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Cocoa agroforests in the Brazilian Amazonia floodplains: a review

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Abstract Cocoa agroforestry systems in the Amazonian basin floodplains are a sustainable and productive way to ensure food security while preserving biodiversity. This narrative review explores the agronomic, economic, and socio-ecological aspects of cocoa cultivation, analyzing its origin, diversity, and distribution from a historical perspective. The region's producer families, including ribeirinho, indigenous, and quilombola communities, have historically managed "wild" cacao through sustainable extractive practices, maintaining high genetic diversity. Cocoa genotype dispersal is closely linked to indigenous migration patterns and the role of river basins in genetic exchange. Ecologically, these floodplain agroforestry systems integrate cacao with other perennial and annual crops, creating high-agrobiodiversity landscapes known as traditional "*caboclo*" agroforestry systems. Beyond these traditional systems, new agroforestry models have been developed in degraded floodplains, promoting sustainable intensification as an environmentally friendly and climate-smart alternative. Proper management can enhance productivity beyond national averages, making these systems economically viable while maintaining ecological balance and ecosystem services. Despite their resilience and potential, cocoa-based agroforests face challenges, including limited technical assistance, market constraints, land tenure insecurity, and insufficient institutional support. Strengthening cooperatives, improving access to credit, and modernizing marketing strategies can enhance economic returns and ensure long-term sustainability. Since cocoa cultivation in the floodplains relies on no external inputs, public policies that add value to riverine products and expand market opportunities are essential. In addition to economic benefits, these systems contribute to the cultural-ecological heritage of Amazonian cocoa cultivation, reinforcing the deep connection between local communities, biodiversity, and sustainable land use, ensuring their continued role in regional livelihoods.

Keywords Wild cocoa · Amazonian *várzeas* · *Ribeirinho* communities · Indigenous peoples · *Caboclo* agroforestry systems · Agrobiodiversity

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Introduction

In Brazil, cocoa (*Theobroma cacao* L.) is planted on 590,600 hectares (IBGE/SIDRA 2024) by 76,402 rural producers, of which at least 80% are classified as small or medium scale producers, with less than 10 hectares of cocoa trees in two biomes: Amazonia and Atlantic Forest (Gama-Rodrigues et al. 2021). In the Amazon biome, there are approximately 9,500 ha of land with "wild" cocoa trees in floodplains in the states of Pará and Amazonas (IBGE/SIDRA 2024). This area constitutes the oldest population of cocoa trees in the region, which corresponds to 5.5% of the total area planted in the Brazilian Amazonia (states of Amazonas, Pará, Rondônia, and Mato Grosso). However, there is evidence that in the Amazonian biome, there are more than 40,000 hectares of "wild" cocoa trees in floodplains (Personal communication by Valdenor Pontes Cardoso, Former President-Director of Institute for Sustainable Agricultural and Forestry Development of the State of Amazonas). In the state of Amazonas, mapping carried out by the Amazon Forestry and Sustainable Business Agency – Department of Non-Wood Forest Products (AFLORAM) and the Federal University of Amazonas (UFAM), in 2006, in a stretch of just 260 km of the Purus River channel, between the municipalities of Pauini and Boca do Acre, in four rural community hubs, identified 11,998 ha of "wild" cocoa trees with great variation in seed production (SILVA 2007), and the average density of cocoa was only 7.84 individuals per hectare (Veras 2009).

Cocoa farmers in the Amazonian floodplains belong to the ribeirinhos (riverside), quilombola, and indigenous populations, representing the traditional peoples of the Amazon forest. They have been exploiting "wild" cocoa trees through sustainable extractive practices for centuries (Mendes 2018), together with other useful species. Local populations recognize and take advantage of this diversity in their gathering, hunting, fishing, and farming activities. This reflects a conservation ethic rooted in the co-evolution of humans and nature (Tourinho et al. 2017). The unique relationship ribeirinhos have with nature makes them great holders of knowledge about aspects of the forest's fauna and flora, which feeds the culture and knowledge orally transferred from generation to generation (Instituto EcoBrasil 2017). "Wild" cocoa trees in floodplain forests can be defined as cultural or domesticated forests (Balée 1989, 2013; Levis et al. 2018). This unique cocoa economy has existed for almost four centuries and is of great regional importance for preserving the riparian forests of large rivers and, as a result, their biodiversity and agrobiodiversity, preventing rural exodus and the advance of deforestation, by providing a secure income alternative for the ribeirinhos. "Wild" cocoa agroforests are focused entirely on organic production. The ribeirinho avoids using any chemical fertilizers or agricultural pesticides on their land, even when it is necessary to correct or replace soil nutrients, or to control pests and diseases (Almeida and Müller 2022a). Thus, "wild" cocoa agroforests in the Amazonian floodplains must be understood as a socio-ecological complex with multiple values at the landscape scale (Gama-Rodrigues et al. 2021).

The ribeirinho communities of the Amazonia have historically lived in isolation and have faced significant challenges in developing their activities to improve their quality of life. Despite its recognized socioeconomic and environmental importance (Brito et al. 2002b; Ribeiro et al. 2004; Santos et al. 2016), a historical retrospective of the last six decades reveals that ideas for modernization of Amazonian agriculture never saw the floodplains as appropriate ecosystems for the sustainable development of the region (Almeida and Müller 2022a). This situation limits the development of public policies for the conservation and sustainable management of these ecosystems. As a result, the cultivation of cocoa in floodplains is still very little studied, and, therefore, little known among the international cocoa community.

The long-standing presence of "wild" cocoa in Amazonian floodplains is not a recent phenomenon. The historical trajectory of this crop dates back centuries, probably millennia, shaping local economies and cultural practices (Patiño 2002; Miller and Nair 2006; Somarriba and Lachenaud 2013). Understanding this past helps contextualize its role in contemporary agroforestry systems. In this context, this review aims to describe the various agronomic, economic, and socio-ecological aspects of "wild" cocoa cultivation in floodplains, considering its origin, diversity, and distribution in Brazilian Amazonia from a historical perspective. This narrative review synthesizes existing knowledge on the topic, integrating and contextualizing relevant literature to provide a comprehensive perspective on cocoa cultivation in Amazonian floodplains.

