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Adaptations of Pre-Columbian Manioc Storage Techniques as Strategies to Adapt to Extreme Climatic Events in Amazonian Floodplains

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Abstract

In Amazonian floodplains, manioc flour is the main plant food product and source of income for local populations. In the context of climate change, extreme flooding is more frequent and intense, making it difficult to cultivate and process manioc. As local knowledge is dynamic and fundamental to adapt in critical times, we studied local techniques for storing manioc roots, which allow them to be processed later. We conducted semi-structured interviews in three floodplains (*várzea*) communities (36 families) and three paleo-floodplain (*paleovárzea*; 1–3 m higher) communities (52 families) in the middle Solimões River basin (Brazil). Residents mention four techniques for storing fresh manioc; two were cited in archaeological or ethnographic studies (burial and basketing), and two were not cited before in the region (bagging and *kanaká*). In the paleovárzea, where manioc production is more important as a source of income, residents have more knowledge of manioc storage techniques. However, this knowledge also persists in areas where manioc has less importance for income generation. Residents of the study area express demand for disseminating these practices, as they can contribute to adaptation in critical periods.

Keywords *Ribeirinhos* · Traditional Ecological Knowledge · adaptive strategies · Indian bread · Brazil

Introduction

In Amazonia, local communities base their diet on fresh foods, from fishing, hunting, and harvesting wild or cultivated fruits and vegetables (Alencar, 2010; Dufour et al., 2016; Posey, 1985). In addition, local communities use traditional food processing, storage, and preservation techniques, such as the production of manioc flour (*Manihot esculenta* Crantz) (Denevan, 1996; Lentz, 2000), the leading plant food of current Amazonian populations and an important food source for past populations (Dufour, 1995; Dufour et al., 2016). In climate change scenarios, where extreme floods have become more frequent and intense (Cai et al., 2014; Marengo et al., 2013), local communities' livelihoods and diets have suffered changes (Ávila et al., 2021; Dubreuil et al., 2017; Funatsu et al., 2019; Langill & Abizaid, 2020; Tregidgo et al., 2020). In this study, we seek to identify the strategies used for manioc storage in the context of extreme floods in Amazonian *várzea* and *paleovárzea* ecosystems.

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Dry manioc flour is a primary source of carbohydrates (Dufour et al., 2016) in the Amazonian *várzeas* and *paleovárzeas* of the middle Solimões River basin. Dry flour is also local populations' main form of manioc storage (Lima et al., 2012). The region has already documented diverse methods for processing and consuming manioc (Venturato & Pereira, 2010). After harvest, the manioc flour produced is often the basis of family food security throughout the year; additionally, surpluses are sold locally (Adams et al., 2009; Fraser et al., 2012). The durability of manioc flour is also advantageous because in much of Amazonia refrigerating food is not viable (Tregidgo et al., 2020). Limitations include the high electricity costs, coming mainly from generators powered by fossil fuels and, rarely, with solar energy (Penteado et al., 2019; Valer et al., 2014), and refrigerators and freezers.

In Amazonia, the *várzeas* are flooded annually by white water rivers. At the same time, the *paleovárzeas* are only inundated in extreme flood years (Irion et al., 2010) because they are 1–3 m above the *várzeas*. Hence, the impacts of large floods between the *várzea* and *paleovárzea* agroecosystems are different and more intense in the latter environment (Ávila et al., 2021). Because manioc plants cannot withstand flooding for many days (Langill & Abizaid, 2020), local producers quickly seek to process the roots in local flour mills. However, these processing areas can also be flooded. Even if manioc flour mills are mounted on floating rafts, the community demand may be too high for everyone to process (Ávila et al., 2021).

Archaeological and ethnographic studies carried out in *terra firme* (non-flooded) regions highlight the importance of pre-Columbian food storage techniques (Furquim, 2018; Mendes dos Santos, 2016; Mendes dos Santos et al., 2021), especially for manioc (Fausto & Neves, 2018). One of the products, popularly called Indian bread (*pão de índio* or *pães de indio*), is currently found by chance or in excavations of archaeological sites (Mendes dos Santos et al., 2021). Many techniques have historically been used to produce *pães de índio*. *Pães de índio* are ways of preserving edible plant biomass for a period, especially starch-rich fruits and/or roots. When made with manioc roots, they first processed the manioc to remove anti-nutritional factors (such as prussic acid) and transformed the manioc into a dough, either cooked or raw; fruit mesocarps or seeds were ground into a dough. The dough is shaped, toasted/smoked or not, wrapped in waxy leaves, and buried. Depending upon treatment, *pão de índio* can last for months or years (Mendes dos Santos et al., 2021).

