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Traditional management affects the phenotypic diversity of fruits with economic and cultural importance in the Brazilian Savanna

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Abstract The management of plant populations may cause phenotypic changes in the characteristics of a plant that is targeted by human selection over time, which can therefore lead to the domestication process. Studies about this approach have shown that managed plant populations have the most interesting features for use by human populations because they have more productive plants and larger fruits. To evaluate this effect, the traditional management of *Caryocar coriaceum* Wittm (pequi) in the Chapada do Araripe region of Northeast Brazil was studied by using a morphometric and ethnobotanical approach. A morphometric analysis of the fruits was conducted, during which the plants were recorded to the following three different management regimes: cultivation, in situ management (collection) and incipient management (the tolerance and protection of individuals). To test the hypothesis that people perceive natural morphological variations in the fruits, local people perception was assessed through different methods. To assess the possible influence of management regimes on fruit morphology, 40 reproductive individuals cultivated, 40 managed in situ and 36 individuals under incipient management were randomly selected, and 20 fruits of each were collected for the morphometric analyses. The fruits from individuals grown under the cultivation system were significantly different from the individuals who were managed in situ and from those under incipient management. The perception study showed that local people perceive great morphological diversity among the study populations, which was consistent with the findings of the morphometric analyses. Based on these results, it could be said that *C. coriaceum* is in the early stage of the domestication process.

Keywords Artificial selection · Directed management · Ethnobotany · Evolutionary ethnobiology · Phenotypic variation · Plant domestication

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Introduction

With the management of resources over time, human selection can lead to genetic and/or morphological changes in organisms that are the targets of human attention (Pickersgill 2007; López-Palacios et al. 2015). Studies on morphological changes in managed plant populations have been used to estimate variations in patterns and levels of diversity (Zizumbo-Villarreal and Piñero 1998; Vargas and Blanco 2000; Zizumbo-Villarreal et al. 2005), and for identifying useful phenotypes for domestication (Gwali et al. 2012).

Some of this research has shown that human selection leads to morphological changes in populations under different management regimes (Arellano and Casas 2003; Casas et al. 2007; Lins Neto et al. 2013). When they are selecting plants, human groups can favor the frequency of individuals that have preferred phenotypes that meet their economic, social and/or cultural needs (Lira and Casas 1998; Gepts 2004; Lins Neto et al. 2012). Plant populations under different management regimes (such as managed in situ and cultivated crops) provide fruits, which are a major target of human selection (Arellano and Casas 2003; Aguirre-Dugua et al. 2012; Lins Neto et al. 2014) and differ significantly when compared with wild populations (or less managed populations) (Casas et al. 1999; Cruz and Casas 2002; Arellano and Casas 2003; Lins Neto et al. 2014). Genetic alterations also occur as a result of managing plant populations that are associated with human selection, and thus play important roles in maintaining genetic diversity (Cruse-Sanders et al. 2013).

Although prospective changes in the target characteristics of human selection are well documented for species of cacti and some herbaceous plants (Casas et al. 2007; Parra et al. 2012), this model has been subjected to incipient testing for woody plants species, especially long-lived tree species (Miller and Gross 2011). In spite of these tests, previous studies on trees have indicated that the preferred phenotypes for human groups have been found in cultivated and tolerated populations (Casas and Caballero 1996; Zárate 2005). Tree species such as *Olea europaea* L. subsp. *europaea* (Zohary and Hopf 2000), *Sideroxylon palmeri* (Rose) Pennington (Gonzáles-Soberanis and Casas 2004), *Ceiba aesculifolia* (HB & K) Britten and Baker (Avendaño et al. 2006), *Spondias tuberosa* Arruda (Lins Neto et al. 2012) and *Crescentia cujete* L. (Aguirre-Dugua et al. 2013) are among the relevant woody species that have been studied from this perspective. These studies have shown that the human maintainers of managed plant populations hold accurate knowledge of the morphological variations in the structures that are targets of selection. The recognition of population variants is a crucial aspect of artificial selection (Blancas et al. 2013). Thus, the perception of morphological variations by people may indicate that the current process of domestication of native economic importance plants is driving by conscious exploitation patterns (see Zohary 2004 for a discussion of conscious and unconscious forms of selection and management of natural resources). Intentional human selection is a prerequisite for domestication (Clement et al. 2010).