Brief history of cocoa in the Brazilian Amazonia

Cocoa was already part of the forest products trade (along with other indigenous products, such as sarsaparilla—*Smilax ornata*, annatto—*Bixa orellana*, vanilla—*Vanilla planifolia*, and indigo—*Indigofera tinctoria*) in the Amazon region since the end of the sixteenth century and beginning of the seventeenth century (Oliveira 1983a). These indigenous products were referred to as "drugs from the backlands" due to their extraction from the Brazilian hinterland during Colonial Brazil, as well as the trade of valuable wood and animal products such as oil from turtle eggs used for food and lighting, and manatee (*Trichechus inunguis*, "peixe-boi") exported salted and dried (OCUPAÇÃO 2017). The "wild" cocoa (*cacau bravo*) was ubiquitous and grew throughout the entire Amazon River system (Alden 1974; Patiño 2002). For instance, Acuña (1865) recorded that during Pedro Teixeira's expedition from the city of San Francisco de Quito in Peru to Belém in Pará in 1639, he was impressed by the large number of "wild" cacao trees present on the banks of the Amazon River with abundant fruiting. The cultivation of cocoa, together with tobacco (*Nicotiana tabacum*), sugar cane (*Saccharum officinarum*), and wood exploitation, prevailed during this colonial period, and was.

> "indubitavelmente suficientes para enriquecer um e muitos reinos; … e manifesta-se bem a grande facilidade do cultivo de semelhantes arvores n'este rio, porquanto, sem o mínimo auxílio da arte, a natureza por si só as enche de abundantes fructos" (Acuña 1865, p.192).

(undoubtedly sufficient to enrich one and many kingdoms; … and the great ease of cultivating similar trees in this river is clearly evident, since, without the slightest assistance from art, nature alone fills them with abundant fruit).

There are records indicating large populations of "wild" cocoa trees existed along the banks of the Madeira River in the eighteenth century (Serra 1857; Gomes 2008; Azevedo 1999). From the 1730s, and for over one century, cocoa became the primary export product from the Amazon, in what is known as the "cocoa cycle in the Amazonia" (Rosário 1986). A considerable amount of the exported cocoa came from "wild" populations found on the banks and islands of the main tributaries of the Amazon River, such as the Negro, Trombetas, and Madeira rivers (Alden 1974). The Jesuits, using indigenous labor, annually harvested over four thousand *arrobas* (1 arroba = 15 kg) of cocoa fruits only along the Madeira River (Azevedo 1999). In 1780, the state of Pará produced over 1,500 tons of cocoa (CACAU 2019). Historical records indicate that, at times, cocoa accounted for over 90% of regional exports, which helped to end the Amazon's isolation and established a regular trade with European markets through the Belém-Lisbon route (Santos 1980).

Several naturalists on scientific expeditions from the 17th to the nineteenth centuries documented the significant presence of "wild" populations (*cacau bravo*) and commercial plantations (*cacau manso*) in several regions of the Brazilian Amazon, such as Cacaual Grande, located between Monte Alegre and Alenquer, on the Amazon River; Cametá, Patos, and islands of the Tocantins River; Itacoatiara, Óbidos, Monte Alegre and Santarém on the Amazon River; the vicinity of Manaus and Careiro Island; the Tapajós, Madeira, Purus, Juruá, Javari, Içá, Metá rivers and the mouth of the Copeá on the Solimões River; Lagoas Maraã, on the Japurá River; and Copeá, on the Solimões River, as well as others widely described by Bates (1979), La Condamine (1944), Coudreau (1977), Ferreira (1983), Spix and Martius (1981), Spruce (2014), and Wallace (1979).

Officially, the cultivation of cocoa trees in the Amazon began near Belém in 1679 (Cardoso 2015). The Jesuit priests, who arrived in the Amazon in the early seventeenth century, were pioneers in encouraging the cultivation of cocoa and exploiting various "drugs from the backlands" (Arenz 2023). They utilized indigenous knowledge and labor for these efforts. The villages established by the Jesuits not only cultivated cocoa but also acquired it from local indigenous communities. Le Cointe (1934) reported that the Jesuits oversaw the planting of approximately 40,000 cocoa trees in the eighteenth century on the right bank of the Amazon River near Óbidos, in an area known as Cacaual Imperial. Bates (1979) noted properties with extensive cocoa plantations in the Itacoatiara region, including one with around 8,000 cocoa trees situated near the mouth of the Madeira River. On the Tocantins River, above the town of Patos, Wallace (1979) reported a plantation with 60,000 cocoa trees that had been established within the forest at the Jambuaçu site. Spix and Martius (1981) documented a cocoa plantation with approximately 20,000 plants on the north bank of the Solimões River, on the outskirts of Manaus, in 1819.

Between 1840 and 1910, the Amazon experienced what is known as the “first rubber cycle,” which drew a large influx of people from northeastern Brazil and foreign nations to the region. During this time, rubber supplanted cocoa as the dominant economic activity, with rubber accounting for 40% of foreign trade revenue by 1910 (Oliveira 1983b). Cocoa exports significantly declined, leading to a complete economic downturn for cocoa farming due to falling market prices.

Origin, diversity and dispersal of cocoa in the Brazilian Amazonia

Origin

The genus *Theobroma* occurs throughout the humid tropical forests of the Western Hemisphere between latitudes 18º N and 15º S, extending from southern Mexico to the Amazon basin (Cheesman 1944). This genus is divided into six sections comprising 22 species. Of these species, 10 occur in Brazilian Amazonia: *T. cacao*, *T. grandiflorum*, *T. bicolor*, *T. silvatum*, *T. obovatum*, *T. subincanum*, *T. speciosum*, *T. microcarpum*, *T. glaucum* and *T. canumanense* (Cuatrecasas 1964). The Upper Amazon basin, which comprises parts of Peru, Ecuador and Colombia, specifically Napo, Putumayo (known as Içá River in Brazil), and Caquetá (also called Japurá River in Brazil) rivers, is the center of genetic diversity and the probable place of origin of the genus *Theobroma*. This is due to the great phenotypic variability observed in the region by Cheesman (1944). Thomas et al. (2012) used a molecular analyses dataset, elaborated by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA), to support the hypothesis that the center of genetic diversity of cocoa trees is located in the Upper Amazon region, on the border of northeastern Peru, Brazil (Acre and Western Amazonas states), southwestern Colombia, and eastern Ecuador. It is believed that cocoa spread in two directions from this region where the aforementioned tributaries of the Amazon River meet. The Forasteiro group dispersed to the east throughout the lowlands, while the Crioulo group dispersed to the north as far as Mexico. The Forasteiro region includes a broad river basin system including the following rivers: Chambira, Huallaga, Japurá, Javari, Morona, Nanay, Negro, Nucuray, Pastaza, Purus, Santiago, Tigre, Ucayali, and Urituyacu, all flowing into the Marañon and Amazonas (CACAONET 2012). During periods of glaciation, cacao populations were confined to several refuges, where they likely experienced genetic differentiation, resulting in multiple genetic clusters that more closely represent the original “wild” cacao populations (Thomas et al. 2012).