In addition, ceramics are historically used in Amazonia to prepare and store food (Costa et al., 2011). Because ceramics resist degradation in tropical climates, they are more easily found in archaeological sites (Neves, 2011). On the other hand, leaves, sticks, and vines rot quickly, making them difficult to record in archaeological sites. However, they were undoubtedly widely used, especially in emergencies, such as during extreme floods. Early reports of *pão de indio* considered it a colony of fungi (Araújo & Souza, 1978; Aguiar and Sousa, 1981) or fungus production for food purposes (Santos et al., 2014). However, more recent compositional analyses identified plant materials, mainly edible roots and fruits rich in starch, and their functionality as a form of food storage was confirmed (Mendes dos Santos et al., 2021). Similar to observations in Amazonia, other tropical countries where the manioc is an essential component of local diets use different short, medium, or long-term storage techniques (Knoth, 1993).

There are reports of manioc conservation through burials (Affran, 1968; Anon, 1944; Balagopalan, 2000; Knoth, 1993; Irvine, 1969), covering with various leaves or sawdust (Fadeyibi, 2011; Knoth, 1993; Osei-Opare, 1990; Rickard & Coursey, 1981), and also in plastic bags (Gallat et al., 1998; Knoth, 1993; Rickard & Coursey, 1981; Westby et al., 1999). Manioc storage techniques are believed to be a derivative of the common practice of leaving the roots stored in the field (unharvested) for several months after reaching maturity (Ingram & Humphries, 1972; Rickard & Coursey, 1981). Archeological studies in Amazonia demonstrate that *food storage* techniques were part of the region's ancient local ecological knowledge (LEK) (Furquim, 2018; Neves et al., 2014; Schmidt et al., 2014).

The knowledge about food storage, such as *pães de índio*, is valuable today, keeps changing, and can contribute to the future of local communities (Avila et al., 2021). Furthermore, it is essential to highlight that changing scenarios, with different social, economic, political, and environmental/ecological pressures, can result in a loss (Reyes-García et al., 2013; Aswani et al., 2018) or changes in LEK (Reyes-García et al. 2014). These pressures influence the dynamics of LEK, a significant area of study in ethnoecology (Gaoue et al., 2017). To manage flood risk, modern adaptation techniques can replace LEK with older techniques (Haughton et al., 2015). In the case of manioc storage, some techniques seem to be in disuse, such as *pão de índio* (Mendes dos Santos, 2021), while modern techniques with the same purpose can take their place. However, different techniques can enhance the resilience of local communities in the context of social, economic, and environmental change (Walker et al., 2004).

Recognizing the great importance of manioc as a source of food and income for *várzea* and *paleovárzea* communities, realizing how extreme flooding can make processing complex, and acknowledging the importance of the dynamics of local knowledge in critical moments, we investigated the techniques known and/or used by local communities

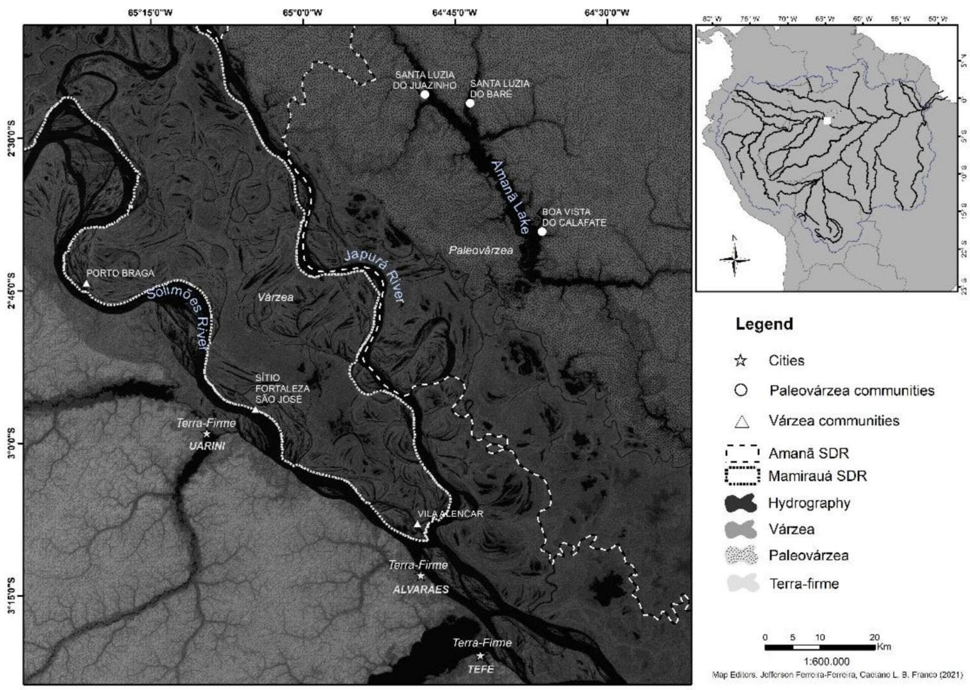

Fig. 1 The study area's map identifies the *várzea* and *paleovárzea* communities in the middle Solimões River region, Amazonas, Brazil