In this context, this paper addresses the pequi (*Caryocar coriaceum* Wittm), a native tree species that bears fruits of great importance to the local people of the Araripe region in northeast Brazil; these people have been handling this species for at least two centuries. Hence, the objective was to analyze the people/plant relations from the perspective of traditional management and the incipient domestication process from two perspectives, namely ethnobotanical and morphometric. For the purposes of this study, agricultural practices at a small scale in local (rural) communities that employ the natural resources of tropical forests are considered traditional management. Thus, the intention was to answer the following: Do the local people perceive the morphological diversity in pequi fruits in light of the different management regimes employed? The hypothesis is that the morphological diversity of pequi fruits will be perceived by local people and related to the distinct management regimes in use.

There was also a question as to whether there are phenotypic differences in fruits between the *C. coriaceum* populations that are subject to different management regimes. The hypothesis is that *C. coriaceum* individuals differ phenotypically among populations under different management conditions (cultivation, in situ and incipient), but that there are no differences between individuals of the same population. Cultivated populations are expected to have higher averages for the study variables when compared with other populations. To test whether the type of management regime affects other plant parts

beyond the reproductive structures (covariance), there was a question as to whether the phenotypic characteristics of the vegetative parts such as the heights and diameters at ground level (DGL) exhibit differences under different management regimes. The hypothesis is that individuals from different management regimes differ phenotypically. There are expected differences in the height and DGL between individuals under cultivation, in situ and incipient management.

Materials and methods

Study area

This study was developed in the Araripe National Forest (FLONA), in the adjacent community of Distrito Horizonte and São José of the Chapada do Araripe region, in the southern state of Ceará (NE Brazil). The National Forest was established in 1946 by the federal government to reconcile nature conservation with the sustainable use of natural resources. The National Forest is a category of protected area that constitutes the Group of Sustainable Use Units (Snuc 2002). The forest has an area of approximately 38,000 hectares, encompassing the municipalities of Crato, Barbalha, Jardim and Santana do Cariri. The vegetation consists of cerrado (Brazilian Savanna) areas and areas of transition between semi-evergreen rain forest, cerrado, cerradão and carrasco (IBAMA 2010).

In the FLONA surroundings, there are approximately twenty human communities that are historically extractive, among which Distrito Horizonte (07°29′36.9″S, 39°22′6 02″W) is one of the largest and most important. This local community has approximately 1120 inhabitants (Lozano et al. 2014) who use the resources of the FLONA as their primary sources of livelihood. Agriculture and extractivism are the primary activities, and the pequi (*C. coriaceum*) is one of the primary resources extracted from the forest. For more than a century (Gonçalves 2008), the human populations from Horizonte have related to the various features found in the National Forest at that location.

At the foot of the plateau is the São José community in the Arisco region, in which a pequi that is locally known as "pequi do Arisco" can be found. At approximately 30 km from the forest, the Arisco region is within the Environmental Protection Area (APA). *C. coriaceum* populations have been historically managed here, presenting, according to the locals, the best fruits, which are larger and of better quality (tasty and attractive fruits) in relation to the fruits of the forest.