Three botanical groups of *T. cacao* were traditionally recognized, based on morphological characteristics and geographic origins (Cheesman 1944; Cuatrecasas 1964; Soria 1966):

i) “Crioulo” or “Criollo” (*Theobroma cacao* subsp. *cacao*) – occurs in Central America, Mexico, and northern South America, and was domesticated more than 3,000 years ago (Dias 2001; Sánchez et al. 2017; Zarrillo et al. 2018).

ii) “Amazon Forasteiro” or “Forastero” (*Theobroma cacao* subsp. *sphaerocarpum*) – occurs in South America, which is divided into Upper and Lower Amazons, according to the region of origin, with “wild” or “semi-wild” populations that grow on the banks of the rivers of the Amazon River basin. The Upper Amazon subgroup is considered the most genetically diverse, exhibiting superior agronomic yield (Bartley 1969), while the Lower Amazon subgroup, including the Amelonado type, the most widely cultivated, presents low genetic diversity and evidence of having been incipiently domesticated in eastern Amazonia (Clement et al. 2010). This domestication specifically took place in the Pará River area of the state of Pará, located in the Lower Amazon region (Dias and Resende 2009). The Amelonado is considered quite vigorous, more resistant to diseases than the Criollo, and quite productive, although less adapted to cultivation without shade, than the Upper Amazon genotypes (Pokou et al. 2009). The Forasteiro is the most cultivated group in Brazil and in Africa, representing more than 80% of total global cocoa production (Almeida and Müller 2022b).

iii) “Trinitario” – this group is the result of a spontaneous hybridization between “Crioulos” and

"Forasteiros", in Trinidad, after the hurricane of 1727 (Bekele 2019). They are cultivated in many Latin America and Caribbean countries, and in some countries in Africa (e.g. Madagascar) and Oceania (e.g. Papua New Guinea).

Recently, several studies have proposed a new more detailed classification to replace the traditional one that better reflects the rich genetic diversity of cocoa populations observed in Amazonia. Thirteen main genetic groups of cocoa germplasm were identified through the use of molecular markers (microsatellites): Marañon, Curaray, Criollo, Iquitos, Nanay, Contamana, Amelonado, Purus, Nacional, Guiana (Motamayor et al. 2008), Piura Porcelana (Arevalo-Gardini et al. 2019), Rondônia (Thomas et al. 2012), and Nacional Boliviano (Zhang et al. 2009, 2012). The Criollo group is found in Central America and northern South America, while all other genetic groups are found in lowland South America north of 15º S. These studies have clarified the distinct genetic profiles among genetic groups in South America. This information enhances our understanding of how genetic diversity in cocoa is distributed across different regions, as a combined result of natural dispersal and human activity. Research on the subject does not seem to have been exhausted due to the broad spectrum of genetic diversity of cocoa, the genetic methodology used, and the representativeness of the new germplasm samples from "wild" cocoa populations studied (Cornejo et al. 2018; Almeida and Müller 2022b).

Diversity and dispersal

Certain populations of cocoa in Brazilian Amazonia have unique morphological characteristics due to geographic or ecological isolation, particularly in populations growing on the banks of big rivers (Almeida 2001). The highest genetic variability is found within river basins, ranging from 63 to 72% (Mota et al. 2009; Silva et al. 2011). Most cocoa subpopulations have exclusive alleles, of which 97% are rare. This supports the hypothesis that the differentiation of "wild" cocoa populations is closely related to the regional-scale river basin system in Brazilian Amazonia (Dias et al. 2003; Sereno et al. 2006; Silva et al. 2012; Guimarães et al. 2023). Zhang et al. (2009; 2012) also found a rich cocoa genetic diversity, stratified at the regional scale by the Peruvian and Bolivian Amazon River systems.

In this context, a predominant type of fruit and a close association between the morphological variability and the river basin can be sometimes observed. Evidence of this is the "wild" cocoa found in the Içá River, which is a tributary of the Solimões River in the state of Amazonas, whose fruit has a bluish hue and is known as "blue cocoa" by local inhabitants. In this region, the cocoa population is primarily composed of the Purús and Iquitos genetic groups (Motamayor et al. 2008). Another example is the Amelonado group, which is found in the Lower Amazon basin from Manaus east to Belém (Motamayor et al. 2008) and presents less morphological variation in fruit characteristics than other Amazonian groups (Dias and Resende 2009; Almeida and Albuquerque 2022).

The Solimões/Amazonas River and its tributaries provided the waterway for the dispersal of the species (Silva et al. 2012). The highest dispersal route of cocoa genotypes is located on the Amazon River, in the stretch between the mouths of the Madeira and Tapajós rivers. This region is east of where the Purus, Negro and Madeira join the Solimões/Amazonas River, where each of these rivers was a dispersal route of cacao genotypes in Brazilian Amazonia.

Some assumptions suggest a connection between the historical migration of indigenous populations in the Amazon River and its major tributaries, and the likely paths taken by cocoa genotypes. Thus, the dispersal of cocoa populations would be associated with the settlement patterns of the Amazon River system by Indigenous Peoples (Almeida 1996; Thomas et al. 2012; Colli-Silva et al. 2024). Evidence of this cocoa population dispersal can be found in several indigenous communities, such as Kayapó, from Pará (Posey 1984; 1985), Tikúna and Tukána from the Solimões and Negro rivers, respectively (Kerr and Clement 1980), Mundurukú, from the Tapajós River (Frikel 1959), Waiãpi, from the Araguari and Jari rivers (Gallois 1981), Yanomami, from the hill range between the Amazon and Orinoco basins (Sánchez and Jaffé, 1992), and Ka'apor, from northern Maranhão (Balée and Gély 1989). However, all of these studies mention cocoa plantations without specifying any genetic groups.

