the production of pulp for the processing of sauces. Thus, it is considered that thicker the pericarp, greater is the transport resistance, longer is the postharvest duration, and greater is the mass yield (Ulhoa *et al.*, 2017). Notably, BGH 8315 accession, in addition to expressing thick pericarp, also expressed higher values than the checks for VC, which is interesting for both commercialization and exploitation of this trait in breeding programs. Moreover, the BGH 8295 accession expressed a higher average value for PT and NFP in comparison to the checks. The accession BGH 8329, in addition to the greater thickness of the pericarp in relation to the checks, expressed PF similar to that of the checks. Previous characterization studies of Amazonian pepper reported values for the pericarp thickness that is higher than that found in the present study. Costa *et al.* (2015), for example, found average values ranging from 3 to 4 mm, while Pimenta (2015) obtained the average value of 2.9 mm for this characteristic.

According to Borem and Miranda (2009), productivity is one of the most important characteristics in plant breeding programs. The average value obtained for PF in this study was higher than that reported by Batista *et al.* (2014), which was an average of 842.9 g. The average value found in this study was also higher than the value reported by Araújo (2013), who reported an average of 685.5 g for this characteristic. For the descriptor NFP, the mean values obtained in the present study were higher than those reported by Batista *et al.* (2014) and Araújo (2013), who reported an average number of fruits per plant of 205 and 685.5, respectively.

Fruit coloration in peppers is related to the presence of bioactive components in fruits such as carotenoids. Thus, the determination of the predominant color of fruits in this vegetable can help in the genetic breeding programs aimed at obtaining cultivars with fruits rich in carotenoids. In addition to the health benefits associated with the consumption of fruits with higher carotenoid contents, the presence of components such as carotenoids provide increased quality in fruit processing. In evaluating the coloration in pepper accessions, Carvalho *et al.* (2014) reported values for the parameter a* of 5.9 to 33.9%, which indicates the predominance of red color in fruits, which is similar to the result found in the present study.

Vitamin C has, among other nutritional aspects, significant antioxidant activity, and its consumption provides important health benefits. In the present study, we identified genotypes with extremely high content of vitamin C in fruits (up to 1510.0 mg 100 g^{-1}). According to TACO (2011), this value is much higher than that reported for species of the same genus of *C. chinense* and for fruits such as acerola, orange, and kiwi, which are excellent sources of vitamin C. The high estimate of VC obtained in the present study is much above the estimates reported by previous studies. When assessing the VC content in the fruits of *C. chinense* in the Federal District, Brazil, Teodoro *et al.* (2013) reported a range for this characteristic of 54.1-129.8 mg 100 g^{-1}. In assessing 123 *C. baccatum* accessions from the Asian Center for Plant Research and Development (AVRDC) in Taiwan, Perla *et al.* (2016) reported a variation for VC content of fruits of 2.5-50.4 mg 100 g^{-1}. On the other hand, when evaluating 216 *C. chinense* accessions from the United States Department of Agriculture/Agricultural Research Service (USDA/ARS), Jarret *et al.* (2009) reported values of up to 1466.0 mg 100 g^{-1} for vitamin C content in fruits.

The soluble solids values found in this study were close to those reported by Faria *et al.* (2013), Braga *et al.* (2013), and Borges *et al.* (2015) when evaluating the accessions of *Capsicum* sp., which obtained the values of 12.9, 10.4, and 11.0 °Brix, respectively. On the other hand, the present results were higher than those reported by Padilha (2017), who reported an average value for this characteristic of 6.7° Brix. The soluble solids content is crucial for fruits when they are intended for fresh consumption, as these solids impart important organoleptic characteristics to fruits (Conti *et al.*, 2002; Braga *et al.*, 2013). Regarding pH, the results found in this study were lower than those observed by Braga *et al.* (2013), when evaluating the *C. frutescens* progenies in Ceará, which revealed an average value for this trait of 5.6. According to these authors, the pH measurement is an important parameter for the determination of a possible and rapid deterioration of the product owing to the presence and growth of microorganisms that are harmful to the health.

The estimates of TA of fruits obtained in this study (0.1-0.3%) were much lower than those reported by similar studies. When performing the characterization of peppers in Roraima, the state of Brazil, Borges *et al.* (2015) observed a variation of 0.3 to 0.5% for this characteristic. Padilha (2017) also observed a variation for this characteristic of 1.05-1.7% when evaluating the species of the genus *Capsicum*. According to Reis *et al.*

(2015), the lower levels of TA favor the conservation of fruits and byproducts. In addition, Santana *et al.* (2004) indicates that titratable acidity is important in characterizing the taste and aroma of fruits.