Data collection

To study the variability and perception of morphological variation, three *C. coriaceum* populations were selected and each was classified into three different management regimes as follows: in situ management, incipient management and cultivation. These management regimes are based on the work of (Gonzáles-Insuasti and Caballero 2007). The intentional (non-selective) and non-opportunistic (not occasional) practice of collecting fruit from native vegetation areas in which individuals that spontaneously occur in the forest are found was considered in situ management. Incipient management is related to the practice of tolerance (plants are left standing) and the protection of individuals that spontaneously occur in areas adjacent to the National Forest (Casas et al. 2007; Lins Neto et al. 2013). In this type of management, pequi is recognized locally as "zelado" (nurtured). Finally, the cultivation thought to favor pequi individuals is locally known as "pequi do arisco". From sowing in a small-scale local management, cultivation involves growing plants in environments with different degrees of protection performed by people, such as control of weeds and predators, irrigation and soil tillage (Pickersgill 2013). For the selection of these populations, the statements of local people were taken into account, and these individuals participated in the previous study (see Sousa Júnior et al. 2013).

Perception of morphological variation

To test the hypothesis that local collectors perceive morphological variations in pequi fruit, it was necessary to collect data on local perception, and thus it was necessary to request consent through the Free and Informed Term of Consent (FITC) (according to Resolution No. 466, dated 12/12/2012). This research was submitted to the Ethics Committee (CEP) and approved under number 412/11 by the CEP of the Health Sciences Center, Federal University of Pernambuco.

Semi-structured interviews were conducted with the community collectors, and they were based on semi-structured scripts (Albuquerque et al. 2014a). Through meetings in the community, some collectors (key informants) who are recognized as experts in collecting pequi were identified and interviewed. After the first interviewees, the rest were sampled and selected on the basis of the "snowball" technique (Bailey 1994), which consists of an intentional sample in which an expert informant indicates others, and the process was repeated for each new informant until all the experts were consulted (Albuquerque et al. 2014b). Thus, the total number of respondents was 56 collectors, with 28 women and 28 men. The following questions are contained in the script: (1) Are there differences between the fruits of the pequi tree? (If there is) What is (are) the difference(s)? Which one is preferred? Why? (2) What is the most frequently used part of the pequi tree?

To categorize the fruit sizes in the study in terms of morphological perception, an activity was held with twenty-two informants (within the sampling of 56 experts), which consisted of asking them to choose (among 500) ten fruits that were perceived as being under cultivation, ten of which were under incipient management and ten of which were under in situ management, with a total of 30 fruits per informant. The same activity was performed for the putamen. To perform this activity, 500 fruits and 500 putamens (the edible portion corresponding to the inner mesocarp, endocarp and seed) were randomly collected in the National Forest area, and then a morphometric analysis was conducted to test the differences according to the perception of fruit morphology (size) with respect to the types of management regimes. To test the perceived differences between each management regime, the lengths and the highest and lowest diameters of the fruits were measured to calculate the fruit volumes. The same was done for the putamens (cores containing the edible part).

Phenotypic variation

To evaluate the possible effect of different management regimes on *C. coriaceum* populations, three representative areas of different management regimes were selected, and individuals were identified for each of them and subsequently selected randomly. In two of the areas (in situ management and cultivation), 40 reproductive individuals were selected. In the area corresponding to incipient management ("zelado" pequi), 36 individuals were selected, for a sum of 116 individuals in the study. For logistical reasons, it was not possible to sample a higher number of individuals from the incipient management area or to sample forest individuals during the same year. The fruits from the "zelado" pequi area were collected in 2011, and the fruits from other areas were collected in 2014 because those were the rainiest years and were consequently more productive. During 2012 and 2013, collection was practically impossible for lack of fruit because of the drought. To collect the fruits in the region, a priori authorization was requested from the Chico Mendes Institute for Biodiversity Conservation (ICMBio), with authorization No 26882-1/SISBIO for 2011 and authorization No. 38093-2/SISBIO for the 2014 collection.

Of the 116 pequi individual trees that were sampled, 20 mature fruits were collected, for a total of 2320 fruits on which morphometric analyses were conducted. The quantitative variables under analysis were as follows: the weight, length and volume of the fruit; the weight and thickness of the bark; the weight, length and volume of the putamen and the thickness of the pulp. The putamen consists of the inner mesocarp, endocarp and seed, which are commonly called the core by the people of the region. The diameter and length measurements of the fruits were measured by using a caliper rule, and the volume was estimated by using the formula $4/3\pi abc$, where a, b and c are the length and the highest and lowest diameters of the semi-axis; the fruit in this study was considered to have an ellipsoid shape. The weights of the fruits and of the fresh bark were obtained with the aid of a semi-analytical balance. The thickness of the fresh pulp was measured with a caliper rule.