in the *várzea* and *paleovárzea* for storage of manioc roots that allow for further processing and consumption when the water recedes, and whether *várzea* communities know more techniques for storing manioc than *paleovárzea* communities. We hypothesize that: (1) local communities from both ecosystems know and/or use traditional (exclusively made using natural components from local ecosystems, such as fibers, sticks, and leaves, and mentioned in archeological studies about practices and knowledge of Pre-Columbian populations of Amazonia) and modern techniques, that use synthetic components (such as plastic bags) to store the manioc mass, and (2) because *várzea* is more frequently and intensely influenced by flooding, residents in these ecosystems know and use more techniques for storing manioc roots than residents living in the *paleovárzea* .

Methodology

Study Area

This study was conducted in the middle Solimões River basin (Amazonas, Brazil, Fig. 1) between August 2017 and May 2019. Local communities are considered *ribeirinhos*, local populations that historically inhabit the banks of rivers and experience the seasonal variation of waters in their daily lives (CNPCT, 2016).

The *várzeas* originated in the Holocene and are periodically flooded in regular annual cycles, in which soils are covered for up to six months with river waters rich in sediments with a high content of nutrients from the Andes (Ayres, 2006; Junk et al., 1989). *Paleovárzeas*, on the other hand, originated in the Late Pleistocene and are positioned in the landscape a few meters above the *várzeas*. However, this difference is more significant in regions closer to the mouth of the Amazon River (Irion et al., 2010). Thus, during the annual flood cycle, the *várzea* areas where *ribeirinhos* live and cultivate are usually covered by water for at least 1 to 2 months (Steward et al., 2020). On the other hand, the agricultural and living areas of *paleovárzea* communities are rarely flooded. During extreme flooding, most of the high *várzea* cultivation areas are covered by water, while in the *paleovárzea* only some cultivation areas are affected.

The *várzea* communities in this study are within the *Mamirauá* Sustainable Development Reserve (RDSM), and the *paleovárzea* communities are within the *Amanã* Sustainable Development Reserve (RDSA) (Fig. 1). According to the Köppen-Geiger system, the region's climate is tropical rainforest (Af), monthly rainfall is greater than 60 mm throughout the year (Peel et al., 2007), and the average rainfall is 2.200 mm (Ayres, 2006). The flood season (winter) is from December to May, and the dry season (summer) is from June to November (Bueno et al., 2019). On average, the water level of the Solimões River in the study region rises 10.6 m during the flood season and may rise by 15–17 m in more severe floods (Ramalho et al., 2010).

We conducted our study in six communities, three *ribeirinho várzea* communities (*Vila Alencar* (composed by 13 families), *Sítio Fortaleza* (14 families) and *Porto Braga* (33 families) and three *ribeirinho paleovárzea* communities

(*Santa Luzia do Juazinho* (23 families), *Bom Jesus do Calafate* (15 families) and *Santa Luzia do Baré* (6 families)). Information on the socioeconomic characteristics of the residents can be obtained from Ávila et al., (2021). Planting in the region is based on the cultivation of manioc in small areas, combined with the cultivation of other annual and perennial crops (Rognant & Steward, 2015).

Data Collection

We conducted semi-structured interviews with one household head per house until all available families were sampled, totaling 52 *ribeirinhos* in the *várzea* and 36 *ribeirinhos* in the *paleovárzea*. We interviewed one man or woman, more than 18 years old, per family unit. The semi-structured interviews focused on the storage of manioc in years of extreme flooding. For this, we asked if *ribeirinhos* knew any technique for storing manioc. In the case of a positive answer, we asked which techniques they knew. Some specific questions to understand the permanence or continuity of these techniques: (a) whether the *ribeirinho* only knew about the technique but did not know how to perform it, (b) whether the *ribeirinho* knew the technique sufficiently to perform it, and (c) whether the *ribeirinho* had already performed the technique (currently or in the past).

Data Analysis

Information about known and used storage techniques was categorized and analyzed using descriptive statistics. We used a generalized linear model with a binomial distribution using the program R (R Development Core Team, 2020) to verify if there are statistical differences in the *ribeirinhos*' knowledge about manioc storage between the *várzea* and *paleovárzea* ecosystems.