The relationship between soluble solids content and titratable acidity observed in the present study ranged from 38.02 to 99.27, which is higher than that reported by Rabelo *et al.* (2013), who reported lower values (31.07%). Our results for soluble solid contents were also higher than those reported for this characteristic by Borges *et al.* (2015), who reported a variation of 19.4-51.3%. According to Rabelo *et al.* (2013), the importance of soluble solid contents in fruits lies in the fact that this parameter suggests the state of balance between sugars and acids present in fruits.

Our results about the agronomic descriptors and chemical-nutritional aspects of *C. chinense* fruits confirm the high potential of this germplasm for production of these fruits specifically for fresh consumption and for the production of processed products.

Variability analysis and contribution of descriptors to the divergence among accessions

The UPGMA hierarchical method confirms that the *C. chinense* germplasm from the Brazilian Amazon and has a wide variability, which makes it a promising germplasm for application in programs aiming for the genetic improvement of this vegetable. According to Domiciano *et al.* (2015), the separation of accessions into distinct groups is important because it may indicate the existence of distinct gene polls that may be exploited in the future in controlled hybridizations as well as for reciprocal recurrent selection (SRR) schemes. In this study, the BGH 8324, BGH 8341, BGH 8288, BGH 8323, and BGH 8325 accessions were the most divergent, suggesting the possibility of combining these accessions with the other studied accessions to obtain a higher hybrid vigor.

The cophenetic correlation coefficient between the dendogram obtained in clustering of the genotypes and the distance matrix among these genotypes (0.63) was <0.7, which is the minimum acceptable value for this parameter (Rohlf, 1970). On the other hand, Vaz Patto *et al.* (2004) showed that cophenetic correlation values >0.56 can be considered satisfactory as they portray distortions that are acceptable by clustering. In this study, we found distortion of only 13.8.

With reference to the relative contribution of the descriptors to genetic divergence, our results were similar to those of Ferrão *et al.* (2011) and Rêgo *et al.* (2011), who also found that the characteristic FL was the major contributor to the genetic divergence among the pepper genotypes.

Conclusions

The germplasm of *C. chinense* evaluated in this study expressed a wide variability for agronomic characteristics and chemical-nutritional aspects of fruits, as observed by noting a significant difference for all these characteristics and the pattern of genotype grouping during the variability analysis.

Based on the UPGMA clustering, it was possible to identify the most promising accessions groups for use in breeding programs. For instance, group VII included BGH 8328-the accession as the highest mean for vitamin C content in fruits. This access is promising for use as a parent in pepper breeding programs that are aimed at increasing the vitamin C content in fruits.

The accessions BGH 8324, BGH 8341, BGH 8288, BGH 8323, and BGH 8325 are promising for use in pepper breeding programs that are aimed at genetic improvement of agronomic characteristics and chemical-nutritional aspects of fruits.

The germplasm of *C. chinense* from the Brazilian Amazon represents a valuable resource for the improvement of this species, and it is therefore important to collect this germplasm and conserve it in germplasm banks.

Authors' Contributions

Conceptualization: Derly José Henriques da Silva. Data curation: Santina Rodrigues Santana. Investigation: Santina Rodrigues Santana, Ronaldo Silva Gomes, Renato Domiciano da Silva, and Paula Cristina Carvalho Lima. Software: Leonardo Lopes Bhering, Ronaldo Silva Gomes. Supervision: Derly José Henriques da Silva. Writing – original draft: Santina Rodrigues Santana. Writing - review & editing: Santina Rodrigues Santana, Derly José Henriques da Silva. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

AOAC (2012). Association of Official Analytical Chemistry. Official methods of analysis (19th ed), Gaithersburg.

Araujo CMM (2013). Genetic analysis in landraces of murupi pepper (*Capsicum chinense* Jacq.) of Amazonia. Dissertação, Instituto Nacional de Pesquisa da Amazônia.

