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RESEARCH PAPER

Morphological assessment reveals high variability for flower and fruit traits in *Capsicum chinense* germplasm from the Brazilian Amazon

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Abstract

The Brazilian Amazon is known to have the greatest biodiversity in the world; however, deforestation poses a high risk to its biodiversity. This highlights the importance of studies involving surveys and approaches aimed at the conservation and rational use of biodiversity in this region. Therefore, this study aimed to (a) assess the morphological traits of a *Capsicum chinense* germplasm sample collected from the Brazilian Amazon region, comprising 55 accessions, and b) analyze morphological variability to identify promising accessions for inclusion in *Capsicum* spp. breeding programs. The variability of accessions was assessed by analyzing the frequency of accessions in the phenotypic classes for each morphological trait using different clustering methods. Variability among accessions was particularly high for flower and fruit descriptors, such as flower position, filament color, anthocyanin spots on fruits, and fruit apex shape. Accessions BGH8288, BGH8309, and BGH8323 exhibited light and dark purple/violet colors in the stems, leaves, fruits, and corollas, which were possibly associated with higher concentrations of anthocyanins. These accessions are promising for inclusion in *Capsicum* spp. breeding programs intended for the ornamental market. In situ conservation of *C. chinense* in the Brazilian Amazon preserves high variability in the region. This germplasm is strategic for the genetic breeding of *Capsicum* spp., which is an essential source of genes for this genus.

Keywords

Diversity, genetic breeding, multivariate analysis, pepper

Introduction

The Amazon is a vast region that spans ~5,800,000 km^2 in South America and covers eight countries on this continent (Amazon Assessment Report, 2021). It is known for its immense biological diversity, housing ~25% of global biodiversity (Malhi et al. 2008), and corresponds to one of the regions with the greatest biodiversity for most taxonomic groups worldwide (Mittermeier et al. 2003; Zapata-Ríos et al. 2021). The Amazon region hosts diverse communities of herbaceous plants in its various ecosystems (Gallo et al. 2022). Similarly, the region is home to a high diversity of vegetables, including peppers and leaf vegetables (Araújo et al. 2018; Gonçalves et al. 2022). This region comprises the Tropical Forest biome, one of the largest biomes (Coiffard et al. 2023), and provides a range of ecosystem services of global importance, such as carbon sequestration and storage, as well as regulating the water cycle (Bovolo et al. 2018; Strand et al. 2018). Brazil is situated in most of the Amazon (5 million km^2) and covers ~59% of its territory (IBGE 2022).

Due to its wide biogeographical extension, the Amazon region in Brazil is home to over 28 million people, comprising both indigenous and traditional populations, as well as migrants from various locations within Brazil and abroad (IBGE 2020). Currently, the Brazilian Amazon economy is based on several activities such as commerce, construction, education, and agriculture. The trade sector of the region is based on the export of food and mineral commodities, such as beef, soy, corn, cassava, bauxite, and iron ore (FAO 2017).

The development of the Brazilian Amazon is closely related to the development paradigm stipulated for Brazil between 1950 and 1960, which advocates for the conversion of forests to achieve economic growth and national security (Hecht and Rajão 2020). Thus, the initial colonization of this region prioritized activities—such as rubber extraction and cattle raising—that allowed the development of large areas at a very low cost. Consequently, livestock farming has been a crucial activity in the Brazilian Amazon and, concurrently, one of the main causes of deforestation, with ~60% of the forest and woodland areas deforested in the region between 2001 and 2013 (Malhi et al. 2008; Tyukavina et al. 2017). More recently, the expansion of agricultural activity in Brazil has driven deforestation in the Brazilian Amazon (Coelho et al. 2021), alongside other factors that have substantially contributed to deforestation in the region, including urbanization and mining (Garrett et al. 2021). Activities leading to deforestation in the Brazilian Amazon pose high risks to biodiversity loss, corroborating the relevance of studies involving biodiversity surveys in this region and research focused on the conservation and sustainable use of biodiversity.