In addition to the above variables, the populations were compared with respect to the phenotypic characteristics of some vegetative parts, such as the height and circumference at ground level (CGL), to check if the management regime types affect other parts of the plant beyond the reproductive structures (fruit). For the analysis, the circumference at ground level was converted to the diameter at ground level, on the basis of the following formula: diameter at the ground level [DGL = Circumference at ground level (CGL/π)].

Data analysis

To test if there are phenotypic differences between the *C. coriaceum* populations that were studied under different management regimes (in situ management, incipient management and cultivation), analyses of variance (ANOVA—one way) were conducted, with a comparison of means by Tukey's test (95 % confidence) a posteriori to assess how the morphological characteristics differed between populations according to their management type. The R 2.3.1 program was used for these analyses (R Development Core Team 2011). To test the hypothesis in which cultivated individuals differ significantly among different management regimes, a hierarchical cluster analysis (CA) was conducted to classify the sampled individuals according to their morphological similarities to explore if their similarities are related to the management regime type. This analysis accounts for the average of all variables per individual, and because of the differences between the measurement units of the variables, the values were standardized. The height and diameter parameters at ground level (DGL) were subjected to non-parametric statistical tests (Kruskal–Wallis test at 5 % probability), given the non-normality of the data. To analyze the perception of the fruit morphology (size) under each type of management regime, the volumes were calculated (from 220 fruits and 220 putamens, corresponding to ten fruits and ten putamens per informant), which were related to each type of management according to their classification as large, medium and small. Subsequently, an analysis of variance was conducted by non-parametric statistical Kruskal–Wallis test (5 % probability) for both the fruits and the putamens.

Results

Perception of variations in *C. coriaceum* fruits

Of the 56 people interviewed, 78.6 % affirmed that there was organoleptic variation in the fruits of the pequi tree (*C. coriaceum*). The taste of the fruit, which can be sweet ("yummy") or bitter, was cited as one of the major organoleptic characteristics for the pequi. Another perceived variation was the color of the pulp, which can be white or yellow. Fruits with white pulp were the most frequent (41.07 %) relative to fruits with yellow pulp (8.92 %), with white-pulped fruits being more preferred by collectors because they are considered to have a better taste. Another feature of the pequi tree, as perceived by the informants, is the size of the fruit. There is variation in the morphological perception of the pequi tree fruits (in 80.35 % of interviews), indicating the existence of varying sizes. The size perception of the fruits and putamens, which were classified as large, medium and small and related to the type of management regime, presented significant differences between each of the different regimes, with the large size related to cultivation, the medium size to incipient management and the small size to in situ (forest) management (Table 1).

The local perception of differences in fruits between cultivated populations that were grown under incipient management ("zelado") and managed in situ is related to the different management practices that the collectors perform on *C. coriaceum* populations. The most significant management practices were collecting the fruit (100 %) in the forest (the area of in situ management) and the so-called practice of "zelar" (*nurturing)* pequi (67.8 %) in the areas of human habitation in the vicinity of the forest (incipient management areas).

The practice of protection (locally called *zelar*) of the pequi consists of pruning the dead branches, opening glades for shady individuals and eliminating host species (epiphytes). The performance of this practice on individuals in the forest interior is not permitted because the FLONA is a protected area. Cultivation (which is very recent and performed at a small scale) is related to pequi trade demands because the collection of these fruits in the forest has not led to this type of demand.