Arruda S (2012). Rondônia climate. Retrieved 2020 November 8 from *http://rondoniaemsala.blogspot.com/2011/12/clima-de-rondonia.html*

Barroca MV, Bonomo R, Fernandes AA, Souza, JM (2015). Irrigation blades in the production components of 'de-odor' and 'dedo-de-moça' peppers. Agro@mbiente 9(3):243-250. *https://dx.doi.org/10.18227/1982-8470ragro.v9i3.2342*

Batista MRA, Silva Filho DF (2014). Morpho-agronomic characterization of non-pungent peppers of the genus *Capsicum* spp. from the Amazon. Agro@mbiente 8(2):204-211. *http://dx.doi.org/10.18227/1982-8470ragro.v8i2.1337*

Bento CS, Sudré CP, Rodrigues R, Riva EM, Pereira MG (2007). Qualitative and multicategorical descriptors in the estimation of phenotypic variability among chili pepper accessions. Scientia Agraria 8(2):147-154.

Borem A, Miranda GV (2009). Plant breeding. (1th ed), Viçosa, Minas Gerais.

Borges KM, Vilarinho LBO, Filho AAM, Morais BR, Rodrigues RNS (2015). Morpho-agronomic and physicochemical characterisation of the pepper for the State of Roraima. Agro@mbiente 9(3):292-299. *https://dx.doi.org/10.18227/1982-8470ragro.v9i3.2766*

Bosland PW, Votava EJ (2000). Peppers: vegetable and spice *Capsicum*. New York, Cabi.

Burle ML, Oliveira MSP (2010). Plant germplasm curators manual: morphological characterization. Brasília, Distrito Federal.

Braga TR, Pereira RA, Silveira MRS, Silva LR, Silva AR, Oliveira MMT (2013). Physical-chemistry characterization of chili peppers progenies grown in Paraipaba-CE. Revista Scientia Plena 9(5):2-6.

Carvalho SIC, Bianchetti LB, Ribeiro CSC, Lopes CA (2006). *Capsicum* peppers in Brazil (1th ed). Brasília, Distrito Federal.

Carvalho AV, Aciel RA, Beckman JC, Poltronieri MC (2014). Characterization of *Capsicum* spp. during maturation. Embrapa Amazônia Oriental. *https://ainfo.cnptia.embrapa.br/digital/bitstream/item/99243/1/BDP90.pdf*

Chunab NC, Duch ES, Castilla LO, Burgos JIR (2011). Valuación de la calidad en la industrialización del chile habanero (*Capsicum chinense*) [Quality assessment in the industrialization of the habanero pepper (*Capsicum chinense*).]. Iberoamericana de Tecnología Postcosecha 12(2):222-226. *https://www.redalyc.org/articulo.oa?id=81320900014*

Conti JH, Minami K, Tavares FCA (2002). Production and quality of some cultivars of strawberry fruits in field experiments at Atibaia and Piracicaba, Brazil. Brazilian Horticulture 20(1):10-17. *https://dx.doi.org/10.1590/S0102-05362002000100002*

Costa LV, Bentes JLS, Lopes MTG, Alves SRM, Junior JV (2015). Morphological characterization of Amazon pepper accessions. Brazilian Horticulture 33(3):290-298.

Cruz CD, Ferreira FM, Pessoni LA (2011). Biometrics applied to the study of genetic diversity (1th ed). Minas Gerais.

Cruz CD, Regazzi AJ, Carneiro PCS (2012). Biometric models applied to genetic improvement (4th ed). Viçosa, Minas Gerais.

Cruz CD (2013). GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta Scientiarum 35(3):271-276. *https://doi.org/10.4025/actasciagron.v35i3.21251*

Di Prado PRC (2013). Genetic parameters and selection gains in goat pepper (*Capsicum chinense* Jacq). MSc Dissertation, University of Goiás.

Domenico CI, Coutinho JP, Godoy HT, Melo AMT (2012). Agronomic traits and pungency of chilli pepper. Brazilian Horticulture 30(3):466-472. *https://doi.org/10.1590/S0102-05362012000300018*

Domiciano GP, Alves AA, Laviola BG, Conceição LDHCS (2015). Genetic parameters and diversity in progenies from Macaw Palm based on morphological and physiological traits. Rural Science 45(9):1599-1605. *https://dx.doi.org/10.1590/0103-8478cr20140909*

FAO (2016). Food and Agriculture Organization of the United Nations. Retrieved 2019 January 25 from *http://www.fao.org/faostat/en/#data/QC*

Faria PN, Laia GA, Cardoso KA, Finger FL, Cecon PR (2013). Genetic variability of pepper (*Capsicum chinense* Jacq.) samples from a germoplasm bank: a case study. Agrarian Sciences 36(1):17-22.