Indigenous communities and ribeirinhos often use mass selection techniques to obtain seeds from fruit trees and other edible species (Kerr and Clement 1980), increasing phenotypic diversity for fruit and seed size (Almeida 1996; 2001). After a few hundred years of cultivation practices and phenotypic selection of plants by ribeirinho populations, in addition to environmental selective pressures, there is greater ecological adaptability of the species to the conditions prevailing in each local agroecosystem, which contributed to the development of genuine "*caboclo*" cocoa variety of the Amazonian floodplains (Almeida and Müller 2022b). On the other hand, as the cocoa tree, when abandoned, easily survives in humid forest ecosystems, it is classified as a species whose populations are in a semi-domesticated condition, rather than fully domesticated populations (Clement et al. 1999).

Cocoa fruits and seeds are also dispersed by animals like small primates, rodents, and birds (Cuatrecasas 1964). One of the earliest observations of the effects of dispersing agents on *cocoa* in Amazonia was recorded by Bates in 1850 during his exploration of the Middle Amazon. He noted the role of two species of monkeys: the capuchin monkey (*Cebus apella*), which often carries more fruit than it can consume, thereby aiding in the colonization of new habitats, and the common squirrel monkey (*Saimiri sciureus*), which tends to feed in the same location (Bates 1979). However, the dispersal of cocoa is limited due to certain species-specific traits, including high rates of vegetative propagation, short pollination distances, flower self-incompatibility and indehiscent fruits (Almeida 1996; Colli-Silva et al 2024).

Ecological aspects of the Brazilian Amazon floodplains

The Amazon biome can be classified into at least six subdivisions: the humid forest, the seasonal forest, mountainous forest, dry savanna, humid savanna, and the floodplain forests (Guzmán 2022). Large river floodplains cover around 11% of the area of the Amazon basin, most of which is forested (Wittmann et al. 2022). The floodplains of whitewater rivers such as the Amazon/Solimões River, associated with the Madeira, Purus, Juruá, Javari, Içá, and Japurá Rivers, are called *várzeas* (Junk et al. 2011), and are the largest eutrophic alluvial area (Gleissolos and Neossolos Flúvicos—Fluvisols) in Brazil, and one of the most extensive in the world. They are predominantly characteristic formations of the Amazonas/Solimões River and its tributaries, enriched annually by sediments brought from the Andes mountains ranges towards the Marajó Island, covering a distance of approximately 5,000 km (Junk et al. 2020). Floodplains are flooded for two to three months, generally from May to July, when the water level can rise up to 2 m. The soils of the *várzeas* have medium to high natural fertility, notably Ca, Mg and P (Falesi 1972). Sustainable use and cultivation of the *várzeas* have been continuously practiced since pre-Columbian times (Schaefer et al. 2023). On the other hand, the floodplains of blackwater rivers (e.g. Negro, Jutaí, Tefé, and Coari Rivers) are of low fertility, while the floodplains of clearwater rivers (e.g. Branco, Trombetas, Tapajós, Xingu, and Tocantins Rivers) are of low to medium fertility; both floodplains are called *igapós* (Junk et al. 2011). Igapó rivers drain old, strongly weathered Tertiary sediments of Paleozoic and pre-Cambrian origin (Wittmann et al. 2022).

Floodplains are characterized by tropical forests, regionally known as "mata-de-várzea," which host approximately 17% of the tree species found in the Amazon basin (Householder et al. 2024), of which a group of 301 tree species have been identified as floodplain specialists. Most tree species exhibit a strong preference for a specific floodplain habitat type: 51% (154 species) favored várzea, while 38% (115 species) preferred igapó. Only a small number, 11% (32 species), were associated with both types of floodplains. Wittmann et al. (2020), based on data from 44 floristic inventories distributed throughout the Amazon basin, mention that Fabaceae is the most important family in floodplain forests, followed by Malvaceae, Euphorbiaceae, Moraceae, Arecaceae, and Salicaceae. In the floodplain forests, the maximum species richness (≥ 10 cm DBH) found in Eastern Amazonia is 84 species/ha, with 142 species/ha in Central Amazonia, and 157 species/ha in the southern part of Western Amazonia (Wittmann et al. 2020). Floodplain forests of the Middle Amazon are characterized by the predominance of the following species (BRASIL 1976): andiroba (*Carapa guianensis*), açacu (*Hura creptans*), breu-branco-da-várzea (*Protium unifoliolatum*), cajurana (*Simaba guianensis*), caxinguba (*Ficus* spp.), genipapo (*Genipa americana*), imbaúba (*Cecropia* sp.), ingá (*Inga disticta*), macacaúba-da-várzea (*Platymiscium paraense*), mamorana (*Pachira insignis*), munguba (*Bombax munguba*), murupita (*Olmedia calophylla*), pau-mulato-da-várzea (*Calycophyllum spruceanum*), seringa-barriguda (*Hevea spruceana*), seringa-itaúba (*Hevea guianensis*), sumaúma (*Ceiba pentandra*—kapok tree), tachi-da-flor-amarela (*Pterocarpus ancylocalyx*), tachi-do-igapó (*Triplaris surinamensis*), taperebá or cajá (*Spondias mombin*) and ucuúba-branca (*Virola surinamensis*).

The cocoa tree is a common species in the floodplain forests of the Brazilian Amazonia (Ducke 1940, 1953). It is typically found in the lower stratum of the forest on higher terraces, where the flood pulse has a shorter duration and the high temperature and humidity are suitable for its growth (Bartley 2005). Cocoa, in association with other tree species of economic value (rubber and various timber, and fruit tree species), adapted to a periodic flood regime, results in highly diverse agroforestry systems known as "*caboclo*" agroforestry systems (Nascimento and Santana 1974). This "*caboclo*" agroforestry systems is observed in the state of Amazonas, particularly along the Amazonas/Solimões River and its tributaries (Içá, Japurá, Negro, Ituí, Jutaí, Juruá, Purus, Igapó-Açu, Madeira, Aripuanã and Canumã) (Fig. 1). These cocoa agroforests in the Amazonian floodplains face significant challenges due to frequent flooding of the Amazon River. This flooding can result in the loss of cocoa trees and lead to the displacement of cocoa clumps in some plantations. This phenomenon, known as "terras caídas" (or fallen lands), occurs when landslides happen along riverbanks (Brito et al. 2002a). It is a common issue in the Middle Amazon, affecting high and low *várzeas*.

