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Traditional Açaí Extractivism and Technological Innovation in Murumuru Quilombo, Brazilian Amazon

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Abstract

In the native açaí groves of Lago do Maicá, in western Pará, harvesting is still performed using traditional techniques such as the peconha, which is a rope device tied to the feet that helps with climbing açaí palms. The absence of affordable and locally adaptable technologies compromises the safety of extractivists and limits the strengthening of the açaí value chain, affecting the development of a forest-based bioeconomy. This study focused on the Quilombo of Murumuru to understand the profile of local extractivists and identify which technologies could be more easily adopted in floodplain environments. After ethics approval, fieldwork involved participatory activities including knowledge-sharing meetings, transect walks, community discussions, and structured interviews. The results indicated that most collectors identify themselves primarily as açaí extractivists. Some rely exclusively on this activity for income, while others complement it with fishing or agro-extractivism. Reports of occupational risks were frequent, especially due to falls and contact with venomous animals. There was also a clear lack of technical assistance and limited access to context-sensitive technologies. The study highlights the need for institutional partnerships that support income diversification, value traditional knowledge, and improve working conditions. Strengthening the native açaí value chain in floodplain regions is essential for reducing socioeconomic vulnerability and advancing a regenerative, community-centered bioeconomy in the Amazon.

Keywords: *Euterpe oleracea* Mart.; traditional communities; Lago do Maicá; non-timber forest products

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1. Introduction

According to the [1], bioeconomy is defined as "production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology and innovation, to provide information, products, processes and services across all economic sectors towards a sustainable economy". This comprehensive definition expands the traditional understanding of nature-based economies by emphasizing the importance of innovation, territorial approaches and knowledge systems in valuing biodiversity.

In this context, the Amazon stands out as a region of exceptional biocultural richness and strategic relevance, not only due to its unparalleled biodiversity, but also because of the socioterritorial diversity shaped by traditional communities and their forest-based livelihoods. Among the native species with recognized bioeconomic potential, *Euterpe oleracea* Mart. (açaí) plays a central role in local economies and food security, especially in floodplain regions. Its fruits are rich in carotenoids and phenolic compounds [2–4], and its pulp has long been integrated into the dietary and cultural practices of riverside populations who manage native açaí groves in várzea environments [5].

The economic relevance of açaí goes beyond pulp extraction. Various parts of the plant are used in crafts, civil construction, cosmetics, bioproducts, and even nanotechnology applications [6–8]. These multifunctional uses reinforce the importance of integrating traditional knowledge with technological innovation to enhance the value chain of açaí while promoting ecological sustainability.

Homma, A.K.O. [9] emphasizes that advancing the bioeconomy in the Amazon requires more than market solutions: it demands inclusive public policies, recognition of traditional knowledge systems, and territorial governance capable of safeguarding the rights and knowledge of forest peoples. The concept of socio-biodiversity value chains, present in several Brazilian public policies [10], has been promoted as a mechanism to support sustainable rural development, food security, forest conservation, and income generation [11,12].

Despite growing national and international demand for açaí [13,14], production systems remain predominantly extractive and communities face constraints in accessing infrastructure, credit, markets, and appropriate technologies [15–17]. In Pará, the state with the highest açaí production and exports, the intensification of extraction has been accompanied by domestication of native groves and the conversion of landscapes into monocultures [5,18]. This transformation raises concerns about biodiversity loss and the weakening of traditional production systems.

In this scenario, floodplain communities such as Quilombo Murumuru, located in the Santarém region, are exposed to multiple vulnerabilities. Açaí harvesting is still performed using ancestral techniques, such as climbing the palms with the "peconha", a traditional rope device. However, the absence of technical assistance, limited access to information, and lack of context-adapted innovations make the harvesting and post-harvest processes risky and economically fragile.

It is worth highlighting that local communities maintain traditional agricultural systems, such as manioc (Manihot esculenta) fields and other subsistence food crops, which are associated with Brazil nut (Bertholletia excelsa) extractivism and artisanal fishing [19]. These practices are part of adaptive strategies aligned with the forest's ecological calendar, aiming to take advantage of the seasonal availability of forest products and to ensure both food and economic security for families [20].

Based on this perspective, the following guiding questions were formulated:

What are the community's main challenges and demands to ensure the strengthening of the açaí value chain, with a view to conserving local ecosystems?

Can açaí agro-extractivists in floodplain areas increase their extractive capacity by using native açaí forest management techniques that have been successful in other areas in the state of Pará?

Can the inclusion of technologies available in science be used and/or adapted to meet the needs of extractivists in flooded areas such as the community studied?

This study aims to analyze the challenges and potentials of açaí extractivism in the Murumuru Quilombo, with a focus on socio-environmental conditions, traditional management practices, and the local applicability of technological innovations for strengthening the açaí value chain in floodplain territories.

2. Materials and Methods

2.1. Study Area

The work was carried out in the community of Murumuru, situated on the banks of Maicá Lake, located between approximately 02°43′47″ S latitude and 54°35′49″ W longitude, in the eastern part of the municipality of Santarém, at the confluence of the Amazon and Tapajós rivers.

Murumuru is a quilombola settlement officially recognized by the National Institute for Colonization and Agrarian Reform (INCRA), located in the rural zone of Santarém, Pará, Brazil. The community traces its origins to the colonial period, when descendants of enslaved Africans settled in the region in acts of resistance and escape. The population maintains strong dependence on the hydrological cycles of Maicá Lake, whose seasonal fluctuations significantly affect the availability and productivity of natural resources, especially native açaí groves (*Euterpe oleracea*).

The absence of formal land demarcation renders these floodplain areas vulnerable to extractive pressure from neighboring communities. External actors often consider it legitimate to harvest açaí in the várzea, since these areas are, under Brazilian law, classified as federal public lands unless otherwise titled. This legal ambiguity, combined with the lack of formal recognition of the traditionally managed zones by Murumuru residents, contributes to recurring land use conflicts and weakens the community's collective rights over natural resources.

Although the village comprises approximately 400 residents distributed across 93 households, only 18 individuals are locally recognized as primary açaí extractivists. These individuals represent the entire population of active açaí harvesters in Murumuru and were thus treated as a census. All 18 extractivists directly involved in the activity participated in the research, constituting a complete population census rather than a sampling procedure. This approach eliminates sampling error and ensures full internal validity of the findings within the context of the community studied. We emphasize that the notion of representativeness here refers strictly to the local universe, which was fully covered.