Ferrão LFV, Cecon PR, Finger FL, Silva FF, Puiatti M (2011). Genetic divergence among sub-samples of pepper based on morpho-agronomic characters. Brazilian Horticulture 29(3):354-358. *https://doi.org/10.1590/S0102-05362011000300016*

Köppen W (1948). Climatology. Translation: Pedro RH. Gráfica Panamericana. Buenos Aires.

Galate RS, Mota MGC, Gaia JMD, Costa MSS (2014). Phenotypic distance among assai palm's mother plants (*Euterpe oleracea* Mart.) from Eastern Amazon. Semina: Agrarian Sciences 35(4):1667-1682. *http://dx.doi.org/10.5433/1679-0359.2014v35n4p1667*

Instituto Adolfo Lutz (2008). Physico-chemical methods for food analysis. (4th ed), São Paulo. *https://wp.ufpel.edu.br/nutricaobromatologia/files/2013/07/NormasADOLFOLUTZ.pdf*

IPGRI-International Plant Genetic Resources Institute (1995). Descriptors for *Capsicum* (*Capsicum* spp). Roma.

Itle RA, Kabelka EA (1997). Correlation between L a b color space values and carotenoids content in pumpkins and squash (*Cucurbita* spp.). Horticultural Science 122(4):594-598. *https://doi.org/10.21273/HORTSCI.44.3.633*

Jäger MA, AMAYA K (2013). Las cadenas de valor de los ajíes nativos de Perú. Compilación de los estudios realizados dentro del marco del proyecto "Rescate y Promoción de Ajíes Nativos en su Centro de Origen" para Perú [The value chains of the native peppers of Peru. Compilation of studies carried out within the framework of the project "Rescue and Promotion of Native Chili Peppers in their Center of Origin" for Peru]. Bioversity International. Cali.

Jarret SD, Berke T, Baldwin EA, Antonious GF (2009). Variability for free sugars and organic acids in *Capsicum chinense*. Chemical Biodiversity 6(2):138-145. *https://doi.org/10.1002/cbdv.200800046*

Lannes SD (2005). Diversity in *Capsicum chinense*: chemical, morphological and molecular analysis. PhD Thesis, University of Viçosa.

Lopes MAP, Gonçalves LD, Morais EG, Rezende CP, Vaz GHB (2016). Characterization of cumari pepper accessions of natural distribution for purposes of genetic improvement. Agrogeoambiental 8(4):105-115. *http://dx.doi.org/10.18406/2316-1817v8n42016898*

MAPA (2013). Ministério da Agricultura, Pecuária e Abastecimento. Method for determining ascorbic acid. Handboo of methods of Analysis of Beverages and Vinegars. Retrieved 2018 December 15 from *file:///D:/Usuario/Downloads/N%C3%83O%20ALCO%C3%93LICOS%20-%2022%20%C3%81cido%20Asc%C3%B3rbico.pdf*

Milligan GW, Cooper MC (1985). An examination of procedures for determining the number of clusters in a data set. Psychometrika 50(2):159-179. *https://doi.org/10.1007/BF02294245*

Mojena R (1977) Hierarchical grouping methods and stopping rules: an evaluation. The Computer Journal 20(4):359-363. *https://doi.org/10.1093/comjnl/20.4.359*

Moreira SO, Rodrigues R, Araújo ML, Sudré CP, Riva-Souza EM (2010). Agronomic performance of recombinant chili pepper inbred lines in two cultivation systems. Science and Agrotechnology 34(4):886-891.

Moura WM, Casali VW, Cruz CD, Lima PC (1999). Genetic divergence of phosphorus nutritional efficiency in sweet pepper lines. Pesquisa Agropecuária Brasileira 34(2):217-224. *https://doi.org/10.1590/S0100-204X1999000200010*

Neto JJS, Rêgo ER, Nascimento MF, Filho VALS, Neto JXA, Rêgo MM (2014). Variability in a base population of pepper (*Capsicum annuum* L.). Ceres 61(1):084-089. *http://dx.doi.org/10.1590/S0034-737X2014000100011* (2014)

Paulus D, Valmorbida R, Santin A, Toffoli E, Paulus, E (2015). Growth, yield and fruit quality of pepper (*Capsicum annuum*) at different spacings. Brazilian Horticulture 33(1):91-100. *http://dx.doi.org/10.1590/S0102-053620150000100001*

Padilha HKM (2017). Genetic resources of peppers (*Capsicum*, Solanaceae): genetic diversity, resistance to anthracnose and production of specialized metabolites. PhD Thesis, University of Pelotas.