Capsicum chinense is a spice vegetable and one of the five cultivated species of the *Capsicum* genus, along with *C. annuum* var. *annuum*, *C. baccatum* var. *pendulum*, *C. chinense*, *C. frutescens*, and *C. pubescens* (Liu et al. 2023). *Capsicum chinense* belongs to the (*C. annuum*, *C. chinense* and *C. frutescens*) complex, which comprises species cultivated and consumed worldwide. They correspond to the species of greatest socioeconomic importance in the *Capsicum* genus (García et al. 2016). A combination of archaeological evidence, genetic analyses, and modern plant distributions has led researchers to suggest that *C. chinense* was domesticated in the northern lowland Amazonia (Pickersgill 1984; Eshbaugh 1993). In a more recent study, Perry et al. (2007) identified a genus-specific starch morphotype at archaeological sites spanning from the Bahamas to southern Peru, dating back to approximately 6000 years BP, associated with the fruits of the *Capsicum* genus.

Studies on the germplasm of *C. chinense* from the Amazon region have reported remarkable variability in the molecular, agronomic, and chemical-nutritional traits of this species (Fonseca et al. 2008; Moses et al. 2014; Santana et al. 2020). In addition to its biological aspects, the variability of *C. chinense* in the Brazilian Amazon is closely linked to the cultivation methods used. Santana et al. (2020) describe that the consumption, cultivation, and conservation of this species in the Amazon is mainly practiced by traditional indigenous and riverside communities and small farmers. Thus, the Brazilian Amazon is an important center of diversity for *C. chinense*.

Morphological characterization of plant germplasm (MCG) involves the assessment of individual plants or a group of plants based on traits— referred to as morphological markers—that can be distinguished and scored visually by the naked eye. Plant morphological markers, also referred to as qualitative traits, have phenotypes that can be divided into discrete classes. They are controlled by one or a few major genes, and their expression is not markedly influenced by the environment (Fehr 1987). MCG is strategic for investigating genetic diversity using biochemical or molecular markers (Gomes et al. 2020). Therefore, morphological characterization of *C. chinense* germoplasm from the Brazilian Amazon is crucial for elucidating the status of in-situ conservation of this species and for implementing strategies for its sustainable conservation and utilization in this region. According to Rivas et al. (2023), such strategies allow the mapping of landraces and facilitate the development of maintenance strategies while minimizing genetic erosion.

Therefore, this study aimed to a) morphologically assess a panel of *C. chinense* germplasms collected from the Brazilian Amazon, comprising 55 accessions, and b) analyze their morphological variability, with a view to identifying promising accessions for use in breeding programs of *Capsicum* spp.

Material and methods

This study involved the collection and morphological assessment of 55 *C. chinense* accessions from the Brazilian Amazon region. The origin of the germplasm and information on the collection sites are detailed by Santana et al. (2020), from the initial assessment of this germplasm as to agronomic and chemical-nutritional traits. These accessions consist of local cultivars or l*andraces* and are commonly preserved, cultivated, and commercialized by local farmers, mostly family-based farmers.

The germplasm collection was conducted between June 2015 and December 2016. After collection, the germplasm was identified with passport data and added to the collection of *C. chinense* maintained in the Vegetable Germplasm Bank of the Federal University of Viçosa (BGH-UFV). Passport data was obtained in accordance with the criteria established by the International Plant Genetic Resources Institute (IPGRI).

Seeds of the germplasm were sown in July 2017 in polyethylene trays containing 128 cells filled with commercial substrate. The substrate used for seedling production was

Carolina Soil®, a substrate composed of 70% *Sphagnum* peat and 30% vermiculite, supplemented with limestone, macro- and micro-nutrients.

Seedlings were transplanted into 10-L pots, 60 days after sowing. They were transplanted when they had between 4 and 6 definitive leaves, and the plants were kept in a protected environment. Thus, the entire crop cycle was conducted under a protected environment. The protected environment consisted of a greenhouse covered with agricultural film and completely closed on all sides. The greenhouse sides were closed with an anti-aphid screen, avoiding possible cross-pollination between plants due to the presence of pollinators.

The substrate for the cultivation of adult plants was produced from a mixture of soil, sand, and aged cattle manure in a 2:1:1 ratio. The soil used in the substrate was collected from the 0–20 cm layer and is classified as a dystrophic Red Yellow Oxisol. The soil chemical, physical, and hydric characteristics were obtained before the experiment was established and are presented in Suppl. material 1: table 1.