Residents of Murumuru do not identify as Indigenous but as Afro-descendants, with roots in their quilombola ancestry. Territorial organization is based on extended family networks, communal land use practices, and Afro-Amazonian cultural traditions. The local economy is driven primarily by non-timber forest extractivism, especially açaí (*Euterpe oleracea*), which is harvested using traditional techniques adapted to the Amazonian floodplain. We acknowledge that the results are not generalizable to other Amazonian communities or regions, and this limitation of external validity is now explicitly stated in the manuscript.

The Murumuru Community was selected as the focal point for this study, which is part of the Inovatec Açaí Project, for strategic and socio-environmental reasons. First, the community stands out as the first in the area to be officially recognized as a Quilombo. Furthermore, it has the highest concentration of native açaí groves among neighboring communities, making it an ideal location for analyzing management systems and environmental service indicators.

In terms of Environmental Services, the community's selection is justified by several factors: Provision, Regulation, and Support: Açaí, the main source of income for residents, highlights the community's importance in providing resources and in ecological regulation and support processes.

Cultural: For over a decade, the Murumuru Community hosted an annual açaí festival in August, a culturally significant event that brings together surrounding communities and reinforces local identity. This combination of historical, ecological, and cultural factors validates the community's selection as the most representative study area for research objectives.

The map (Figure 1) presents the georeferenced delimitation of the Murumuru quilombola territory in western Pará. The blue-shaded area represents the floodplain zone of Maicá Lake, which remains submerged for approximately six months during the high-water period (December to June). During the dry season, especially in October and November, this zone becomes dry land, locally known as "restingas". These areas are then used by the community for small-scale livestock grazing, including cattle (Bos taurus), sheep (*Ovis aries*), and pigs (*Sus scrofa domesticus*), thus justifying their inclusion within the traditionally used territory.

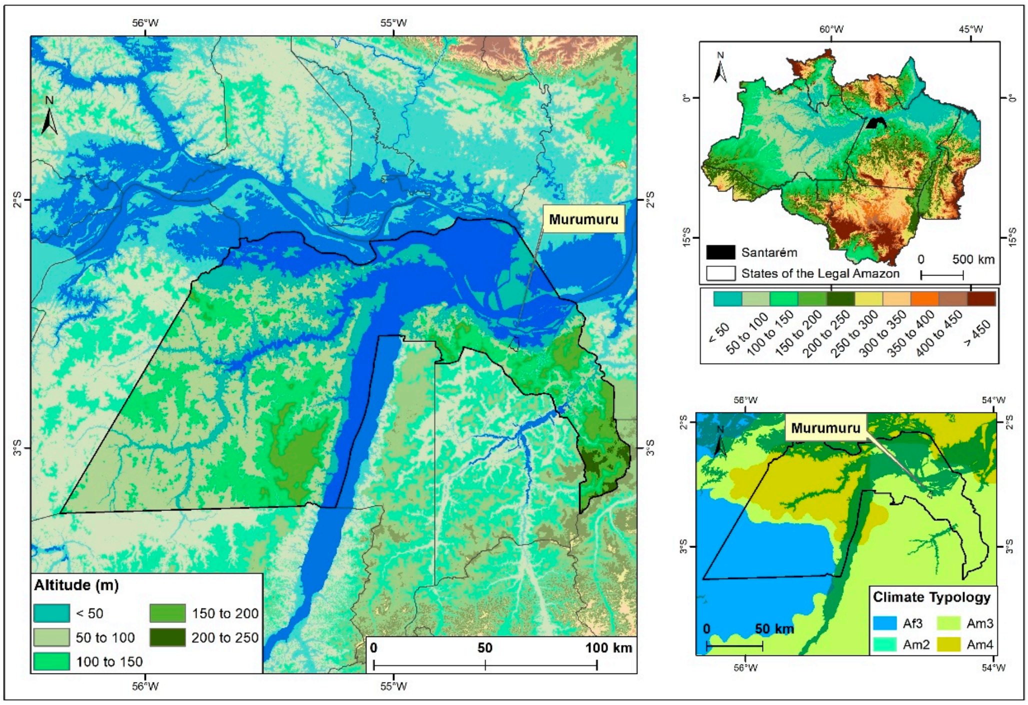

Figure 1. Location, altitude, and climate typology of the Murumuru Quilombola Territory, Santarém, Pará. Source: Authors.

The green areas indicate native açaí groves (*E. oleracea*) that play a central role in the extractivist economy. Higher relief zones, depicted with gradient tones, correspond to terra firme forest remnants and areas of subsistence agriculture. These include small plots of cassava (*Manihot esculenta*), macaxeira (a local variety of *cassava*), maize (*Zea mays*), and agroforestry home gardens composed mainly of species such as cupuaçu (*Theobroma grandiflorum*), cashew (*Anacardium occidentale*), and peach palm (*Bactris gasipaes*), among others, cultivated according to each household's specific interests.

Figure 1 presents three maps that geographically situate the Murumuru territory, located in the municipality of Santarém, in the state of Pará. The main map, on the left, displays the altitudinal variation in the region, with the Murumuru territory outlined in black. A predominance of areas below 50 m is observed, typical of floodplain environments, along with a gradual altitudinal transition toward the south. Altitude classes range from <50 m to 250 m, with the highest elevations within the Murumuru territory corresponding to areas of natural vegetation, characteristic of Dense Ombrophilous Forest in the Amazon biome.

In the upper right corner, the location map shows the position of Santarém within the Brazilian Legal Amazon. This representation highlights state boundaries and regional elevation distribution, with a color gradient ranging from <50 m to >450 m, allowing for a broader physiographic context of the study area [21,22]. The lower right map presents the climate typology, based on an adapted Köppen classification [22]. Four predominant climate classes are identified in the study area: Af3 (super-humid equatorial climate), Am2, Am3, and Am4 (variations in the monsoon climate). The Murumuru territory lies in the transition zone between Af3 and Am2, reflecting the influence of contrasting pluvial regimes and the presence of both more-humid environments and areas with reduced rainfall supply, according to [23]. All maps are georeferenced using the SIRGAS 2000 geographic coordinate system.

2.2. Data Collection

The research objectives were presented to the Murumuru community association by members of the InovaTec Açaí Project. Following the agreement with community leaders and residents, the research was approved by the UFOPA Research Ethics Committee under substantiated opinion number 6.042.441.

Semi-structured interviews were conducted using a flexible questionnaire designed to capture both the socioeconomic characteristics and perceptions related to açaí agro-extractivism in the Murumuru community. The questionnaire included items on local production systems, main challenges, and the perceived potential of extractivism [24,25].