Results

Manioc Storage Techniques

In both the *paleovárzea* and the *várzea*, people from all communities reported that during significant floods they employ various storage techniques to store raw peeled manioc roots (locally called *massa da mandioca/*manioc mass) during the flood and process them into flour when waters recede. They say these techniques were practiced historically and learned from their grandparents and indigenous peoples. The guiding principle of most manioc storage techniques is the creation of an anoxic environment in order to eliminate or reduce oxygen. Four techniques were described in the study area: burial of manioc mass, basketing of manioc mass, bagging of manioc mass, and *kanaká* of manioc *puba.*

The first technique uses soil and leaves to create a more anoxic environment, called *enterrar a massa da mandioca* (burial of manioc mass). It consists of *ribeirinhos* burying the freshly peeled roots in pits excavated in the soil, which will remain submerged during the flood. The interviewees recognized this technique as widespread and ancient, practiced both in the *várzea* and *paleovárzea*. The technique follows these steps: (1) a 1-meter square pit is dug in the ground (depending on the amount of manioc to store, it can be larger or smaller), (2) the inner walls of the pit are lined with *cauaçú* (*Calathea lutea* (Aubl.) Schult.) leaves, which serve to prevent the roots from direct contact with the soil (one of the respondents mentioned that *embaúba* (*Cecropia* sp.) leaves may also be used for this purpose), (3) peeled manioc roots are placed in the pit up to the edge of the soil surface, (4) *cauaçú* leaves are used to cover all of the manioc roots, and (5) soil excavated from the pit is piled over the manioc to cover the storage pit (Fig. 2).

The second technique, *empaneirar a massa da mandioca* or *empalhar a massa da mandioca* (basketing or wrapping manioc mass), is also locally recognized as ancient and known in both ecosystems; it is cited as a simplified alternative to the first technique. It consists of (1) constructing a fiber basket (popularly called *paneiro*) using dry petioles of *cauacú* or some Arecaceae, (2) lining the fiber basket with *cauaçú* leaves or other leaves, such as *pariri* (cf. *Pouteria pariry* (Ducke) Baehni), (3) filling the basket with peeled manioc roots, (4) covering the top of the basket with *cauaçú* leaves, (5) tying the covering tightly with fiber rope (made using hanging aerial roots of *ambé* (cf. *Philodendron* spp.)), and (6) immersing the basket in the water. When employing this technique, the basket must be completely submerged during the entire storage period (Fig. 2). One of the interviewees also mentioned that the basket could be buried as in the first technique. Others recommended using a rope to support the basket on a tree without touching the river bottom because the manioc stored precisely where the fiber basket touches the river may show rotting signs.

Because major floods often rise quickly, the considerable work required for mass storage of manioc in pits, baskets, or cones may be impractical. About 30 years ago, residents adapted the basketing technique with woven plastic-fiber bags. It is essential that the bag be of woven fiber and not solid plastic since woven fiber bags allow water movement into and out of the bag. This variation is called *ensacamento da massa da mandioca* (bagging of manioc mass). The bagging consists of (1) placing the whole peeled manioc in woven fiber bags, (2) closing the bag with a rope, (3) with another rope, hanging the bag on a tree so that the bag is