The experiment was conducted between September 2017 and September 2018 in the Experimental Garden of the Department of Plant Science at UFV. The region where the experiment was conducted has an average annual temperature of 20.2 °C, an average annual precipitation of 1,261.6 mm, an average annual relative humidity of 79.4%, and an average annual insolation of 5.91 hours per day (INMET 2025).

The experiment was conducted using a completely randomized design according to the following model:

$$Y_{ij} = \mu + G_i + \varepsilon_{ij}$$

where:

Y_{ij} represents the observed value of a given trait for the i^{th} treatment in the j^{th} repetition,

μ represents the general mean,

G_i represents the effect of the i^{th} genotype, which is considered random, and

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

Each treatment consisted of five replicates, and each plot consisted of a pot with one plant. Morphological assessments were performed in one replicate, with a spacing of 0.60 cm between rows and 0.40 cm between plants within each row. Drip irrigation was adopted, and water was applied twice daily (RIBEIRO et al. 2008). A fertilizer consisting of potassium nitrate, calcium nitrate, monoammonium phosphate, boric acid, and magnesium sulfate was applied weekly. Nutrients were applied via fertigation, and the description of nutrient sources and their respective concentrations is detailed in Suppl. material 1: table 2. Phytosanitary control, both preventive and curative, was performed on a weekly and biweekly basis, as needed for the crop (Nick and Borém 2016). Culture treatments were performed according to the recommendations for pepper cultivation.

The morphological assessment was performed based on 20 multi-categorical descriptors recommended by IPGRI (1995). The descriptors and their respective classes are presented in Table 1.

Table 1. Morphological descriptors used in the assessment of the *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon.

Phase/ organ	Descriptors
Vegetative	Plant growth habit: (1) prostrate, (2) intermediate, (3) erect, and (4) other. Stem pubescence: (1) sparse, (2) intermediate, and (3) dense. Stem color: (1) green, (2) green with violet streaks, and (3) violet. Stem shape: (1) cylindrical, (2) angled, and (3) flattened. Leaf shape: (1) deltoid, (2) ovate, and (3) lanceolate. Leaf margin: (1) entire, and (2) undulated. Leaf pubescence: (1) sparse, (2) intermediate, and (3) dense. Leaf color: (1) yellow, (2) light green, (3) green, (4) dark green, (5) light purple, and (6) purple.
Flower	Flower position: (1) pendant, (2) intermediate, and (3) erect. Corolla color: (1) greenish white, and (2) white with purple spot. Anther color: (1) yellow, (2) blue, and (3) violet. Fillet color: (1) White, and (2) purple. Stigma position: (1) same level, and (2) excerpt.
Fruit	Anthocyanin spots: (1) present, and (2) absent. Ripe fruit color: (1) red, (2) yellow, (3) salmon, (4) orange-yellow, (5) dark purple, (6) wine red, (7) orange-red, and (8) orange. Fruit shape: (1) elongated, (2) rounded, (3) triangular, and (4) blocky. Fruit shape at the peduncle union: (1) truncate, (2) obtuse, and (3) acute. Fruit apex shape: (1) pointed, (2) obtuse, and (3) hollowed/sunken. Fruit epidermis: (1) smooth, (2) semi-rough, and (3) rough.
Seed	Seed size: (1) small, and (2) intermediate.

To assess the variability of the accessions, the data associated with the 20 morphological descriptors were transformed into dissimilarities based on the average Euclidean distance. The dissimilarity matrix was obtained using the mode of each descriptor for accessions without repetition. Subsequently, a dissimilarity matrix was generated based on a simple coincidence complement (1-C), which considers the agreement of values (Cruz et al. 2011). The distance between the genotypes *i* and *j* is given by the following equation:

$$D_{ij} = C/C + D \qquad \text{(Equation 1)}$$

where:

C represents the concordance of values, and

D represents the discordance.

The variability of accessions was assessed using Tocher optimization clustering methods and the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) from the dissimilarity matrix of the accessions. These methods allowed an analysis of the graphical behavior of the accessions in the dendrogram. Variability analyses were performed using Genes (Cruz 2013).