Given the small number of individuals directly engaged in açaí extraction and the internal social dynamics of the community, snowball sampling was adopted as the most appropriate strategy. This non-probabilistic sampling method is widely applied in social research and involves the identification of initial participants, who, in turn, refer others to participate. The process continues until the saturation point is reached, which occurs when additional interviews no longer generate new information [26,27].

2.3. Data Systematization and Analysis

The open-ended responses obtained from semi-structured interviews and participatory activities (e.g., community meetings, transect walks) were transcribed verbatim and analyzed thematically, following the six-phase framework proposed by [28]: (i) familiarization with the data; (ii) generation of initial codes; (iii) search for themes; (iv) review of themes; (v) definition and naming of themes; and (vi) production of the analytical report. Coding was conducted manually, without the use of specialized software, following the analytical framework described above. This process allowed the identification of recurring patterns, divergences, and context-specific perceptions related to açaí extractivism and the applicability of technological innovations.

Quantitative analysis—Closed-ended questionnaire items were analyzed using the Statistical Analysis System (SAS, version 9.4). Statistical procedures included descriptive statistics (means, frequencies, percentages), cluster analysis, and correlation matrices to identify underlying patterns and associations. The variables analyzed encompassed demographic aspects (e.g., age, gender), production characteristics (e.g., scale, frequency), and socio-environmental perceptions. Principal Component Analysis (PCA) was applied to increase interpretive capacity through dimensionality reduction, an approach particularly valuable given the limited sample size. These tools ensured methodological rigor in characterizing community member profiles, production scales, and socio-environmental perceptions.

The principal findings were illustrated using bar charts, line graphs, dendrograms, and biplots, supporting the interpretation of trends and categorical groupings. Although the number of participants may appear modest, the study encompassed the entire population of individuals who either identified or were locally recognized as açaí extractivists, thus ensuring internal validity for the Murumuru context.

It is important to emphasize that extractivist activities involve substantial occupational risks, given the slender stems of açaí palms and dense fruit clusters, which often shelter venomous animals. In addition, harvesting requires traversing flooded and unstable areas, posing significant physical and environmental hazards. The integrated qualitative–quantitative analytical framework adopted here enhanced the depth and robustness of interpretations, allowing the identification of strategic points for strengthening the açaí value chain in the Murumuru Quilombo.

3. Results

3.1. Environmental Characterization of the Murumuru Community

Figure 2 presents spatial data that characterizes the environmental conditions of the Murumuru Quilombola Territory. The map at the top left displays the annual average temperature, indicating that most of the territory falls within the 26.0 to 26.5 °C range. Neighboring areas reach values above 27 °C, confirming the presence of a hot and humid tropical climate typical of the western Amazon. These thermal conditions support the development of species adapted to high temperatures and high relative humidity, such as *Euterpe oleracea* (açaí palm), which dominates the floodplain vegetation in the region.

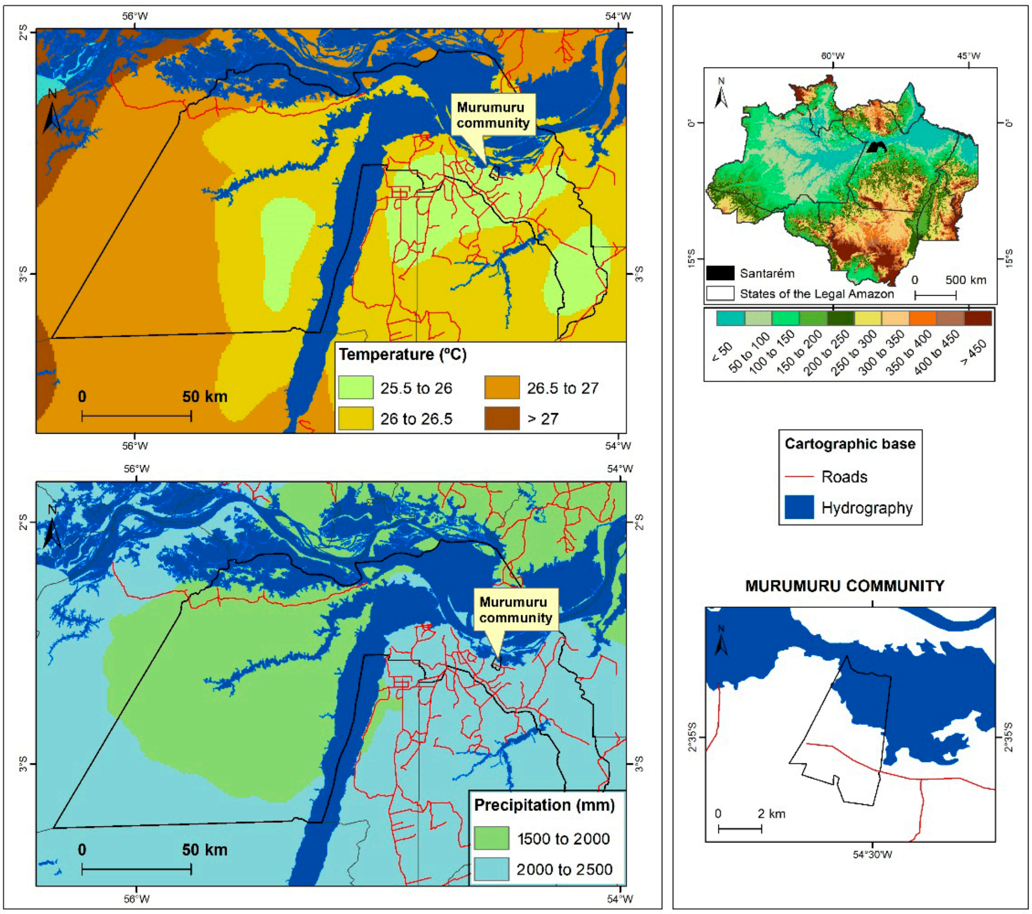

Figure 2. Annual temperature and precipitation patterns in the Murumuru Quilombola Territory, with cartographic reference to regional location, roads, and hydrography.

The map at the bottom left shows the annual average precipitation, with values ranging from 2000 to 2500 mm throughout the territory. This level of rainfall reinforces the classification of the area as humid, with a climate regime strongly influenced by Amazonian rainfall patterns. Such precipitation levels are essential for maintaining environments with hygrophilous vegetation and floodplain forests, which are characteristic of the local landscape.

The map on the right side offers a broader regional context, situating the Murumuru Territory within the municipality of Santarém and the Brazilian Legal Amazon. It also includes infrastructure elements such as roads and hydrography, as well as a detailed locator map of the Murumuru community (bottom right), which helps illustrate the proximity to major water bodies and floodplain systems. Together, the temperature and precipitation maps demonstrate that the Murumuru community is located in a highly dynamic and sensitive socioecological zone, where the interaction between climate, hydrology, and topography shapes land use, vegetation distribution, and the viability of traditional extractive systems such as native açaí harvesting.