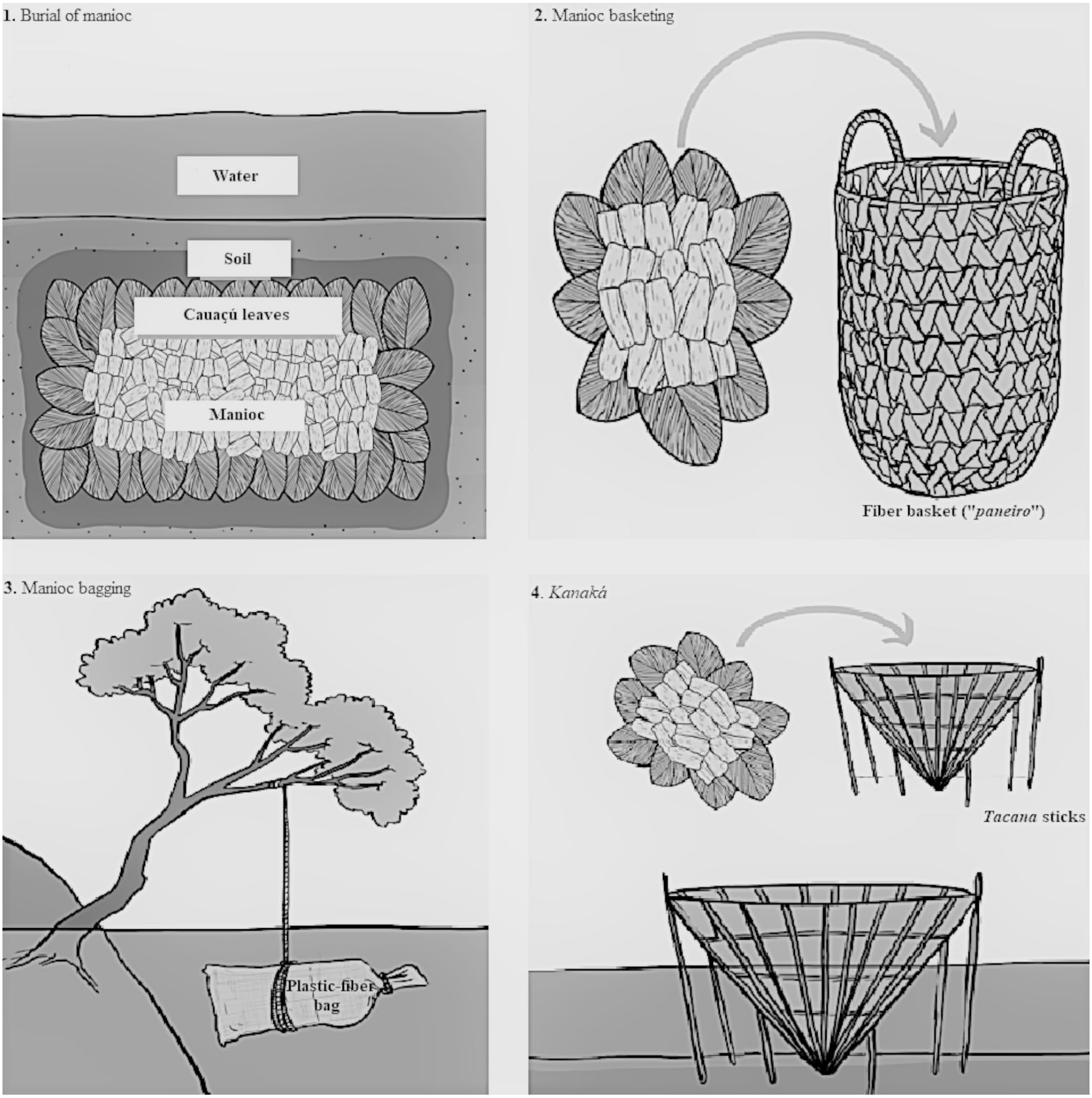

Fig. 2 Schematic drawings of techniques used for manioc storage during large floods in *ribeirinho* communities in *várzea* and *paleo-várzea* areas in the middle Solimões River region, Amazonas, Brazil. (1) Burial of manioc; (2) Manioc basketing; (3) Manioc bagging; (4) Peeled manioc roots wrapped in *cauaçú* leaves for storage in *Kanaká* and *Kanaká* submerged in water (Figures created by Maurício Afonso)

completely immersed in the water and does not touch the riverbed during storage (Fig. 2).

A fourth technique, locally called "*kanaká*" (Fig. 2), different from the techniques described above, uses ground manioc root mass (locally called *pubar a mandioca*), which is prepared in a sunken canoe along the river edge where the manioc roots are submerged in water for 2–4 days. As *kanaká* uses only natural components for its construction and was cited as used in the past, it was considered an ancient technique to preserve manioc. The *kanaká* steps include (1) in a region that will be flooded, build a cone with *tacana* sticks (cf. Poaceae) fixed to the ground, which is tied with *ambé* vine (cf. *Philodendron* spp.), (2) line the *kanaká* structure with *cauaçú* leaves, (3) place the wet ground manioc mass in the *kanaká*, (4) cover the *kanaká* with *cauaçú* leaves. In this technique, the wet ground manioc mass is

Table 1 Techniques of manioc storage are described in *várzea* and *paleovárzea* communities along the middle Solimões River in Central Amazonia, Brazil

	Cited in archaeological or ethnographic studies in Amazonia	Material required	Manioc preparation	Labor time	Duration of preservation	Threats like predation	Capacity	Quality of flour
Burial	Yes	*Cauaçú* leaves	Fresh peeled roots	Intermediate	At least 6 months	Low	High	Low
Basket (touching river bottom)	Yes	Fiber basket, fiber rope and *cauaçú* leaves	Fresh peeled roots	Intermediate	At least 6 months	Intermediate	Low	Low
Basket (free in current)	Yes	Fiber basket, fiber rope and *cauaçú* leaves	Fresh peeled roots	Intermediate	At least 6 months	Intermediate	Low	Intermediate
Bagging (touching river bottom)	No	Woven fiber bags	Fresh peeled roots	Fast	At least 6 months	Intermediate	Low	Low
Bagging (free in current)	No	Woven fiber bags	Fresh peeled roots	Fast	At least 6 months	Intermediate	Low	Intermediate
Kanaká	No	*Tacana* sticks, *ambé* and *cauaçú* leaves	Manioc root mass (manioc "*puba*")	Time consuming	At least 6 months	Intermediate	High	Intermediate

isolated from oxygen by the *cauaçú* leaves, allowing storage without oxidation and rot. In a large *kanaká*, manioc can be stored from an entire field (about 0,5 – 1.0 ha). After processing, such a kanaká yields between 8-10 bags of manioc flour- weighing 60 kg each.