Floristic and structural analysis carried out by Brito et al. (2002a) in 35 sites (Municipalities from São Pedro de Iracema to Parintins) in the Middle Amazon River (whitewater) revealed the presence of more than 40 plant species associated with cocoa clumps, with an average density of 230 plants/ha and a range of variation from 76 to 401 cocoa trees. The predominant species were rubber (53%),

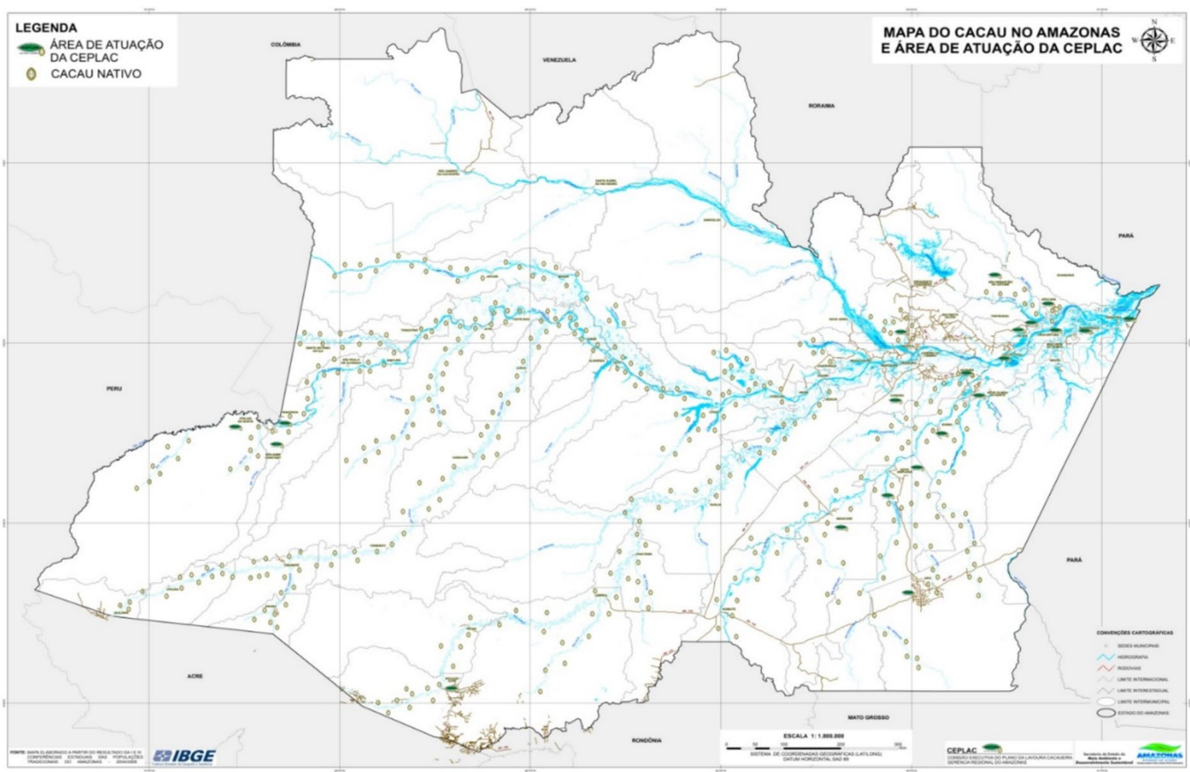

Fig. 1 Map showing the distribution of "wild" cocoa along the Solimões/Amazonas River and its tributaries in the state of Amazonas

açaí (*Euterpe oleracea*) (15%), imbaúba (7%), taperebá (6%), ingá (3%), mango (2%) and bacaba (*Oenocarpus distichus*) (2%). While in the high *várzeas* of the Lower Amazon, from the municipalities of Lontra da Pedreira to Ilha de Juruparí, the species that stand out, either due to their economic value or their frequency index, are: rubber (*Hevea brasiliensis*), andiroba, ucuúba-branca, açacu, pracuúba (*Mora paraensis*), kapok, taperebá, açaí and buriti (*Mauritia flexuosa*) (Lima et al. 2001). A forest inventory in seven agroforests of the Juba River *igapós* (clearwater), in the Lower Tocantins River basin, found 27 families, 53 genera, and 61 species, with the five most commonly found species (8%) being: açaí (1561 plants/ha), cocoa (869 plants/ha), ucuúba-branca (194 plants/ha), rubber (94 plants/ha) and andiroba (94 plants/ha) (Santos et al. 2004). In turn, a forest survey conducted in four agroforests located in other floodplains of the Lower Tocantins River found a total of 10 families, 13 genera, and 13 species, with an average density of 2,458 individuals (average DBH $\geq$ 9.6 cm) per hectare (Santos et al. 2016). The predominant species in these agroforests were cocoa and açaí.

Due to this richness of species, traditional extractivism is common, featuring a diverse range of products, such as açaí, amapá (*Parahancornia amapa*), andiroba, babaçu (*Orbignya martiana*), breu (*Protium* spp), castanha-do-brasil (*Bertholletia excels*—Brazil nut), caucho (*Styrax* spp), copaíba (*Copaifera duckey*), cumaru (*Coumarouma odorata*), lacre (*Vismia cayennensis*), patauá (*Oenocarpus bataua*) and rubber, in addition to the extraction of timber and fish (Almeida et al. 2012). Also common is the practice of cultivating temporary crops such as pineapple (*Ananas comosus*), rice (*Oryza sativa*), banana (*Musa* spp), beans (*Phaseolus vulgaris*), jute (*Corchorus capsulares*), mallow (*Urena lobata*), manioc (*Manihot esculenta*), watermelon (*Citrullus vulgaris*), maize (*Zea mays*), papaya (*Carica papaya*), when establishing new cocoa plots. Manioc is the most commonly cultivated crop. The perennial crops most commonly cultivated include avocado (*Persea americana*), cocoa, soursop (*Anona muricata*), guaraná (*Paullinia cupana*), genipapo, orange (*Citrus sinensis*), mango (*Mangifera indica*), passion fruit (*Passiflora edulis*) and taperebá.