The relative contribution of descriptors to genetic divergence between accessions was determined using the Singh method (Singh 1981).

Results and discussion

Morphological traits of germplasm

Most accessions exhibited intermediate growth habits (82%), followed by those with erect growth habits (18%) Suppl. material 1: table 3. Similarly, Sudré et al. (2010) emphasized that growth habits are crucial in the management of pepper crops, particularly in determining crop spacing, which in turn influences cultural practices such as weed management and harvesting.

Pepper plants have stems that vary between the erect and prostrate stages (Costa et al. 2015; Brilhante et al. 2021). They often have stems with a fragile structure and varied colors, which, depending on the hue, may be related to the presence of pigments such as anthocyanins, which belong to the flavonoid group that protects plants from oxidative damage. In this regard, considerable variation was observed in stem color among the accessions, with a predominance of purple/violet streaks (58%) and green (24%) classes, as shown in Fig. 1. Green stems with purple/violet nodes (11%) and purple/violet stems (8%) were also observed in Suppl. material 1: table 3.

Padilha (2017) evaluated 21 accessions of *Capsicum* spp. and observed variations in stem color, reporting green with purple/violet streaks (76.19%), green stems (19.05%), and purple/violet (4.7%). We observed five phenotypic classes of leaf color, with light green (51%) the most common, followed by green (42%). Dark-purple classes were observed in 1% of the accessions. Leaf color is a crucial trait that can be used to assess the health and nutritional condition of plants. Leaf color is also essential in the ornamental pepper market because this trait may be related to the presence of anthocyanins, which are common in some pepper varieties.

Regarding leaf pubescence, 51, 27, and 22% of the accessions expressed intermediate pubescence, dense pubescence, and scarce pubescence, respectively Suppl. material 1: table 3. Leaf pubescence is a plant defense mechanism against herbivory and insect attacks, which can cause direct and indirect damage to pepper crops, corroborating the agronomic importance of this trait (Lannes 2005; Moura et al. 2013). When evaluating 60 accessions of *Capsicum* spp., Neitzke (2012) reported that most accessions have green leaves (65%) and sparse pubescence (90%). Similarly, Padilha (2017) reported a predominance of green color (67%) and intermediate pubescence of leaves (95%).

The accessions exhibited a greenish-white color in the flower corolla (87%) and a greenish-white color with purple streaks (13%) (Fig. 2). Padilha (2017) reported greenish-white (38.09%), white (57.14%), and greenish-white with purple streaks (4.76%).

The accessions also exhibited high variability in anther color, with four distinct classes observed: purple/violet (47%), dark purple (24%), blue (22%), and yellow (7%) (Fig. 3).

When evaluating 38 accessions of *C. chinense* from the Upper Rio Negro, Amazonas, Fonseca et al. (2008) observed a predominance of purple anthers (47%). When evaluating anther coloration, Costa et al. (2015) observed violet/purple (77.5%) and blue (10%) coloration. Traits—such as anthocyanin stains on immature fruits and dark purple coloration of fruits—add value to pepper varieties in the ornamental market and, as a result, are traits of interest for improving peppers for ornamental purposes. Among the accessions, 44% expressed anthocyanin stains in the immature fruits (Fig. 4).

Capsicum chinense is recognized for its high variability among domesticated *Capsicum* species, characterized by significant variation in the color and shape of its fruits (Carvalho et al. 2003). Corroborating this, the present study identified eight classes of fruit color among the accessions: red (63%), yellow (11%), salmon (11%), orange-yellow (5%), dark purple (4%), wine-red (2%), orange-red (2%), and orange (2%). Additionally, Fonseca et al. (2008) observed nine classes of fruit color in *C. chinense* accessions.

The variability in fruit color observed here is a crucial characteristic of *C. chinense* germplasm, as this trait influences consumer purchasing decisions and is also related to aspects that add value to the crop trade, such as fruit pungency. Descriptors, such as fruit color and shape, are crucial in characterizing pepper germplasm, as they help breeders define the type of cultivar they want to obtain, whether for fresh consumption, processed consumption, or ornamental use (Neitzke 2012). Fig. 5 illustrates the high variability observed in the fruit color and shape of *C. chinense* germplasm collected from the Brazilian Amazon region and evaluated here.