3.2. Multidimensional Preference Analysis

Figure 3 displays the results of the Multidimensional Preference Analysis, illustrating the distribution of responses to 22 questions (Q1 to Q22) across two principal components. Component 1 explains 89.72% of the total variance, while Component 2 accounts for 10.28%, jointly representing 100% of the variability in the data. This indicates that the two-dimensional projection fully preserves the internal structure of respondents' preferences.

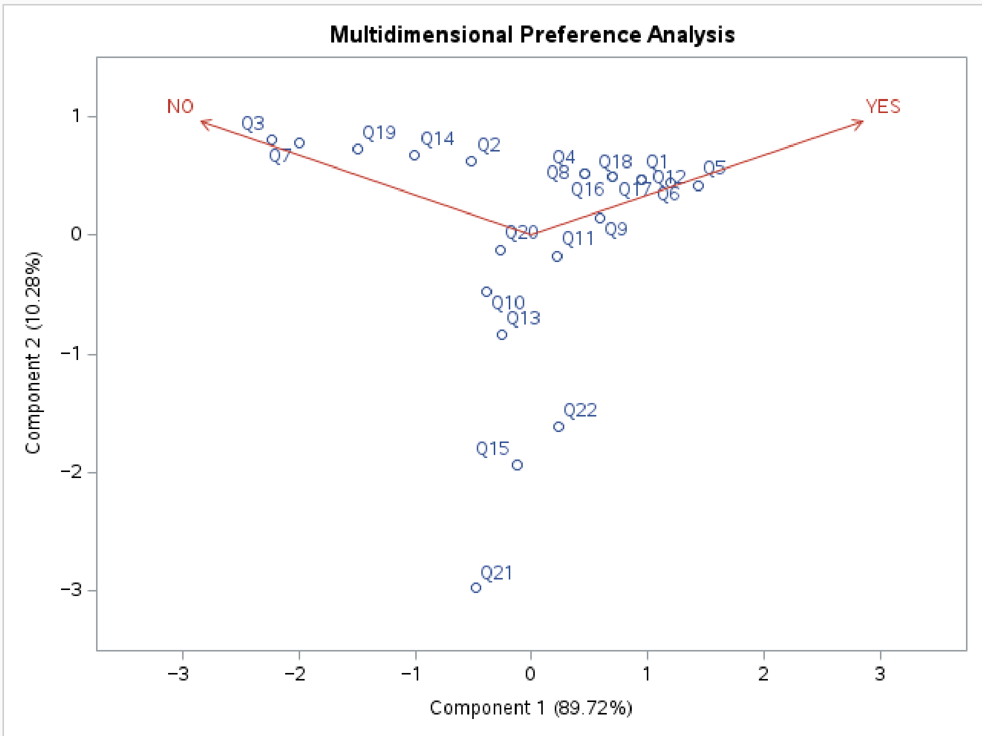

Figure 3. Biplot of Multidimensional Preference Analysis, showing the distribution of questionnaire items across agreement vectors.

The red directional vectors labeled "YES" and "NO" represent the polarities of agreement or disagreement. The orientation of these vectors reveals the direction of the respondents' preference gradients. Questions positioned closer to the "YES" vector were generally associated with positive or affirmative responses, while those nearer to the "NO" vector reflected disagreement or disapproval. A significant concentration of questions appears in the upper right and central areas of the graph (e.g., Q1, Q2, Q4, Q5, Q6, Q8, Q12, Q16, Q17, Q18), indicating a high level of agreement or acceptance by respondents toward the topics covered in these areas. Conversely, questions such as Q3, Q7, and Q19 are located closer to the "NO" vector on the left-hand side of the graph, suggesting lower acceptance or greater resistance to the propositions they addressed. These may highlight critical perspectives or dissatisfaction with specific aspects.

Questions Q10, Q13, Q15, Q21, and Q22 appear more distant from the origin, especially along Component 2, suggesting distinct or atypical response patterns. These items may reflect more divergent opinions, lower consensus, or a need for clarification in interpretation due to their departure from the general trend. Overall, the graphic analysis reveals that most items cluster positively along the "YES" vector, indicating a general trend of favorable perception or agreement among the respondents. The clear separation of question groupings also points to underlying thematic axes or structural dimensions within the expressed preferences.

3.3. Cluster Analysis of Questionnaire Items

Figure 4 presents the results of the Cluster Analysis applied to the 22 questionnaire items (Q1 to Q22), displayed as a dendrogram based on the average linkage method (between-groups) and using Euclidean distance as the dissimilarity measure. The x-axis represents the average distance between clusters, while the hierarchical tree on the y-axis illustrates how items were grouped according to response similarity.

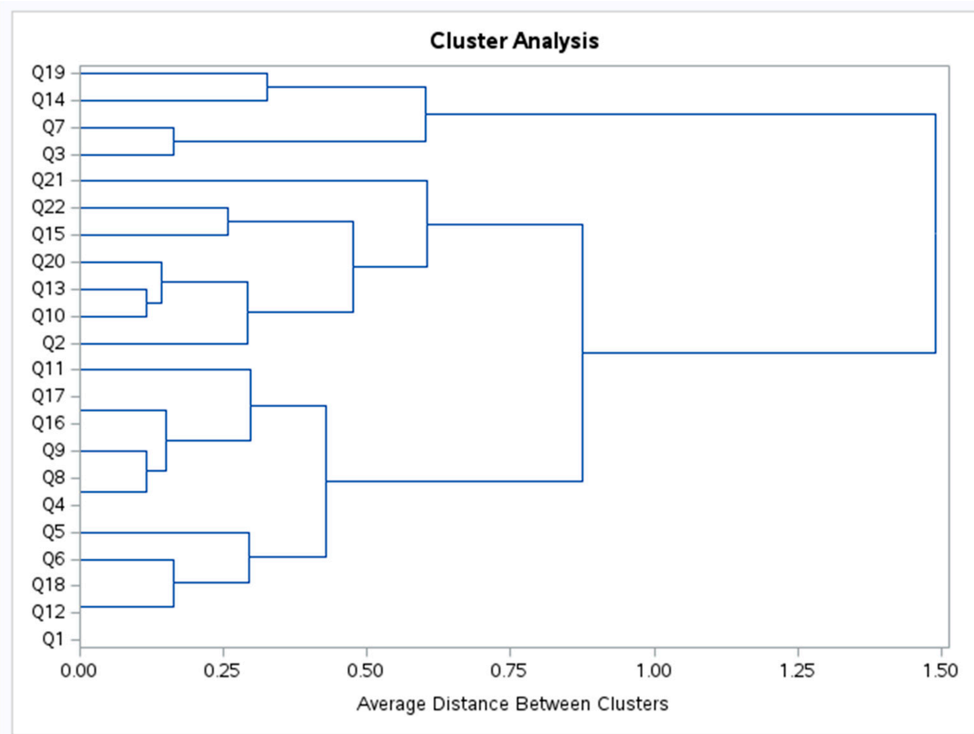

Figure 4. Cluster analysis of extractivists' responses to perception-based questions using average linkage.