Furthermore, cultivation involves some local management practices such as large seed selection (from individuals who are recognized as having large fruits), seedling irrigation during the dry season, and plant protection. The local farmers also perform dormancy breaking using some local practices, such as drying the seeds under the sun for three days and subsequently immersing them in the water for three additional days. Moreover, rural farmers do not use chemicals in the management of this species. Information on the breeding system of this species is scarce. However, since its congener (*Caryocar brasiliense*) is self-compatible (Gribel and Hay 1993), it is possible that *C. coriaceum* also shows this behavior.

Table 1 Perception of local experts on the sizes (volume) of pequi (*Caryocar coriaceum* Wittm) fruits and putamens with respect to three different management regimes

Population	Size of fruit Mean* ± SD	Putamen Mean* ± SD
Cultivated (large)	181.56 ± 9.16	625.93 ± 58.84
Incipient management (medium)	110.49 ± 17.6	415.74 ± 62.69
In situ management (small)	61.43 ± 14.14	261.92 ± 43.57

* All averages differed significantly ($p < 0.001$) with one another by Kruskal–Wallis test at 5 % probability

Phenotypic variation

There are significant differences among the three populations with regards to different management regimes for all morphological characteristics. The analyses indicated that there are differences in the nine studied traits (Table 2). Except for the variable length of the fruit ($F = 23.9823$, $p > 0.05$), the cultivated population was significantly different from the others in terms of all other variables. The populations managed in situ and under incipient management, zelado (nurtured) pequi, differed significantly in the fruit length ($F = 23.9823$, $p < 0.01$), putamen length ($F = 146.9718$, $p < 0.01$), pulp thickness ($F = 33.8946$, $p < 0.05$), fruit volume ($F = 238.49$, $p < 0.01$) and putamen volume ($F = 136.5118$, $p < 0.01$) variables. According to the analyses of variance, the fruits were generally observed to be larger in the cultivated population relative to the populations that were managed in situ and under incipient management, thus confirming our hypothesis. The CA was consistent with the results of the variance analysis, indicating the formation of two groups according to their morphological similarities (Fig. 1). One of the groups was formed by individuals under the cultivation regime and in situ management, and the second was formed by the incipient management population.

The hypothesis that individuals from different management regimes differ phenotypically with regards to their vegetative parts, heights and diameters at ground level (DGL) was refuted. There was no significant difference between the populations of different management regimes for the height

Table 2 Analysis of morphometric variables in *Caryocar coriaceum* Wittm fruits under three different management regimes (cultivation, in situ management and incipient management) of the Chapada do Araripe region, northeast Brazil, with data collected in 2011 and 2014

Variables	Population		
	Cultivation Mean ± SD*	In situ management Mean ± SD	Incipient management Mean ± SD
Fruit length	5.75 ± 0.58a	4.80 ± 0.65ab	5.45 ± 0.92ac
Fruit weight	127.09 ± 44.69a	87.42 ± 28.27b	75.30 ± 22.56b
Fruit volume	892.16 ± 277.25a	501.51 ± 184.76b	131.32 ± 45.30c
Bark weight	86.29 ± 32.17a	63.96 ± 21.60b	53.82 ± 16.34b
Bark thickness	1.04 ± 0.24a	0.92 ± 0.24b	0.92 ± 0.19b
Putamen length	4.67 ± 0.45a	3.81 ± 0.46b	3.23 ± 0.39c
Putamen volume	255.84 ± 65.40a	146.74 ± 45.39b	107.02 ± 34.66c
Putamen weight	40.62 ± 15.61a	23.31 ± 8.24b	21.07 ± 8.18b
Pulp thickness	0.37 ± 0.09a	0.30 ± 0.07b	0.26 ± 0.05c

* Means followed by the same letter on the line do not differ significantly from one another according to the Kruskal–Wallis test at 5 % probability