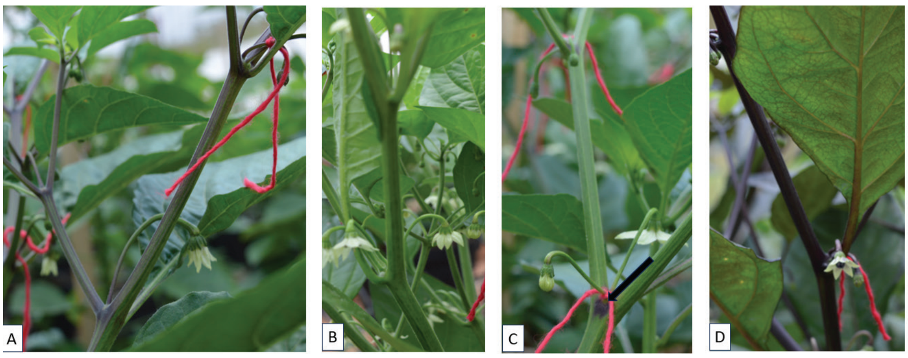

Figure 1. Variation in stem color among *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon. **A.** Stem with purple/violet streaks; **B.** Green stem; **C.** Green stem with purple/violet nodes; **D.** Purple/violet stem.

Figure 2. Variation in flower color among *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon. **A.** Greenish-white corolla; and **B.** Greenish-white with purple streaks.

Figure 3. Anther color observed among *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon. **A.** Purple; **B.** Dark purple; **C.** Blue; and **D.** Yellow.

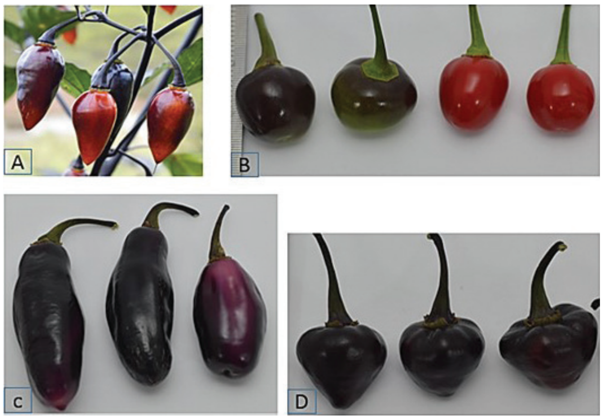

Figure 4. Fruit coloration among *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon. **A.** Fruits of BGH 8326; **B.** BGH 8309, fruits with anthocyanin spots; **C.** fruits of BGH 8288; and **D.** BGH 8323, dark purple fruits, possibly associated with higher levels of anthocyanin.

Matsufuji et al. (2007) evaluated the concentration of antioxidants in different-colored pepper fruits (*C. annuum* L.). They observed that ripe fruits with red, orange, and yellow colors expressed higher concentrations of carotenoids, alpha-tocopherol, sugars, and organic acids, compared to unripe fruits. According to these authors, red fruits expressed high concentrations of carotenoids, orange fruits presented concentrations of alpha-tocopherol, while the highest concentrations of sugars and organic acids were observed in red and orange fruits.

