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

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**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
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 et 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 km² 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

| Accesions | Place of collect | Coordinates | Accessions | Place of collect | Coordinates |
|-----------|----------------|-------------|-----------|----------------|-------------|
| BGH 8287 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8322 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8288 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8324 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8290 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8325 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8291 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8326 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8292 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8327 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8293 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8328 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8296 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8329 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O |
| BGH 8297 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8330 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O |
| BGH 8298 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8333 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O |
| BGH 8299 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8338 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8300 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8339 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O |
| BGH 8301 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8289 | Cacoal | 11º 26' 46.38" S 61º 26' 53.35" O |
| BGH 8302 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8314 | São Fco do Guaporé | 12º 03' 57.14" S 63º 34' 10.48" O |
| BGH 8303 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8335 | Novo Horizonte D'Oeste | 11º 43' 28.60" S 62º 02' 32.02" O |
| BGH 8304 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8336 | Novo Horizonte D'Oeste | 11º 43' 28.60" S 62º 02' 32.02" O |
| BGH 8305 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8295 | Novo Horizonte D'Oeste | 11º 43' 28.60" S 62º 02' 32.02" O |
| BGH 8306 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8315 | Novo Horizonte D'Oeste | 11º 43' 26.71" S 61º 59' 55.04" O |
| BGH 8307 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8316 | Novo Horizonte D'Oeste | 11º 43' 26.71" S 61º 59' 55.04" O |
| BGH 8308 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8317 | Novo Horizonte D'Oeste | 11º 43' 26.71" S 61º 59' 55.04" O |
| BGH 8309 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8294 | Novo Horizonte D'Oeste | 11º 43' 28.60" S 62º 02' 32.02" O |
| BGH 8310 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8295 | Novo Horizonte D'Oeste | 11º 43' 28.60" S 62º 02' 32.02" O |
| BGH 8311 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8318 | Rolim de Moura | 11º 43' 39.95" S 66º 07' 47.38" O |
| BGH 8312 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8323 | Feira-Presidente Médici | 11º 10' 5.96" S 61º 54' 14.23" O |
| BGH 8313 | Feira-Cacoal | 11º 25' 59.71" S 61º 27' 50.97" O | BGH 8331 | Feira-Pimenta Bueno | 11º 41' 07.78" S 61º 10' 07.93" O |
| BGH 8319 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8332 | Feira-Ji-Paraná | 10º 52' 37.38" S 61º 57' 07.47" O |
| BGH 8320 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8334 | Mercado- Porto Velho | 8º 45' 54.14" S 63º 54' 34.30" O |
| BGH 8321 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8337 | Mercado- Porto Velho | 8º 45' 54.14" S 63º 54' 34.30" O |
| BGH 8340 | Feira-Cacoal | 11º 26' 27.20" S 61º 26' 41.03" O | BGH 8341 | Presidente Médici | 11º 18' 15.87" S 61º 46' 59.54" O |
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:

\[ Y_{ij} = T_i + \mu + \epsilon_{ij} \]

Where,

- \( Y_{ij} \) corresponds to the observed value for a variable under study regarding the \( i \)th treatment in the \( i \)th repetition;
- \( T_i \) corresponds to the effect of the \( i \)th treatment, which is considered as a random effect;
- \( \mu \) corresponds to the general average and;
- \( \epsilon_{ij} \) 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:

**Agronomic**

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 (PPL, 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*) (Itole and Kabelka, 2009):

\[ C^* = \sqrt{a'^2+b'^2} \]
\[ \text{Hue} = \tan^{-1}(b^*/a^*) \]

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 °C. For this analysis, we used 200 g of the ground fruit pulp.

The analysis of soluble solids (ºBrix) 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 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 triturbated 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: \( a_j > 6k \), where \( a_j \) is the value of distances from the fusion levels corresponding to stage \( j \) (\( j = 1, 2, ..., n \)) and \( 6k \) is the cut off reference value, expressed as \( 6k = a' \cdot k + a \sigma a' \), where \( a' \) and \( a \sigma a' \) are, respectively, non-biased estimates of the mean and standard deviation of \( a \) 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 dendrogram, 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 trait corresponded to BGH-8290 access (721.00) and the lowest to BGH-8296 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 BGH8335 to 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 \((Cv\%_g)\), the descriptors DF (64.8) and FL (63.9) expressed the highest values for this parameter. The \(Cv_g/Cv_e\) 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   | 92.7** | 504.0** | 1.7** | 179.3** | 0.74** | 361.3** | 985.08** | 905.00** | 117.1** | 9.3** | 0.1** | 0.01** | 3.7** |

**VF:** variation factor; **PH:** plant height (cm); **CD:** canopy diameter (cm); **FL:** Fruit Length (mm); **FD:** fruit diameter (mm); **PT:** pericarp thickness (mm); **P:** 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; \( \psi \): overall mean; \( \psi _{g} \): phenotypic variance \( h^{2} \): heritability; **CVg/t:** genotypic coefficient of variance; **CVg/CVc:** relation of the genotypic coefficient of variance and the environmental variance coefficient; **CV:** coefficient of variation. ***, ** Significat at 1 and 5% probability, respectively, by the F test.

**Average test**

By comparing the averages by Dunnert’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 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 | 0.12** | 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 | 1264.0ab | 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   | 60.0b | 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 | 22.9b | 12.6a | 1.3 | 300.0ab | 383.0ab | 57.8a | 1223.0ab | 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 | 69.0b | 18.0a | 20.7a | 2.7 | 225.0 | 741.0a | 49.4ab | 1214.0ab | 8.0ab | 5.0ab | 0.12** | 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 | 0.15ab | 52.4ab |
| BGH 8297   | 86.0a | 73.0ab | 14.9b | 10.6ab | 1.1 | 513.0 | 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 | 44.9b | 1063.0ab | 8.7b | 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 | 1219.0ab | 10.2a | 5.2b | 0.17ab | 58.2ab |
than the check of highest average, 'Biquinho vermelho' (26.0 mm). Regarding the FD descriptor, most of the accessions expressed averages higher than the check of the highest average for this characteristic, 'Biquinho amarelo' (commercially named as 'Biquinho amarelo') (55.0 cm). The accessions BGH-8288, BGH-8310, BGH-8323, both checks. For the descriptor canopy diameter (CD), most of the accessions did not differ from the checks, BGH-8326, BGH-8327, BGH-8336, and BGH-8339 expressed the highest PHs, averaging higher than the checks. 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 both of 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

| Checks          | PH | CD | FL | Thickness | NFP | TF | TA | SS/AT | VC | Soluble Solids | Titratable Acidity | Colorimetric Parameter | Contribution of Red | Vitamin C | Soluble Solids | Hydrogen Potential |
|-----------------|----|----|----|-----------|-----|----|----|-------|----|----------------|--------------------|----------------------|---------------------|-----------|---------------|----------------------|
| BGH 8340        | 87.0 | 26.0 | 15.4 | 1.9 | 378.0 | 627.0 | 56.1 | 1041.0 | 9.0 | 4.7 | 0.16ª | 56.3ª | 0.15ª | 72.3ª |
| BGH 8341        | 55.0 | 22.2 | 13.4 | 1.8 | 416.0 | 569.0 | 39.8 | 1112.0 | 8.1 | 4.9 | 0.17ª | 47.3ª |
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 fruit 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 et 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.
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 pools 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.

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