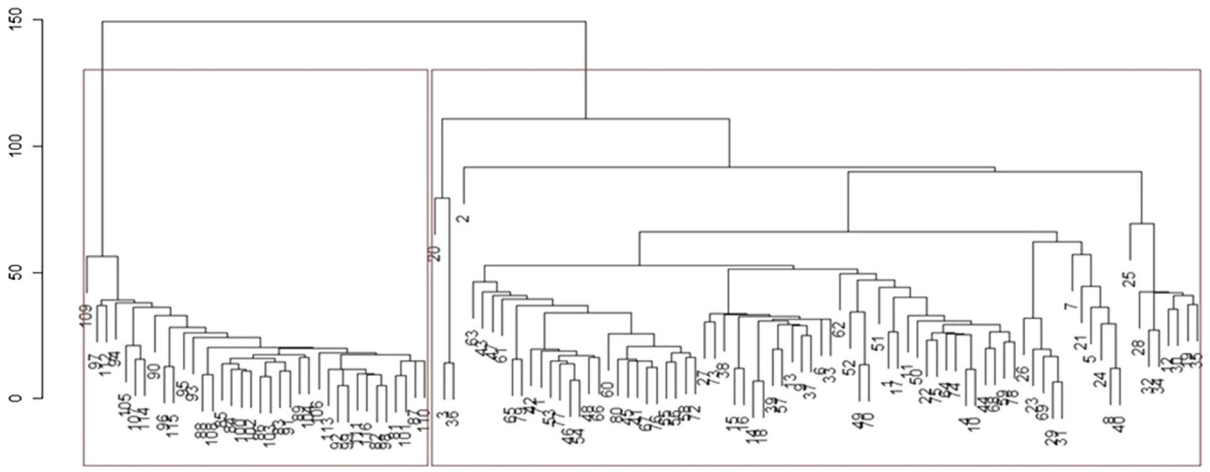

Fig. 1 Classification of populations *Caryocar coriaceum* using cluster analysis. (There is formation of two groups delimited in *red*: a largest formed by the cultivated and managed in situ populations and a less formed by the incipient managed population)

parameter (H = 1.42; $p = 0.49$) or the DGL (H = 5.22; $p = 0.07$) (Table 3).

Discussion

Perception of morphological variation

The color and size of the pequi tree fruits were also noted by collectors as target characteristics for selection, a trend that is also observed in other studies that distinguish populations under different management regimes (Casas et al. 1997; Casas 2005). Our hypothesis that the morphological diversity in pequi fruits is perceived by local collectors was confirmed. The fruit size was the primary characteristic that was perceived as a variant in relation to the different management regimes employed in the Araripe region. The perception of morphological variation has allowed human groups to manage plant species to favor the varying characteristics between populations (Casas and Caballero 1996; Lins Neto et al. 2010, 2013). This perception is also important for the conscious selection of desirable traits in plant species during the process of in situ domestication (Casas et al. 2007). In addition, the local perception indicates that traditional management and the plant domestication process are currently being conducted solely by intentional (conscious) selection (Zohary 2004). Besides being a favorable condition for the occurrence of domestication (Clement et al. 2010), conscious selection is also a distinctive landmark of in situ management during the plant domestication process (Casas et al. 2007; Pickersgill 2013). This perspective is a counterpoint to the understanding of conscious selection as an after-domestication occurrence (Zeder et al. 2006).

Table 3 Phenotypic characteristics of *Caryocar coriaceum* Wittm individuals from the Chapada do Araripe, northeast Brazil, under three management regimes

Management	Height (m) $X \pm$ SD*	DGL (cm) $X \pm$ SD
Cultivation	9.3 ± 1.8a	38.3 ± 12.8a
In situ	9.4 ± 2.9a	38.2 ± 13.9a
Incipient ("zelado")	8.5 ± 2.9a	30.4 ± 14.2a

DGL diameters at ground level

*Means followed by the same letter on the line do not differ significantly from one another according to the Kruskal-Wallis test at 5 % probability

This view suggests that management is directed to favor features of human interest, which is a strong factor in morphological diversity, especially with regards to the species of great economic importance. Therefore, this management is often intensified (Blancas et al. 2013). This type of management (directional), which is considered the primary cause of phenotypic diversification (Rieseberg et al. 2002), is an important activity because it can contribute to the sustainable management and genetic diversity of plants in traditional agro ecosystems (Duputié et al. 2009) and amplify the divergence between these populations over time (Casas et al. 2006). Studies have often shown that plant populations of managed and

cultivated areas present the most interesting features for local human groups in relation to wildlife populations (Cruz and Casas 2002; Carmona and Casas 2005; Rodrígues-Arévalo et al. 2006). Although each human community has its own selection criteria, the conscious management directed at obtaining the preferred characteristics is an important driving force for social-ecological systems.