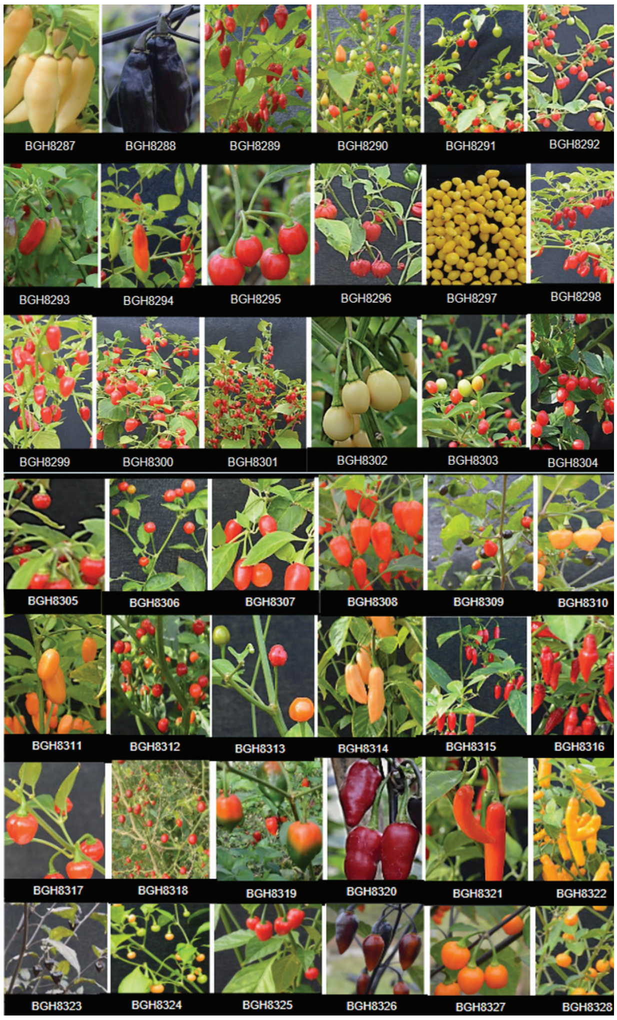

Figure 5. Color and shape variability of fruits among *C. chinense* germplasm collected from Rondônia in the Brazilian Amazon.

A triangular fruit shape was predominant among the accessions (40%), followed by round fruits (27%). Elongated and block fruit shapes were observed in 24% and 9% of the accessions, respectively Suppl. material 1: table 3. When evaluating 40 pepper accessions in Amazonas, Costa et al. (2015) observed a predominance of rounded, elongated, and other fruit shapes, including triangular, bell-shaped, and rectangular shapes at 35%, 25%, and 40%, respectively. Fonseca et al. (2008) evaluated 38 accessions in the Upper Rio Negro, Amazonas and observed triangular (42.1%), elongated (36%), and rounded (7.9%) shapes. Variability in the diversity of fruit color and shape is intrinsic to *C. chinense* spp. (Carvalho et al. 2003; Lannes et al. 2007).

Fifty-three percent of the accessions expressed a pointed fruit apex, 36% an obtuse apex, and 11% a hollowed/sunken fruit apex Suppl. material 1: table 3. Regarding the fruit shape at the peduncle union, 64% of the accessions expressed a truncated shape, 18% an obtuse shape, and 18% an acute shape. Most accessions expressed a smooth (80%), semi-rough (15%), and rough (5%) epidermis. Costa et al. (2015) observed fruits with a smooth (52.5%) and semi-