From left to right, the dendrogram progressively merges individual questions into larger clusters based on the internal consistency of respondent answers. Three major clusters can be identified at distinct levels of similarity: Group A—High agreement and internal coherence (Q1, Q12, Q18, Q6, Q5, Q4, Q8, Q9). This group includes items that are closely associated with very low distances (<0.25) between them. These questions likely reflect shared affirmative perceptions among respondents, related to widely accepted practices or positive community experiences.

Group B—Intermediate agreement with some divergence (Q2, Q10, Q13, Q15, Q20, Q22, Q11, Q17, Q16). This cluster contains items with moderate internal distances

(0.3 to 0.7), indicating partial thematic alignment but greater variability in opinions. These questions may involve more context-sensitive or nuanced issues, with mixed perceptions depending on the respondent's background or experience.

Group C—Outliers and low consensus (Q3, Q7, Q14, Q19, Q21). These questions are grouped only at higher dissimilarity levels (distances > 0.8), indicating low consensus and greater divergence from the central pattern. Some of these items, such as Q3 and Q7, had already emerged as outliers in the Multidimensional Preference Analysis (Figure 3). Their positioning suggests contentious or ambiguous themes, potentially linked to disagreement, confusion, or resistance among respondents.

3.4. Hierarchical Cluster Analysis

Figure 5 presents the results of the Hierarchical Cluster Analysis using the average linkage method (between-groups) and Euclidean distance. The dendrogram illustrates the proximity of responses given by extractivists to the 22 questionnaire items (Q1 to Q22), indicating how the items group together based on similarity patterns. The vertical axis shows the average distance between clusters, while the horizontal axis lists the individual items or the merged clusters formed progressively. The questions asked are listed in Appendix A.

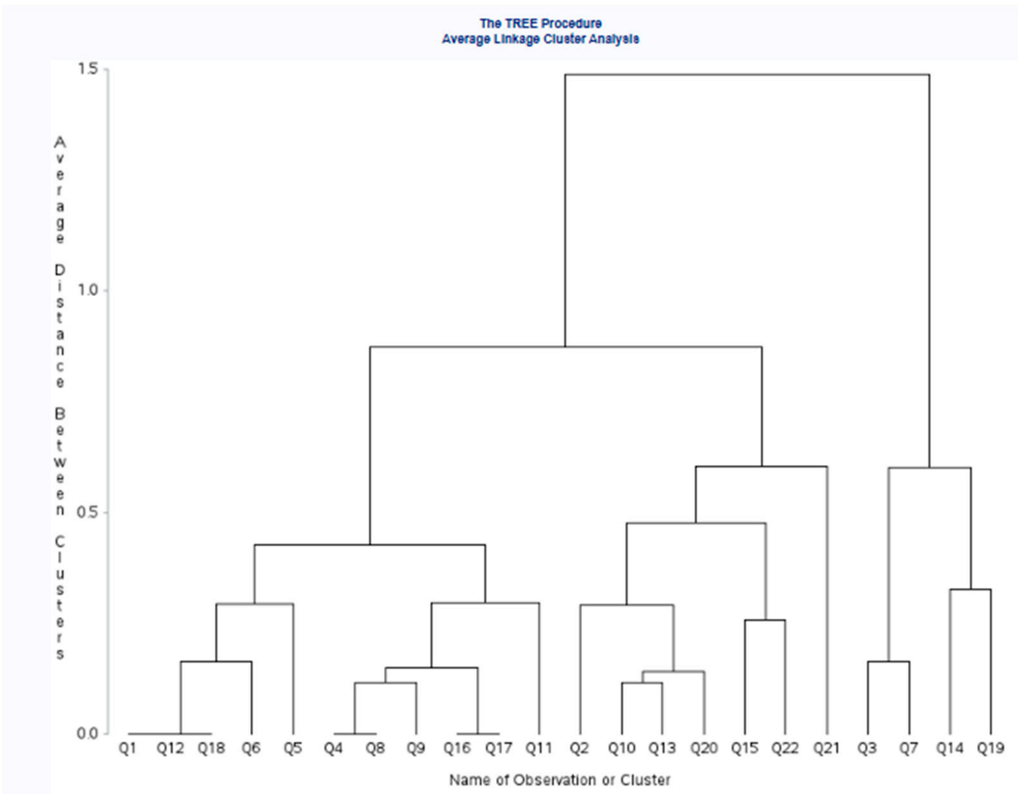

Figure 5. Dendrogram of extractivists' responses based on hierarchical cluster analysis using average linkage and Euclidean distance.

Group 1—High conceptual proximity (Q1, Q12, Q18, Q6, Q5, Q4, Q8, Q9, Q16). This group exhibits very low distances, reflecting a high degree of similarity in responses. These items form a cohesive perceptual core, likely related to practical experiences, productive activities, or positive evaluations of extractive practices. The inclusion of Q16 strengthens the operational dimension of this group.

Group 2—Intermediate variability (Q2, Q10, Q13, Q20, Q22). This group shows moderate distances, suggesting partial agreement or variability in interpretation. These items may involve context-dependent perceptions or diverse viewpoints among respondents, indicating the need for further clarification or qualitative validation.

Group 3—Peripheral and less-integrated items (Q3, Q7, Q14, Q19, Q21). Like what was observed in Figures 3 and 4, this set of questions only merges with the others at higher dissimilarity levels (average distance > 1.0).

These items appear to be less aligned with the core perceptual structure and may reflect conceptual divergence, ambiguous phrasing, or lack of familiarity with the topics addressed. The consistency of the groupings across Figures 4 and 5 reinforces the reliability of the perceptual patterns identified. Cohesive clusters can serve as foundations for future thematic categorization, while more dispersed clusters should be approached with caution and may require semantic revision or qualitative exploration to enhance interpretability.