The food and economic importance of pequi is a factor that has contributed to the use of different management practices on this species. The extensive collection of fruits in the forest is related to the abundance of pequi populations in relation to other areas. This relation indicates that the areas that are more frequently assessed for collection will necessarily be the managed ones, as found by Lins Neto et al. (2010) for *Spondias tuberosa*, because the commercial value is a relevant factor that influences the degree of management intensity (Gonzáles-Insuasti and Caballero 2007; Blancas et al. 2013). Furthermore, the population areas with a higher degree of management (cultivated) are very few when compared with the native vegetation areas (FLONA). The areas with incipient management individuals ("zelado" pequi) are also fewer. It is noteworthy that the "zelado" (*nurtured)* pequi (populations considered to be under incipient management in this study) was, in this case, the tree individual that was maintained and protected in a similar way to the protection provided to other plant species, which was also observed in other studies (Avedaño et al. 2006; Lins Neto et al. 2010), indicating that the promotion and protection of individuals is a management tool that plays an important role in the domestication process. The elimination of unwanted individuals as shown in other plant species (Casas et al. 1997) was not observed in the case of pequi, according to collectors, which was similar to a study of another important tree species in northeastern Brazil (*Spondias tuberosa*) (Lins Neto et al. 2010), which did not show elimination. Pequi is not eliminated because it represents an important source of income and food. In addition, people collect the best fruits from pequi trees, even when they are less desirable (smaller and less tasty) because the fruits can be used to produce an oil that has commercial value. The importance of *C. coriaceum* can also be noted in the appreciation that collectors have for the species, which is often compared by local people to a "family man" (Sousa Júnior et al. 2013). This description indicates its cultural importance from the perspective of traditional management and underlines the theoretical gaps that have not yet been filled, with questions about what leads certain species to be selected over others for management. Therefore, cultural and economic factors such as the importance of plants in human subsistence and ecological factors such as the distribution and abundance of species play crucial roles in the interactions between people and plants (Casas et al. 2007). Blancas et al. (2013) also show that the number of uses of a species and its abundance and distribution are important indicators for the management of plants, which is driven in response to food security and resource scarcity.

Morphological variation

Morphometric analyses have indicated that *C. coriaceum* individuals differ phenotypically according to their management type, confirming our hypothesis that *C. coriaceum* individuals differ phenotypically between populations under different conditions (cultivation, in situ management and incipient management). In general, the phenotypes preferred by local people were more abundant in cultivated populations, and therefore, the average values for the studied characteristics were different between the management types. As described above, the fruit size is a major feature for humans, and this fact indicates that human selection has favored this feature, particularly in cultivated populations in which the desirable characteristics are selected. The confirmation of our hypothesis shows that the management regime model for analyzing morphological diversity from the perspective of human selection and incipient domestication process, as already tested for many other non-woody plant species, is also suitable for woody species, as studied in *Spondias tuberosa* (Lins Neto et al. 2012), *Crescentia cujete* (Aguirre-Dugua et al. 2013) and in this work on pequi.