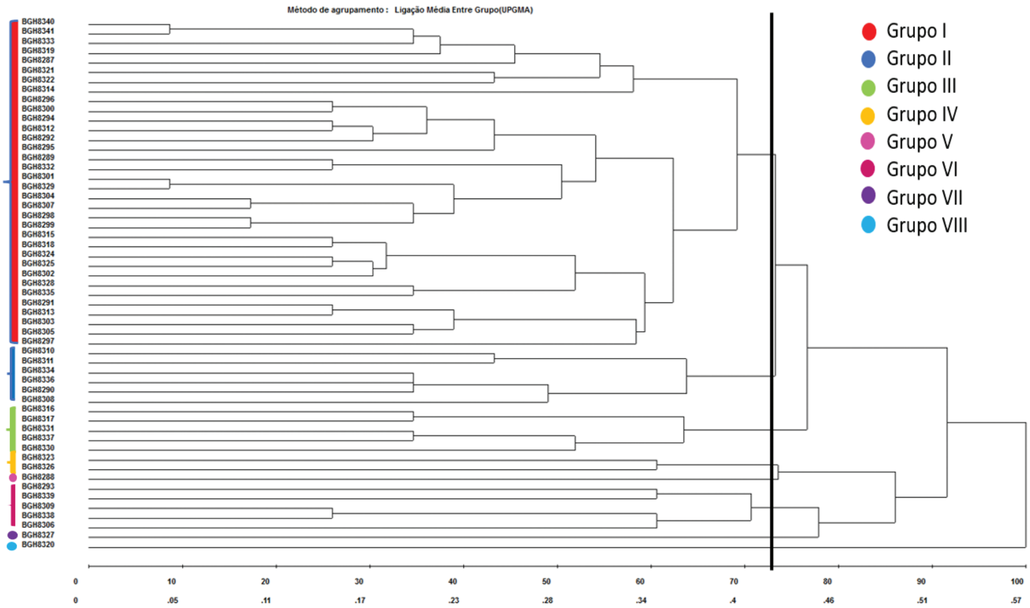

Figure 6. Dendogram showing the dissimilarity between the 55 *C. chinense* accessions, obtained by the hierarchical UPGMA method, based on 20 morphological descriptors.

rough (30%) epidermis, whereas Padilha (2017) recorded a smooth surface (19.04%), semi-rough surface (66.66%), rough and semi-rough epidermis (9.52%), and epidermis with streaks (4.76%). To analyze the dendrogram (Fig. 6), we considered the possibility of a considerable cut, as suggested by visual examination of the dendrogram, in accordance with Cruz et al. (2014). Thus, the cut reached ~73% dissimilarity, allowing the formation of eight distinct groups.

Büttow et al. (2010) investigated the genetic diversity of peppers and chilies, employing the same clustering method for 34 morphological descriptors and cutting at a genetic distance of 52%, which resulted in four groups. Costa et al. (2015) used a cut-off distance of 75%, forming eight groups based on 17 morphological descriptors.

Germoplasm clustering

The clustering (Fig. 6)—formed after the cut made in the UPGMA dendrogram—showed eight groups, allowing for better visualization. Most accessions were allocated to Group I (62%), which was similar to the Tocher cluster (Table 2). This demonstrates a high degree of similarity between these accessions with respect to the morphological descriptors of *C. chinense*.

The accessions in Group I were monomorphic for the following descriptors: growth habit, intermediate pubescence of the stem, angular shape of the stem, entire leaf margin, greenish-white corolla color, stigma position at the same level as the anthers, and intermediate seed size.

Clustering based on the Tocher optimization method formed eight distinct groups (Table 2), demonstrating coherence with the UPGMA method (Fig. 6). Group II clustered with six similar accessions. Common characteristics of these accessions include anthocyanin staining in the fruits, a triangular shape of the fruits, and a pointed apex. Group III clustered five accessions that exhibited similarities in terms of stem color, characterized by a green color with purple streaks on the stem. Group IV clustered two accessions that expressed 13 common characteristics: purple leaves and filaments, dark purple anthers, white corolla with purple spots, and anthocyanin staining on the immature fruit. Group V was isolated with only one accession, BGH 8288, which expressed an exclusive characteristic, dark purple leaves.

Groups III, IV, and V clustered the accessions that expressed characteristics of ornamental potential; therefore, it is possible to recommend these accessions for ornamental and gardening use. Group VI clustered five accessions that expressed seven common characteristics: intermediate pubescence of the stem, green leaves with entire margins, greenish-white corolla, anthocyanin staining in immature fruits, position of the stigma at the same level as the anthers, smooth surface of the fruit epidermis, and intermediate seed size. Groups VII and VIII consisted of only one accession each: BGH8327, with orange-colored fruit, and BGH8320, with wine-red fruit. According to Sudré et al. (2006), the qualitative characteristics of fruits, such as color and shape, are essential attributes in the consumer market.

Analysis of the dissimilarity matrix allowed identification of the most similar and dissimilar pairs of accessions. The greatest dissimilarity was observed between accessions BGH8306 and BGH8320 at a distance of 0.80%. These accessions differed from the others in expressing 16 different characteristics that corresponded to the most divergent accessions. Therefore, crossing accessions of agronomic and ornamental interests is recommended. Accessions BGH8340 and BGH8341 were the most similar, with a similarity value of 0.05%, indicating coincidence for 19 descriptors and differences only in fruit color, demonstrating a low level of polymorphism. These accessions belong to a group known as "biquinho" from the same parental lineage.