The *kanaká* technique was mentioned only by one *ribeirinho* from the *várzea*. He was the oldest man interviewed (63 years) in *Sítio Fortaleza*, with greater traditional knowledge about the community. He was born in a municipality close to the study area (Fonte Boa) and remembered doing these techniques when he was young. However, in other projects conducted by the *Mamirauá* Institute, the *kanaká* practice was observed in other local communities along the middle Solimões River. As our interviews were not conducted in those communities, other mentions about *kanaká* in the region were not included in the results and figures of the present manuscript.

The techniques described above differ in difficulty, speed, and cost (Table 1). Manioc bagging is the fastest, easiest and cheapest technique, as it reuses bags used to pack manioc flour or other plant products. In the case of burial, the leaves must be collected, and there is more physical labor to dig the pit and bury the manioc. The basket, in addition to requiring the collection of leaves, sticks, and ties, also demands the ability to weave the fiber basket and sometimes bury or elevate it with a rope. Finally, the most time-consuming and laborious technique is the *kanaká.* It requires the collection of sticks, ties, and leaves and the structure's construction. The manioc mass must also be softened and ground, which takes at least three days to prepare.

Storage time varies with each technique, spanning the time from when cultivation areas are flooded, and the period they need to rebuild the manioc flour houses, which can vary from 1 to 4 months. In the scenario where extreme floods last longer, the *ribeirinhos* confirm that any manioc storage technique mentioned is effective and increasingly necessary.

Ribeirinhos interviewed mentioned that the flour from the stored roots can turn bitter. Because of this, they adopt specific processing techniques to remove the bitter taste. The primary way to do this is to place the previously stored manioc in a sunken canoe near the riverbank, letting the river water soak the roots and wash away the bitterness (in the same way they traditionally soften manioc to prepare the flour). Another strategy to help to remove the bitterness is to let the rainwater wash it off. Even when done effectively, interviewees mention that the flour produced for stored manioc is mainly reserved for family consumption, as its flavor and color can be less acceptable in the market.

Distribution of Knowledge in Different Ecosystems

Among the 88 people interviewed, 32% did not know any technique for storing manioc roots, 20% knew a little about it, 12% knew it in detail but had never practiced it, and 36% knew some technique and had performed one in the past. These proportions, however, varied substantially between

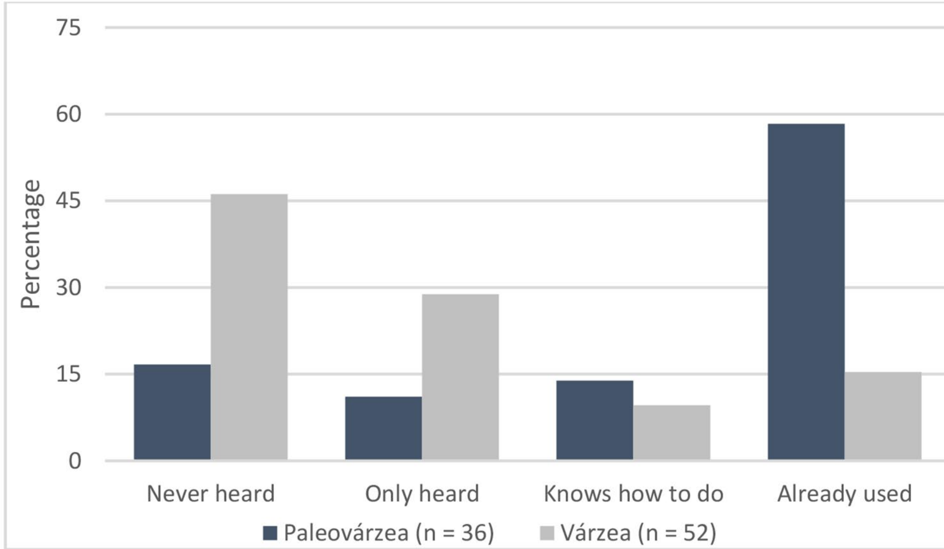

Fig. 3 Percentage of *ribeirinhos* from both ecosystems in the middle Solimões River region, Amazonas, Brazil, who know and/or use manioc storage techniques during extreme floods