The choice of the average linkage method is appropriate for capturing intermediate perceptual trends, balancing the sensitivity of single linkage with the structure-preserving properties of Ward's method. The resulting configuration reveals a perceptual model divided into zones of consensus, ambiguity, and conceptual divergence.

Figure 6 illustrates the percentage distribution of extractivists' responses to eleven questionnaire items (Q1 to Q11), grouped into two categories: negative responses (in red) and positive responses (in blue). The horizontal bar chart enables a visual comparison of approval and disapproval levels for each question.

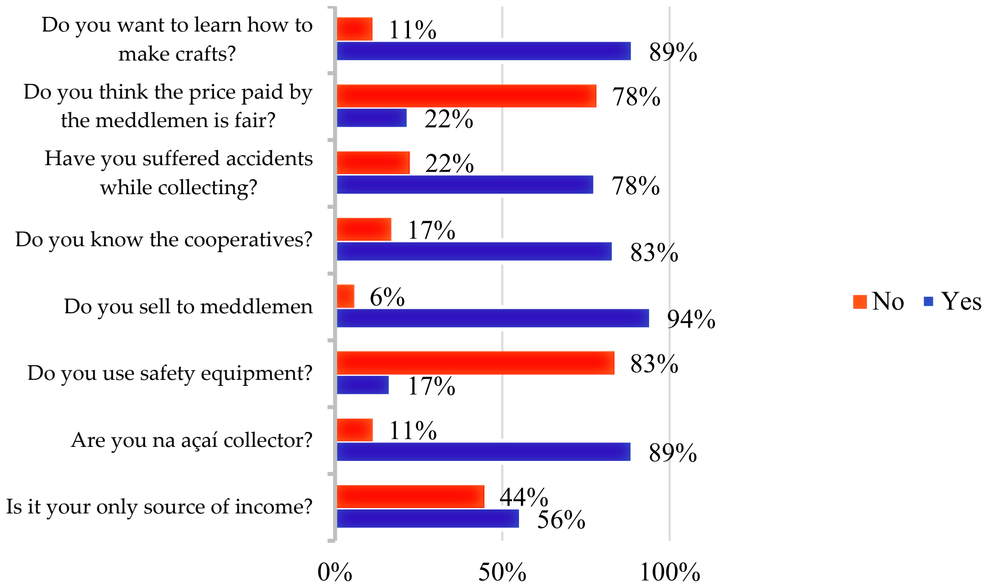

Figure 6. Distribution of 'Yes' and 'No' Responses on Occupational and Commercial Aspects of Açaí Harvesting. Affirmative (blue) and negative (red) percentages based on responses from agro-extractivists.

3.5. Predominantly Positive Responses

Most questions received a high proportion of positive answers, with percentages exceeding 70% in several cases: Q1: 77.8% positive; Q2: 83.3% positive; Q4: 77.8% positive; Q5: 83.3% positive; Q6: 83.3% positive; Q10: 83.3% positive. These values indicate a strong consensus and favorable perception regarding the aspects addressed by these questions. They may reflect well-established practices, benefits acknowledged by the community, or agreement with statements aligned with local experience. Some questions showed a more balanced distribution between positive and negative responses, suggesting partial agreement or mixed interpretations: Q3: 38.9% negative/61.1% positive; Q7: 27.8% negative/72.2% positive; Q8: 44.4% negative/55.6% positive. These items may involve more complex or contextual issues, generating greater variability among respondents. The presence of more critical responses points to potential tensions, doubts, or differences in lived experience.

The lowest positive rate was observed for. Q9: 44.4% positive/55.6% negative. This result suggests that Q9 represents a more contentious or misunderstood issue, where respondents may have expressed resistance, concern, or lack of clarity. This item may require rephrasing or further qualitative exploration.

Figure 7 presents a conceptual flow of technological adaptations that combine innovation and traditional knowledge to support the açaí extraction process in the Murumuru community. The scheme is organized into three key operational components:

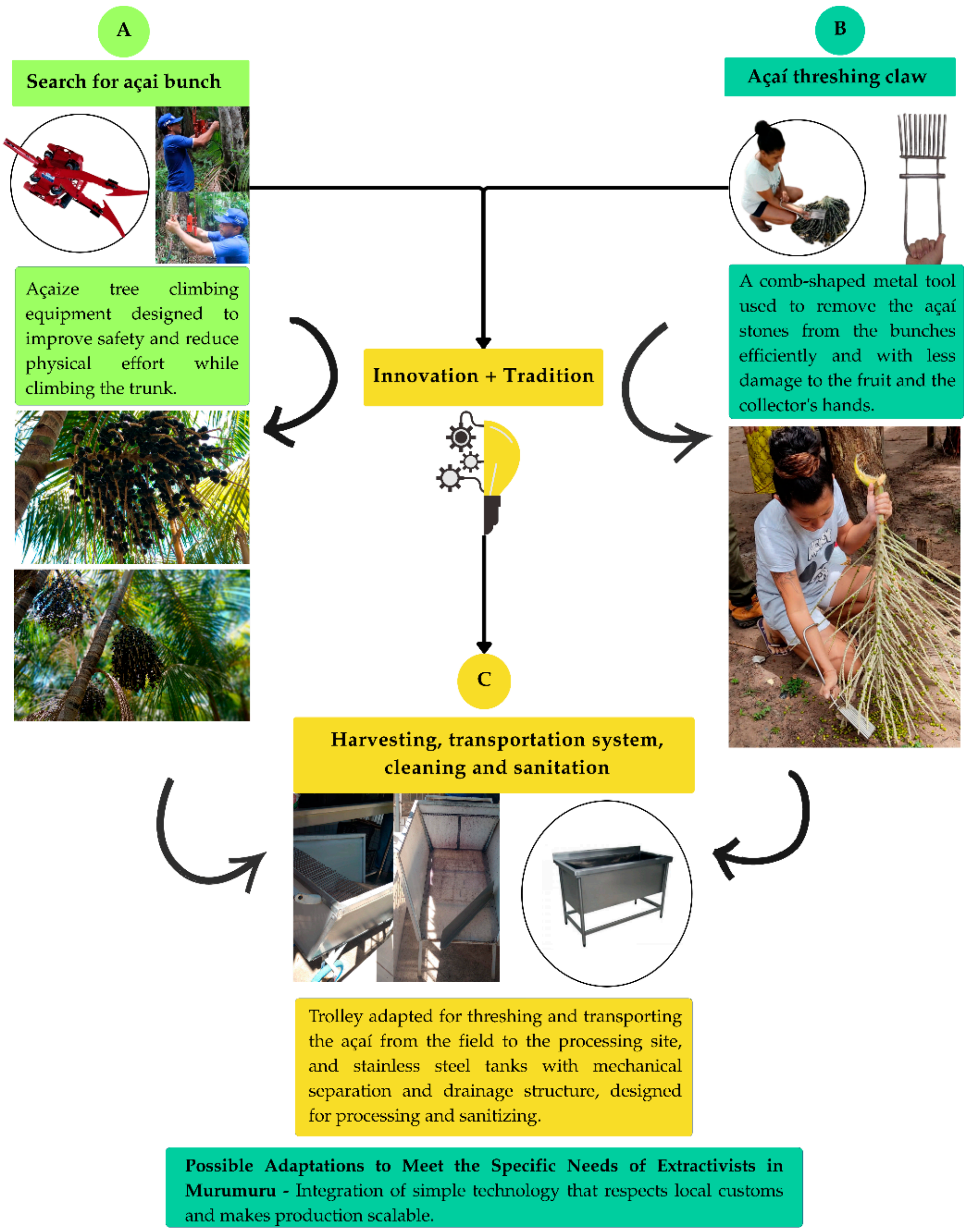

Figure 7. Integration of Local Knowledge and Simple Technologies for Açaí Harvesting and Processing in the Murumuru Community. A. Search for Açaí Bunches; B. Açaí Threshing Claw; C. Harvesting.

A. Search for Açaí Bunches. This stage introduces the use of the Açaize climbing device, a tool designed to improve safety and reduce physical effort during tree climbing. Its use enables collectors to access palm tree crowns more efficiently and securely, minimizing occupational risks and enhancing ergonomic performance during the search and harvest of mature açaí bunches.

B. Açaí Threshing Claw. The next step features the metal claw tool, a comb-shaped device that facilitates the removal of açaí fruits from bunches. It allows for greater efficiency and reduces manual strain, minimizing damage to the fruits and preventing injuries to the collectors' hands. This innovation preserves the quality of the product while increasing processing speed.

C. Harvesting, Transportation, Cleaning, and Sanitization. The final component integrates mechanized support for post-harvest operations, including a trolley adapted for threshing and transporting the açaí from the field to the processing unit. Additionally, stainless-steel tanks equipped with mechanical separation and drainage systems are utilized to ensure hygienic handling and scalable processing, in line with food safety standards.

At the center of this flow is the guiding principle of Innovation + Tradition, emphasizing the integration of simple, low-cost technologies that respect local knowledge and improve working conditions without compromising cultural practices. The caption reinforces the importance of these tools in scaling production while maintaining alignment with the specific needs of Murumuru's agro-extractivists.

4. Discussion

The results of this study highlight the socio-environmental complexity surrounding açaí extraction in the Murumuru quilombola territory, marked by a strong dependence on non-timber forest products and limited institutional support. Although the community is located within the Maicá Environmental Protection Area (APA-Maicá), it faces conflicting land uses such as the implementation of port infrastructure, which threatens the ecological integrity of the floodplain and the livelihoods of agro-extractivist families. This situation is directly aligned with the findings presented in [29], which show that the açaí value chain in Murumuru is grounded in traditional non-timber forest extractivism practices carried out under structurally vulnerable conditions. The research identified that the lack of continuous institutional support, combined with poor working conditions and a high level of dependence on intermediaries, limits the potential for sustainable development of the activity, even in the face of increasing regional and national demand for fruit.

These limitations, the community demonstrates detailed knowledge of the ecological functioning of native açaí groves and a collective interest in adding value to the product through local processing and reuse of by-products such as seeds and fibers in circular bioeconomy initiatives. These elements are also addressed in [29], which emphasizes the potential for sharing technologies developed in the Amazon and Cerrado biomes, including harvesting and processing tools, adapted agroforestry systems, and community-based production models. These strategies are considered essential for improving the quality of production and increasing the autonomy of extractivist families, but the absence of data related to the use of these new technologies in the research, showing the possible reductions in the number of accidents and gains in açaí productivity in the community were not quantified, but this could be carried out in future research.

These findings reinforce the need for differentiated public policies that recognize the territorial specificities of quilombola communities, along with integrated actions in rural extension, participatory research, and access to credit. By valuing traditional knowledge and incorporating technologies suited to the floodplain context of the Amazon, it is possible to consolidate a sustainable development model rooted in territorial justice, biodiversity conservation, and the strengthening of the agro-extractivist economy.

The data collected in Murumuru reveal precarious working conditions among açaí extractivists, with 78% reporting accidents during harvesting and 83% performing the activity without any type of personal protective equipment (PPE). This reality is strongly marked by using rudimentary tools, such as peconhas (foot loops) and machetes, and by the intense physical effort required. These findings are consistent with the results presented in [30], which identified significant environmental risks, including prolonged exposure to sunlight, high heat, and humidity, as well as extreme physical exertion involved in climbing açaí palms. The study also reported high levels of muscular pain and physiological strain in the upper limbs, lower back, shoulders, knees, and ankles, confirming the strenuous and hazardous nature of the activity. Using ergonomic protocols, the harvesting process was classified as high risk for the development of occupational diseases, requiring immediate corrective actions. Therefore, the data from Murumuru corroborates the literature by highlighting the absence of targeted public policies for occupational health in agro-extractivist populations, indicating the urgent need for technical and ergonomic interventions adapted to forest-based work.

In addition to its economic relevance, the açaí palm (Euterpe oleracea) demonstrates significant potential for the development of functional products based on its seeds and other by-products. Experimental evidence has shown that açaí seed extract presents selective anticarcinogenic effects, such as tumor size reduction, even though it did not substantially improve the overall condition of cachectic laboratory animals [31]. These findings reinforce the versatility and high value of native açaí, opening new opportunities for product diversification beyond pulp consumption. In the context of Murumuru, where most extractivists already demonstrate interest in reusing waste for crafts and construction, such results emphasize the importance of research and innovation policies aimed at maximizing the use of açaí's full biotechnological potential. They also justify strategic investments in local processing units and bioeconomy hubs capable of incorporating scientific findings into community-based practices.

The predominance of middlemen in the commercialization of açaí in Murumuru, reported by 94% of respondents, reveals a system of dependence shaped by logistical constraints and the absence of direct marketing channels. Although 78% of extractivists consider these relationships unfair due to low purchasing prices, many remain bound to this dynamic due to the lack of viable alternatives. This pattern is consistent with findings from the state of Amapá, where middlemen were analyzed from two perspectives: as exploitative market agents and, in specific cases, as potential logistics operators capable of structuring value chains [32]. In Murumuru, middlemen more closely resemble the former, as the absence of formal contracts, shared infrastructure, or established quality standards reinforces negotiation asymmetries and heightens extractivists' vulnerability in market transactions.