Perla V, Nadimi M, Hankins G, Reddy UK, Nimmakayala P, Alaparthi S, Ebert A (2016). Vitamin C and reducing sugars in the world collection of *Capsicum baccatum* L. genotypes. Food Chemistry 202:189-198. *https://doi.org/10.1016/j.foodchem.2016.01.135*

Pimenta S (2015). 'Carioca' and 'Uenf carioquinha': New pepper cultivars (*Capsicum annuum* var. *annuum*) resistant to bacterial spot. PhD Thesis, University of Norte Fluminense.

Pinto CMF, Pinto CLO, Donzeles SML (2013). Chemical, nutritional, pharmacological and medicinal properties and their potential for agribusiness. Sustainable Agriculture 3(2):108-120. *https://docplayer.com.br/28910286-Pimenta-capsicum-propriedades-quimicas-nutricionais-farmacologicas-e-medicinais-e-seu-potencial-para-o-agronegocio-1.html*

Reifschneider FJB (2000). *Capsicum:* peppers and peppers in Brazil. (1th ed), Brasília.

Rabelo BT, Pereira RCAS, Silva LR, Oliveira MMT (2013). Physico-chemical characterization of pepper (*Capsicum frutescens* L.) progênies. Revista de la Facultad de Agronomía 12(1):6-10.

Rêgo ER, Finger FL, Rêgo MM (2011). Production, genetics and breeding of peppers (*Capsicum* spp.). (1th ed), Recife.

Reis DR, Barbosa CMD, Silva FS, Porto AG, Soares EJO (2015). Biometric characteristics and physical-chemistry biquinho pepper variety. Scientific Center Know 11(21):454.

Rigon JPG, Capuani S, Cherubin MR, Rosa GM, Wastowski AD (2012). Agronomic performance and genetic dissimilarity unflower. Rural Science 42(11): 1954-1959.

Rodrigues R, Bento CS, Pimenta S, Sudré CP (2016). Pepper and Pepper Breeding. In: Nick C, Borem A (Eds). Improvement of vegetables. Viçosa, Minas Gerais pp 221-250.

Rohlf FJ (1970). Adaptive hierarchical clustering schemes. Systematic Zoology 18:58-82. https://doi.org/10.2307/2412027

Rufino JLS, Penteado DCS (2006). Economic importance, prospects and market potential for pepper**.** Agricultural Report 27(235).

Santana LRR, Matsuura FCAU, Cardoso RL (2004). Improved genotypes of papaya (*Carica papaya* L.): sensory and physico-chemical evaluation. Science and Food Technology 24(2):217-222. *https://dx.doi.org/10.1590/S0101-20612004000200010*

Santos CEM, Pissioni LLM, Morgado MAD, Cruz CD, Bruckner CH (2008). Strategies of selection in yellow passion fruit progenies for vigor and scab incidence. Brazilian Journal of

Fruit Growing 30(2):444-449. *https://dx.doi.org/10.1590/S0100-29452008000200030*

Singh D (1981). The relative importance of characters affecting genetic divergence. The Indian Journal of Genetic and Plant Breeding 41:237-245.

TACO (2011). Table brazilian food composition table. UNICAMP. Retrieved 2018 September 18 from *http://www.cfn.org.br/wp-ontent/uploads/2017/03/taco_4_edicao_ampliada_e_revisada.pdf*

Teodoro AFP, Alves RBN, Ribeiro LB, Reis K, Reifschneider FJB, ... Agostini-Coata TS (2013). Vitamin C content in Habanero pepper accessions (*Capsicum chinense*). Brazilian Horticulture 31(1):59-62.

Ulhoa AB, Pereira TNS, Ribeiro CSC, Moita AW, Reifschneider FJB (2017). Development and morpho-agronomic characterization of yellow jalapeño pepper lines. Brazilian Horticulture 35(3):343-348. *https://dx.doi.org/10.1590/s0102-053620170305*

Vaz Patto MC, Satovic Z, Pêgo S, Fevereiro P (2004). Assessing the genetic diversity of Portuguese maize germoplasm using microsatellite markers. Euphytica 137(1):63-72. *https://doi.org/10.1023/B:EUPH.0000040503.48448.97*