BGH8323, BGH8326, and BGH8288 deserve special mention because of their peculiar characteristics associated with high concentrations of anthocyanins in the stems, leaves,

Table 2. Representation of the accession clustering from the Tocher optimization method.

GRUP	Accessions						
I	BGH8340	BGH8341	BGH8333	BGH8319	BGH8287	BGH8321	BGH8322
	BGH8314	BGH8298	BGH8296	BGH8300	BGH8294	BGH8312	BGH8292
	BGH8295	BGH8289	BGH8332	BGH8301	BGH8329	BGH8304	BGH8307
	BGH8299	BGH8324	BGH8325	BGH8315	BGH8318	BGH8302	BGH8328
	BGH8335	BGH8291	BGH8313	BGH8303	BGH8305	BGH8297	
II	BGH8310	BGH8311	BGH8334	BGH8336	BGH8290	BGH8308	
III	BGH8316	BGH8317	BGH8331	BGH8337	BGH8330		
IV	BGH8323	BGH8326					
V	BGH8288						
VI	BGH8293	BGH8339	BGH8309	BGH8338	BGH8306		
VII	BGH8327						
VIII	BGH8320						

fruits, and corollas, which confer light-purple and dark-purple/violet colors to these structures. This characteristic is highly valued in the ornamental sector, demonstrating that these accessions are promising for pepper breeding programs for ornamental purposes. Sudré et al. (2006), Neitzke et al. (2010), and Rego et al. (2011) also identified accessions with the potential for ornamental use in their studies on *Capsicum* spp.

Relative contribution of traits to variability

Analysis of the relative contribution of morphological descriptors to variability among the accessions revealed that flower position, fillet color, anthocyanin spots, and fruit apex shape contributed the most to diversity at 10.7%, 10.1%, 10.6%, and 9.3%, respectively (Table 3). It is worth highlighting that, although SP and SS expressed contributions < 1% (Table 3), they were still important in assisting in accession discrimination and should not be eliminated in diversity studies.

Table 3. Relative contribution of morphological descriptors to genetic divergence among the 55 accessions of *C. chinense*.

Traits	Contribution %	Traits	Contribution %
PGH	6.4	**AC**	3.5
SP	0.97	**FC**	10.1
SC	3.53	**SP**	6.4
SS	2.9	**AS**	10.6
LS	4.8	**RFC**	2.3
LC	2.85	**FS**	3.5
LM	1.5	**FSP**	6.9
LP	5.2	**FAS**	9.3
FP	10.7	**FE**	3.2
CC	4.8	**SS**	0.8

PGH: Plant growth habit; SP: Stem pubescence; SC: Stem color; SS: Stem shape; LS: Leaf shape; LC: Leaf color; LM: Leaf margin; LP: Leaf pubescence; FP: Flower position; CC: Corolla color; AC: Anther color; FC: Fillet color; SP: Stigma position; AS: Anthocyanin spots; RFC: Ripe fruit color; FS: Fruit shape; FSP: Fruit shape at the peduncle union; FAS: Fruit apex shape; FE: Fruit epidermis; and SS: Seed size.

Conclusion

The germplasm panel assessed here showed high variability for most morphological descriptors, reflecting a high number of phenotypic classes. The observed variability was particularly high for the morphological descriptors of flowers and fruits, such as flower position, filament color, anthocyanin spots on fruits, and fruit apex shape.

Accessions BGH8288, BGH8309, and BGH8323 exhibited light and dark purple/violet colors in their stems, leaves, fruits, and corollas, possibly due to higher concentrations of anthocyanins in these structures. These accessions are promising candidates for inclusion in *Capsicum* spp. breeding programs targeting the ornamental market.

The results of this study elucidated the conservation status of *C. chinense* germplasm in the Brazilian Amazon, indicating that the in-situ conservation of this species preserves high variability in the region and is strategic for the genetic breeding of *Capsicum* spp., which are an important source of genes for this genus.

Author contributions

Conceptualization: D.J.H.d S. Data curation: S.R.S. Investigation: S.R.S. Sofware: R.D.S.R. Supervision: D.J.H.d S. Writing of the original draft: S.RS. Writing, reviewing, and editing: R.S.G.

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Supplementary material

Supplementary material 1
Supplementary information (docx)
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