Two distinct management models

Traditional cultivation

Planting

Cocoa plantations are established through two processes: 1) Natural dispersal agents carry out the first process, especially by frugivorous animals and water, and 2) Plantation by the ribeirinho population (Almeida et al. 2012). This second process has two variants: a) Establishment of cocoa under the floodplain forest after eliminating the understory vegetation—a kind of "*Amazonian cabruca*", and b) Establishment of cocoa in previously deforested land, using early intercropping of cocoa with maize and manioc and a mixed shade canopy with naturally regenerated native tree species and planted useful tree species.

In both variants, the farmers collect seeds from a mixture of fruit types from both "wild" cocoa in the forest and old plantations owned by their ancestors or neighbors (Fig. 2A). Cocoa trees may be planted randomly, without following any pre-established design and spacing (Fig. 2B), but this is changing. In the last twenty years, the action of CEPLAC (Executive Committee of the Cocoa Farming Plan) has encouraged the establishment of plantations in an orderly manner, generally at a spacing of 3.0 × 3.0 m (Fig. 2C). In the Middle Amazon, such plantations are predominantly small, around 90% with less than 3.0 ha (Brito et al. 2002a). In the Tocantins River region, plantations of 7.1 ha in size predominate (Mendes and Mussói 2005).

Cocoa tree management

Multi-stem plants, known as "clumps," are typical of cocoa plants in floodplain areas (Fig. 2B). Ribeirinho farmers believe that plants with more trunks are more productive (Almeida et al. 2012). A clump, may consist of 20–30 trunks and reach more than 20 m in height. In the Middle Amazon, there are around nine adult trunks per clump and 410 cacao clumps per hectare (Brito et al. 2002a). On the other hand, in the Tocantins River region, the number of cacao clumps per hectare is approximately 700 (Mendes and Mussói 2005). Cocoa plantations in the Amazonia floodplains look very different from those in

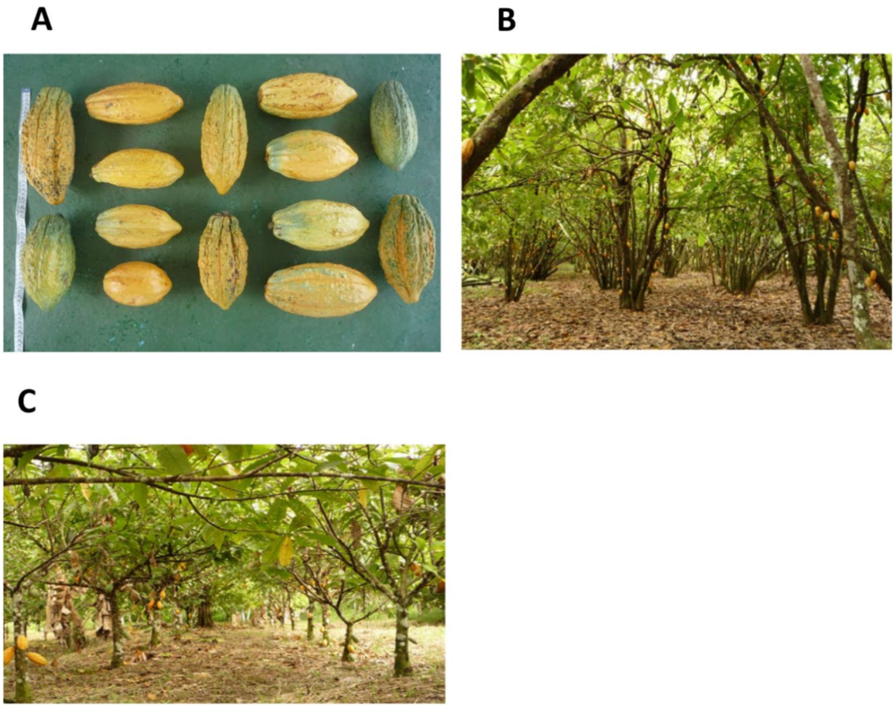

Fig. 2 **A**) Mix of types of cocoa fruits from riverine plantations in the Middle Amazon; **B**) Cocoa trees in clumps without a pre-established spatial arrangement; and **C**) Plantations of cocoa trees with regular spatial arrangement

other cocoa-producing regions in Brazil, where single-stemmed plants are maintained through regular pruning.

The production system used in the cocoa plantations of the Amazon floodplains can be considered as having a low technological level (Brito et al. 2002a). Typically, it involves basic practices such as weeding, harvesting, breaking the fruits, partial fermentation, and drying the seeds. The ribeirinho people generally conduct one to three weedings annually to facilitate the harvest, which usually takes place from January to July or August, with the peak fruiting from March to June. Excessive density of shade tree occurrence is common since farmers do not thin these trees to reduce shade. Farmers tend to avoid cutting down valuable shade trees such as açaí, taperebá, ingá, mango, and bacaba among others.

Cocoa fruits are harvested using a loop made from cowhide, nylon line, or vegetable fiber, attached to the end of a long stick. With this harvesting tool, the cocoa fruit may have its peduncle cut or part of the bark removed from the trunk or branches, damaging flower cushions and eventually reducing cocoa yield. Farmers have recently started to use a pruning hook-type of tool with a handle on the end of a long pole to harvest the cocoa fruit. This change is particularly evident among younger generations (Almeida et al. 2012). As flooding is more common during harvest season, ribeirinho dwellers often use canoes to carry out all tasks (Figure S1).

Cocoa fermentation and drying

A small proportion of farmers have facilities for fermenting and drying of cocoa seeds (Almeida and Müller 2022a). Ribeirinhos usually sell “green cocoa” or “soft cocoa” to local traders. Only 10% of farmers have a barge for drying seeds. The barge is a type of wood dryer, known for decades in the region, with a mobile cover, fixed ballast, and mobile drawers that run on wheels and wooden supports, with dimensions of 3.0 × 5.0–4.0 × 6.0 m, although there may be small variations in this structure (Figure S2). However, most ribeirinhos use waxed canvas or polyethylene plastic canvas for drying, a process that is made difficult during the flood season, when growth of mold is common on cocoa seeds.