In addition to the fruits, other plant parts tend to be analyzed, such as flowers and some vegetative parts (branches, height) (Parra et al. 2012), to test whether the management regime type affects other parts of the plant beyond the reproductive structures. For *C. coriaceum*, there were no observed differences in the studied vegetative parts (height and DGL). This finding may be indicative that the selection of a particular characteristic as a target does not

necessarily lead to concurrent changes in other parts of the plant. Furthermore, there may be more variations in secondary metabolites for tree species as a result of human selection than in other syndromes commonly related to annual species (Meyer et al. 2012). Although other characteristics (in the reproductive and vegetative parts, such as in the flowers and branches, respectively) were not analyzed in this study, the results of the local perception along with morphometric data are strong evidence of the role of human selection in the evolutionary process of plants at the incipient stage of domestication. If human selection is considered a decisive factor in this process, then a selection that is directed to a particular target characteristic is expected, even if other features are indirectly selected or not during the process. Thus, the results for *C. coriaceum* indicate a strong trend in the influence of human selection on plant species populations, and they are in accordance with the findings of other studies (Cruz and Casas 2002; Arellano and Casas 2003; Lins Neto et al. 2012, 2014), which are therefore indicative of the role of traditional management in morphological changes in plant populations.

The formation of two groups, according to the cluster analysis, was not consistent with the perception of a continuum that local collectors have in relation to the fruit's morphological diversity. According to this continuum, the populations under cultivated and incipient management would be more similar to one another; however, incipiently managed populations were observed to be less similar to the cultivated plants and more similar to those managed in situ, and the latter were more similar to the populations under cultivation. This finding may be related to the proximity of these management types (incipient and in situ management) or because the populations under in situ management likely have the same management history as the populations under incipient management. This fact may be evidence of past management that was conducted in the area in which the population was managed in situ (National Forest), which was once inhabited by local human groups approximately 60 years ago and is a sustainable-use conservation unit today. Thus, the native individuals that are found inside the FLONA experienced some degree of management in the past, which is why we have not considered the forest individuals to be wild.

The size of the *C. coriaceum* fruit is a very important characteristic that influences even the collection dynamic inside the FLONA (Sousa Júnior et al. 2013), with the largest fruits generally collected for sale while the smaller ones are used for oil production. In this way, people grow pequi trees individuals with the aim of producing larger fruit that is of better quality, not only for consumption but also for trade (Sousa Júnior et al. 2013). This observation highlights the socio-economic aspect as a driving force based on the economy (Bürgi et al. 2004), which favors the manipulation of plant populations to meet the demands of human groups. Human selection (artificial) and traditional management are mechanisms that are therefore leading plant populations to domestication (Casas et al. 2007). Although environmental and genetic variables (which are not included in the current study) influence morphological variation, our evidence indicates human selection along with different management regimes (cultivation, in situ and incipient management) as strong factors favoring the differences in *C. coriaceum* fruit, and it follows the trends in studies of other species (Cruz and Casas 2002; Arellano and Casas 2003; Lins Neto et al. 2012, 2014). However, it is important to note that the perennial species may have different domestication syndromes from those found in annual plants (Meyer et al. 2012), therefore making it necessary to focus more on these differences in future studies.

Conclusion

The results presented here allow us conclude that the pequi fruits (*C. coricaceum*) shows great morphological diversity and that it is perceived by local people. Fruits from cultivated areas were significantly higher than from all others, corroborating the local perception of morphological variation related to the distinct management regimes in use. The fruit size is preferred feature for humans, who select this feature and keep it in cultivated populations. Although this study has some limitations (such as lack of sampling in other areas for each type of system studied), a crucial contribution of this work was to identify cultivation as the probable consequence of this human selection of a particular character (fruit). This result is observed in other tree species already described above. Although environmental factors can influence morphological variation, human selection is shown to be the driving force that favors morphological differences of the target character of this selection. In this study, for

example, the fruit, compared to other parameters of the species examined here (DGL and plant height), has shown morphological variation in relation to the management systems studied. The intentional selection of *C. coriaceum* fruit as well as the management forms used by local people may be evidence of the incipient process of domestication because the management of the pequi tree is a process that has was started long ago, and, as in all studies, the data from this work fit the time frame of this process. Nonetheless, genetic studies are needed for greater clarity on this issue.

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