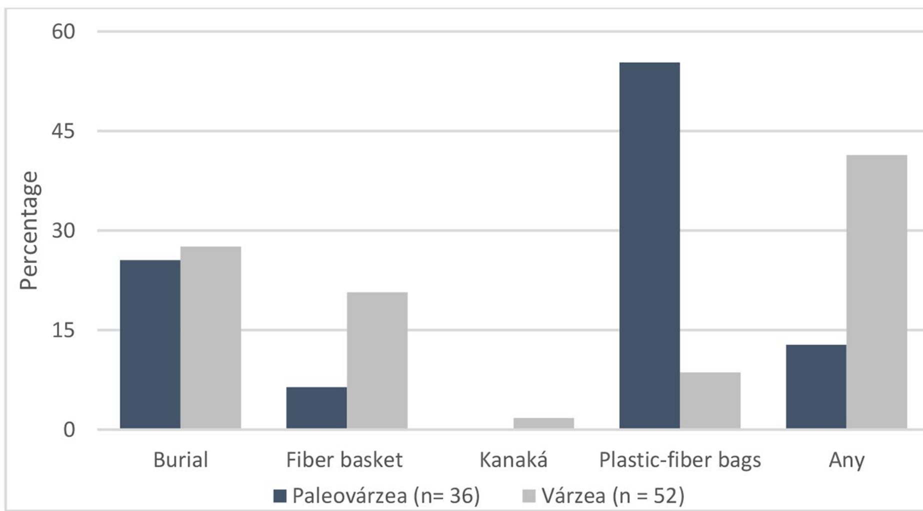

Fig. 4 Distribution of knowledge (%) about each manioc storage technique in the study ecosystems in the middle Solimões River region, Amazonas, Brazil, considering only people who know at least one technique

environments; in the *paleovárzea*, most of the interviewees (58%) had performed some technique; in the *várzea* most of the interviewees either did not know any technique (46%) or knew little about it (29%). In this sense, *ribeirinhos* from *paleovárzea* communities use and know more about traditional techniques (72%) than those from *várzea* communities (25%) (Fig. 3).

In general, ribeirinhos from the paleovárzea know more about traditional manioc storage techniques (87%) than those from the várzea (59%) (Fig. 4). In the várzea they know mainly the burial technique (47%) and basketing (35%), while in the paleovárzea the bagging technique is better known (64%), and the burial technique is used (29%). As for the knowledge, the bagging technique is the best known, followed by the burial technique, the basketing technique, and the kanaká.

Among the known techniques, the *kanaká* was mentioned by only one *ribeirinho* in the *várzea*. The burial and basketing techniques are known by at least one *ribeirinho* from each community in both ecosystems. In contrast to what we hypothesized, the results of the generalized linear model to test the knowledge about manioc storage related to the *várzea* and *paleovárzea* ecosystems indicate that in the *paleovárzea ribeirinhos* know more about storing manioc than *ribeirinhos* in the *várzea* (β = -1.45, SE = 0.53, z = -2.76, p =0,005).

Discussion

Four manioc storage techniques were cited as applicable in the case of extreme and unpredictable flooding. Two of these techniques have not yet been described in the literature for the region: *kanaká* and *ensacamento* (bagging). One consists of burying manioc roots, and the other three consist of ways in which the peeled manioc is stored in different fiber packages (natural or synthetic), which are submerged in water (basketing, bagging, and *kanaká*). One technique was exclusively mentioned in the *várzea* (*kanaká*), and only the most recently developed technique (bagging) is currently used in both ecosystems. The most significant knowledge dissemination and manioc root storage were in the *paleovárzea*. In climate change, in which extreme flooding is more intense and unpredictable, *ribeirinhos* from both ecosystems, which do not know the techniques were very interested in learning about them. The technique is more used today, given the last extreme flood (2015).

Around the world, local communities also use traditional food storage techniques to preserve potatoes, maize, rice, cowpea, millet, quinoa, sorghum, etc. For example, they use underground pits, wooden structures/silos, or bags (jute, sisal, local grass, cotton, or polyethylene) (Tapia & Torre, 1998; Mobolade et al., 2019).

Manioc storage techniques using burials are cited in old (Edmondson, 1922; Lancaster et al., 1982; Monteiro, 1963) and recent studies in Amazonia (Acosta Muñoz et al., 2005; Mendes dos Santos et al., 2021). Archaeological and ethnographic work highlights the long history of this burial technique in the region who could be used to store starchy plant materials that would be used after the temporary migrations of indigenous groups (Furquim, 2018). Burial is also a technique historically used in Africa (Affran, 1968; Irvine, 1969) and on Mauritius island (Anon, 1944). In the latter case, it is referred to as "Reine's method,“ where layers of peeled manioc roots are alternated with layers of 7.5 cm of earth and then covered with earth (15 cm deep), allowing storage for more than one year (Anon, 1944). In India, there are also studies of manioc burials, where it was observed that after two months in soil with 15% moisture, 80–85% of the roots were undamaged and could be used (Balagopalan, 2000).