The habit of not fermenting cocoa seeds in the Amazon dates back centuries, being part of the culture of these rural populations (Almeida and Müller 2022a). It was the habit of ancient ribeirinhos and indigenous communities to prepare juices, fermented drinks (*capilé*), and alcohol and sugar-based drinks (*cacauari*), locally highly appreciated, based on cocoa pulp. Seeds were then dried, without previous fermentation. Younger generations have become more interested in fermenting cocoa before drying it because proper fermentation and drying are essential for making high-quality artisan chocolate.

New cocoa-based agroforestry systems

New agroforestry system models using "wild" cocoa genotypes are being implemented in areas affected by shifting cultivation, particularly in the state of Amazonas. These models could be beneficial for restoring riparian forests and promoting sustainable intensification as an environmentally friendly and climate-smart alternative. They are slight adaptations of the models proposed by CEPLAC (Brito et al. 2002b), made necessary by the need for closer spacing of the taperebá due to its less dense canopy, and wider spacing for the soursop (*Annona muricata*). This approach allows for the cultivation of subsistence crops between the rows for an extended period. The following sections describe two of these models.

Intercropping of cocoa with açaí

This model consists of two rows of açaí, at a spacing of 4.0×4.0 m, alternating with thirteen rows of cocoa trees, at a spacing of 3.0×3.0 m, in an East–West direction (Fig. 3). A distance of 3.0 m remains between the two species, thus the double rows of açaí are 42 m apart. The temporary shading of the cocoa consists of manioc, at a spacing of 1.0×1.0 m, and banana at 3.0×3.0 m. The banana varieties Caipira, Thap Maeo, and FHIA 18 are recommended, due to their resistance to the Panama disease (*Fusarium oxysporium*), yellow Sigatoka (*Mycosphaerella*

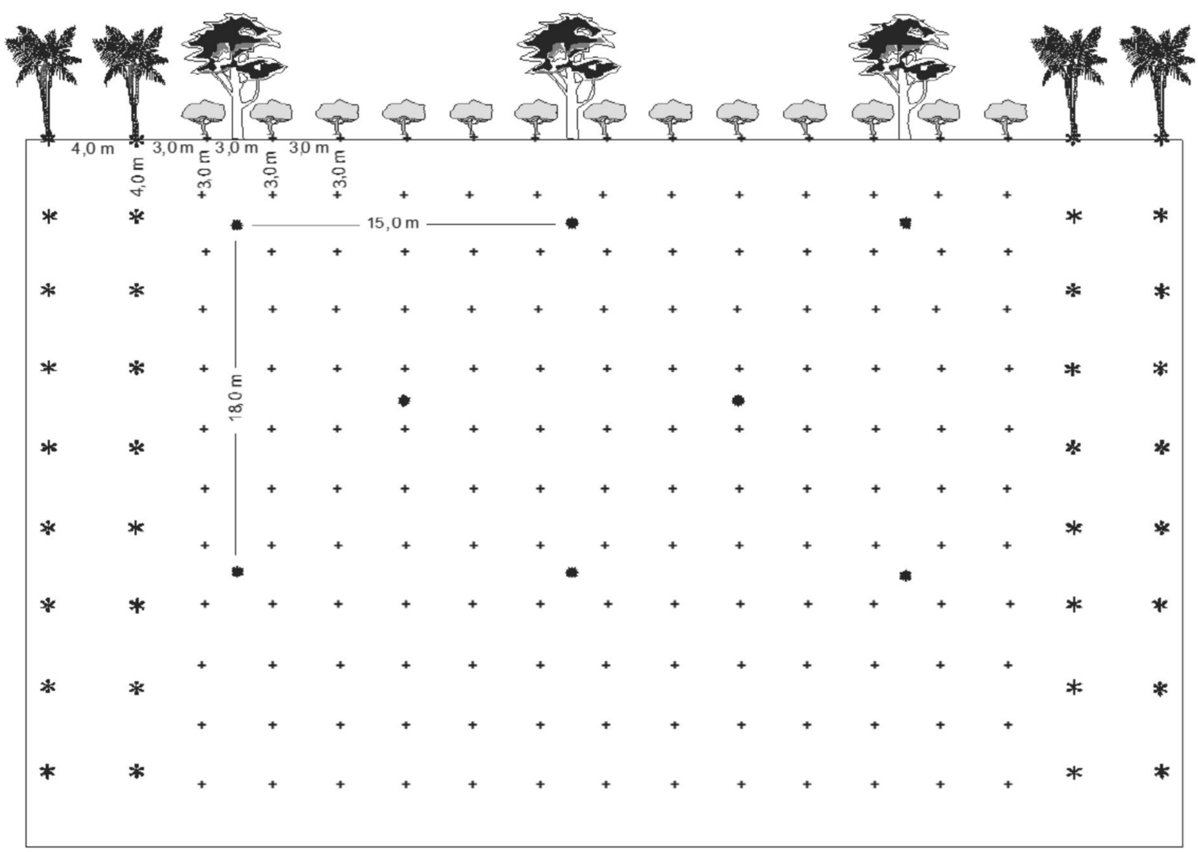

Fig. 3 Schematic diagram showing the spatial arrangement of cocoa (+), açaí (⁎) and taperebá (*Spondias mombim*, ✸) intercropping in Amazonas floodplains. The population density is 910 cocoa trees, 182 açaí trees, and 43 "*taperebazeiros*" per hectare

musicola), and black Sigatoka (*M. fijiensis*), which are now endemic in region.

The taperebá or cajá is planted as a shade tree between the cocoa trees, with a spacing of 15×18 m, and one plant diagonally. Pruning the canopy of the taperebá is necessary to reduce excessive shade over the cocoa tree and facilitate the harvest of the taperebá fruits. This fruit is widely used in the state of Amazonas due to its ease of propagation both by seed and rooted stakes, good adaptation to the conditions of floodplains, rapid vegetative growth, shade canopy suitable for cocoa, and an additional income alternative by selling its pulp, which is widely used in the region for the preparation of sweets, juices, ice creams, wines, liqueurs, etc. The population density of this system is 910 cocoa, 182 açaí, and 43 taperebá per hectare. This agroforestry system covers more than 331 ha in Amazonas and is suitable for both floodplain and upland (*terra firme*) situations.