In addition to challenges in commercialization, the potential for value addition through by-product reuse was highlighted by many respondents, particularly in the form of seeds and fibers. This finding aligns with [33], who demonstrated the feasibility of developing furniture from açaí tree residues, emphasizing the ecological and economic value of materials often discarded in traditional extractivism. In Murumuru, interest in transforming açaí waste into inputs for artisanal production or sustainable construction reflects an emerging awareness of circular economy principles. Such practices not only expand income opportunities but also contribute to waste reduction and territorial resilience. Empowering extractivists to access technical guidance and simple processing tools may be key to fostering community-based bioeconomy initiatives rooted in local knowledge and available resources.

Furthermore, the findings highlight opportunities for adding value through waste reuse. Most respondents demonstrated interest in transforming açaí by-products such as seeds and straw into materials for handicrafts or construction. This aligns with circular bioeconomy strategies recently proposed for forest communities, emphasizing sustainable use of native species and reuse of forest residues [34]. However, this potential remains underutilized due to structural and institutional limitations. The limited awareness of cooperatives, reported by 83% of participants, reflects a critical gap in local governance and organization. Without a formal structure, the community faces challenges in negotiating fairer prices, organizing harvest activities, accessing public programs such as PRONAF, and protecting harvesting territories.

The establishment of a local cooperative could enhance social cohesion and provide an institutional foundation for collective decision-making, shared infrastructure, and knowledge exchange. Such arrangements would strengthen the community's position in the açaí value chain and create opportunities for technological innovation and value aggregation. For these transformations to materialize, public policies must be adapted to the socio-environmental characteristics of agro-extractivist territories. The results reinforce that regenerative bioeconomy strategies in traditional Amazonian communities require not only technical and economic interventions but also participatory governance and mechanisms to ensure territorial equity [35].

Simultaneously, ecological risks have emerged in response to the intensification of açaí cultivation driven by increased domestic and international demand. Studies conducted in eastern Amazonian floodplain forests indicate that the current management model adopted by riverine communities, maintaining an average density of 200 açaí stems per hectare, has resulted in the loss of more than 50% of tree species diversity and a 63% reduction in pioneer species. This process leads to floristic homogenization favoring economically valuable species. These findings underline the urgency of multi-taxon studies to inform sustainable management plans and ecological–economic zoning, aiming to prevent the large-scale loss of cryptic biodiversity in floodplain forests managed for açaí [35].

5. Conclusions

This study reveals the complex reality of açaí extractivism in the quilombola territory of Murumuru, where traditional knowledge coexists with structural vulnerabilities and emerging opportunities for innovation. The strong reliance on açaí as the main source of income, together with frequent occupational risks, insufficient technical support, and the persistence of unfair trade relationships mediated by intermediaries, characterizes a fragile socio-productive dynamic marked by inequality and limited institutional integration.

The results suggest an important adaptive capacity within the community. The incorporation of simple and locally appropriate technological innovations, including climbing equipment, mechanical threshers, and stainless-steel tanks, can improve safety, efficiency, and hygiene while valuing traditional practices. The community's interest in transforming by-products such as seeds and straw into materials for crafts or construction reinforces the potential for a circular and regenerative bioeconomy rooted in forest territories.

The absence of cooperative structures and the lack of access to market information limit the autonomy of extractivists and restrict possibilities for negotiating fairer commercial arrangements. These barriers point to the importance of strengthening participatory governance and local organization to ensure broader access to rights and benefits within the value chain.

When supported by inclusive public policies and investments in social technologies, açaí extractivism can become a strategic axis for environmental conservation, social resilience, and economic inclusion in the Amazon region.

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Abbreviations

The following abbreviations are used in this manuscript:

APA	Environmental Protection Area
PRONAF	National Program to Strengthen Family Farming
RIDE-DF	Integrated Development Region of the Federal District and Surroundings
UFOPA	Federal University of Western Pará

Appendix A. Questionnaire on the Socioeconomics of Açaí Collectors in the Murumuru Community

1. Do you belong to the Murumuru community and/or which community do you belong to? ( ) yes ( ) no Community: ________________________________
2. Are you an açaí gatherer? How many years have you been collecting açaí? ( ) yes ( ) no ( ) 1 year ( ) 2 years ( ) 5 years or more________________________________
3. Is collecting açaí your only source of annual income? ( ) yes ( ) if no, what other activity?________________________________
4. Can you identify the most productive açaí plants in the collection areas? ( ) yes ( ) no
5. Can you identify the insects (bees, beetles) that fly around the blooming bunches of your açaí trees? ( ) yes ( ) no
6. Do you think the insects (bees, beetles) that fly around the blooming bunches of your açaí trees are decreasing? ( ) yes ( ) no, if yes, why ________________________
7. An açaí bunch weighs on average how many kilos? ________________________
8. Do you use any safety equipment when collecting açaí? ( ) yes ( ) no
9. During your years of work, have there ever been any accidents related to harvesting açaí in the field?
10. ( ) yes ( ) no and, if yes, which accident? ________________________________
11. Have you heard any reports of accidents at work while harvesting açaí? ( ) yes ( ) no and what is the most frequent report________________________________

12. Based on the collection and sale of açaí, does anyone buy açaí from you and take it to the city? ( ) yes ( ) no, how often do you sell?________________
13. If you sell it to someone to take back to the city, do you think they'll pay you a fair price for the açaí you've harvested? ( ) yes ( ) no ________________
14. Do you think a lot of açaí is wasted during the harvest period? ( ) yes ( ) no
15. Does the community use any method to control the entry of people into the açaí groves? ( ) Yes ( ) No, if yes, how is this controlled? ________________
16. Have you heard of açaí cooperatives or associations? Do you think they are beneficial for those who use them? ( ) yes ( ) no and what do you think? ________________
17. Have you ever heard of handicrafts made from açaí stones, straws, and bunches? ( ) yes ( ) no, what do you think? ________________
18. Would you like to learn how to make handicrafts from açaí waste and earn more income from it? ( ) yes ( ) no, what do you think about it?________________
19. Can you see any forest animals eating açaí? ( ) yes ( ) no, if yes, which animal?
20. You watched the demonstrations on harvesting equipment and removing the fruit from the bunches. ( ) yes ( ) no
21. Did you already know about the technologies presented by the Inovatec_Açaí Project? ( ) yes ( ) no, if yes what did you think? ________________
22. Would you like to plant Embrapa's BRS Açaís? ( ) Yes ( ) No

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