As for the basketing technique, use was reported among indigenous groups from other traditional populations of the Solimões River (Sousa et al., 2017) and the upper Negro River (Maia, 2018). In some regions of Hispanic America, where the *cauaçú* also occurs (also known locally as *bijão*), leaves are used to wrap food and protect it from humidity (Sousa et al., 2017). In an archaeological study in the Purus River basin, the authors reported that the basketing technique was used to produce *pães de índio* in the interfluve of the Jacareúba-Mucuim Rivers due to its specific conservation conditions (Cangussu & Perez, 2017). Concerning the current use of burial and basketing techniques, other studies observed evidence of these practices near the middle Purus River, the upper Negro River, and the upper Madeira River, suggesting that these techniques continue to be used, although infrequently (Mendes dos Santos et al., 2021). In addition, the historical importance of the burial and basketing techniques has been highlighted for the storage of other roots (such as the *mairá* potato (*Casimirella* sp.)) and also fruits (such as *pupunha* (*Bactris gasipaes* Kunth) and *buriti* (*Mauritia flexuosa* L. f.) (Lancaster & Coursey, 1984; Mendes dos Santos et al., 2021).

Concerning the *kanaká*, the *puba* process causes the manioc to ferment. This process is also used for manioc flour preparation (locally called *farinha d´água*); the fermented softened roots facilitate the grinding into a homogenous mass and liberate part of the prussic acid (Lancaster et al., 1982). For the *kanaká* storage technique, some similar methods were observed in Uganda: wooden boxes with damp sawdust. The box is coated with plastic to prevent the sawdust from drying out for 4–8 weeks (Nahdy & Odong, 1995). However, in the case of *kanaká* the wooden structure has a cone shape, the plastic is substituted with local leaves, and manioc *puba* is used.

Storage in conical piles was observed in traditional indigenous silos in Colombia. In these, a thick layer of straw is placed, and the roots are piled up. The mounds, with between 300 and 500 kg of manioc, are covered with straw and earth, with openings left at the bottom for ventilation. The method allows storage for about one month, depending on the temperature and rainfall of the season (Rickard & Coursey, 1981). In the Philippines, conical piles are also used to store manioc for 25 days (Baybay, 1922).

The use of bags to preserve manioc roots is recognized as an extension of traditional storage methods, where plastic bags are used to prevent moisture loss and water stress (Rickard & Coursey, 1981). With bagging, tightly woven bags without chemical treatment were observed in Ghana (Gallat et al., 1998) and Tanzania (Westby et al., 1999), allowing 7–10 days of storage. Polyethylene bags were also used with damp sawdust associated with chemical treatments, preventing post-harvest deterioration and increasing root quality (Carvalho et al., 1985). In Colombia, this type of storage allowed conservation for 14 days (Best, 1990). Comparing the techniques present in the literature with those mentioned in the communities, we can identify that bagging and basketing have similarities with the other techniques of storing manioc in water. Compared to older techniques to store manioc, the bagging technique is more manageable, fast, and practical and demonstrates local knowledge dynamics (Haughton et al., 2015). However, alternatives and old techniques provide options to store manioc, and the knowledge about different techniques are essential factors in enhancing resilience in climate change (Altieri et al., 2015).

Várzeas are at high risk for major periodic flooding (Denevan, 1996). In the *várzea* areas studied, *ribeirinhos* emphasized that they do not cultivate as much manioc as they used to because extreme floods are recurrent and unpredictable (Avila et al., 2021). Consequently, in *várzea* ecosystems, as there is less manioc to be processed into flour, the need for these storage techniques is lesser compared to the past or the *paleovárzea*. This may be why *várzea ribeirinhos* know less about manioc storage than *ribeirinhos* in the *paleovárzea*.

Conclusion

Ribeirinhos of *várzea* and *paleovárzea* communities are familiar with four techniques for storing fresh manioc. However, in both ecosystems, people used only a recently adapted technique (manioc bagging). *Ribeirinhos* from the *paleovárzea* know more about storage techniques than those from the *várzea*. In the *paleovárzea*, crops do not suffer from annual flooding; thus, the swiddens are more important for income generation and, consequently, are more significant, which could justify that knowledge of this technique is better distributed in this ecosystem. The differences in LEK are due to their histories of interaction with each ecosystem's environmental characteristics, especially susceptibility to extreme flooding. In addition, many *ribeirinhos* in the study area want to know more about manioc storage techniques to avoid losing their crops. This demand illustrates how traditional and adapted technologies are dynamic, need to be shared, and can be crucial in strengthening communities' food security and sovereignty in critical periods, favoring the resilience of these communities even in the context of climate change.

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Data Availability The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interests.

Informed consent The interviews were conducted after the interviewees signed the informed consent form wherein they agreed to participate in the study and authorized the disclosure of the results. The Ethics Committee approved this research for Research with Humans at Mamirauá Institute (CEP authorization number: 2.964.758), registered in the National System for the Management of Genetic Heritage and Traditional Knowledge (SISGEN A494ADE), and obtained authorization from the System of Authorization and Information on Biodiversity (SISBIO 65374-1).

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