Intercropping of cocoa, soursop and açaí

This model consists of three planting zones: two rows of açaí, spaced 4.0×4.0 m; triple rows of soursop planted at 6.0×4.0 m and ten rows of cocoa trees, at a spacing of 3.0×3.0 m, in an East–West direction (Fig. 4). Between the three intercropped species, a distance of 3.0 m is maintained between rows. Thus, the rows of açaí will be 63 m apart, while those of soursop will be 33 m apart. The same technical recommendations defined for the temporary shading of cocoa in intercropping cocoa and açaí in rows are also used for this system. The taperebá will also be used for definitive shading, at a spacing of 18×18 m, and one plant diagonally. In addition, it will also be necessary to prune the canopy of the taperebá to facilitate fruit harvesting and reduce excessive shade over the cocoa trees. This model presents a population density of 444 cocoa, 200 soursop, 28 taperebas, and 133 açaí

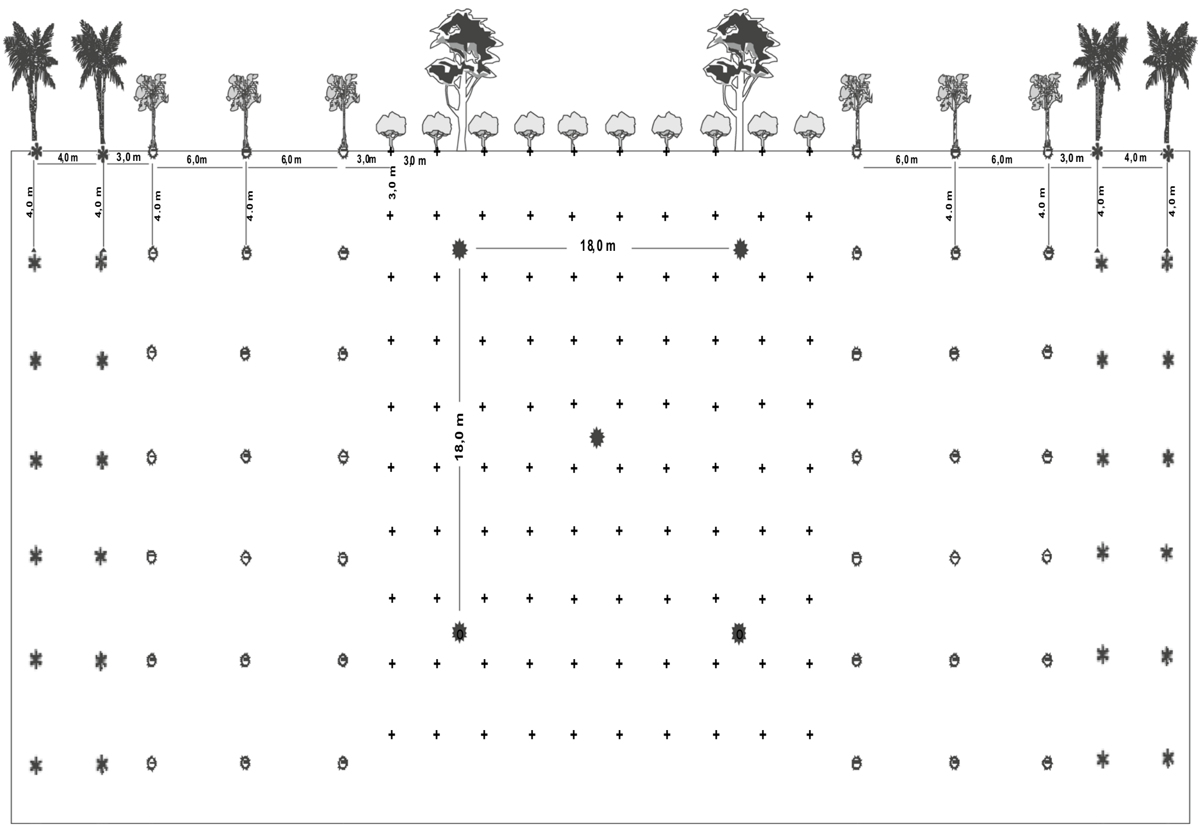

Fig. 4 Schematic diagram showing the spatial arrangement of cocoa (+), soursop (G), açaí (✱) and taperebá (*Spondias mombim*,✹) intercropping in Amazonas floodplains. The population density is 444 cocoa trees, 200 soursop trees, 28 taperebas trees, and 133 açaí trees per hectare

per hectare. It currently covers over 635 ha in Amazonas (Fig. 4).

Both models incorporate early intercropping young cocoa with short-term crops, such as papaya, passion fruit, gherkin (*Cucumis anguria*) and watermelon. Other crops used are also: pumpkin (*Curcubita pepo*), beach beans (*Vigna sinensis*), maize, sweet pepper (*Capsicum chinense* 'Adjuma'), and okra (*Hibiscus esculentus*). Early intercropping generally occurs until the fifth year of age of the cocoa agroforestry system.

Socioeconomic aspects

Profile of the ribeirinho cocoa community

Traditional cocoa farmers in the Amazonian floodplains typically have low levels of education, live on their properties, and have many children (1 to 15, average of five) per family (Figure S2). As these young individuals start their own families, the rural properties tend to be subdivided to create independent sources of income. This results in many small properties, usually five to twenty hectares, often with kinship ties among residents in a given area (Almeida et al. 2012). These small family communities are marked by a deeply religious culture and have a strong spiritual connection to the surrounding nature (Tourinho et al. 2017) and cultivate their land for self-consumption, combined with the marketing of certain products collected from the rich biodiversity found in the caboclo cocoa agroforests. Besides cocoa, farmers and communities utilize a wide variety of other species for food, animal feed, attracting wildlife, traditional medicine, organic fertilizer, construction materials (for houses, canoes, boats, furniture, tools etc.), firewood and charcoal, handicrafts, and various other uses (Santos et al. 2016). The use of synthetic agricultural inputs is not part of the ribeirinho culture and practice. Cocoa is produced organically but is not certified and marketed as such. Ribeirinho farmers lack social organization and are reluctant to engage in cooperatives or associations to facilitate cocoa certification (Almeida et al. 2012). This individualistic behavior prevents ribeirinho cocoa farmer from financially benefiting from the certification and marketing of the unique ethical, social, and ecological characteristics of this cocoa.

Cocoa production in the Amazonian floodplains

Historical records of cocoa production in floodplains areas are found in only 22 municipalities in the states of Pará and Amazonas (IBGE/SIDRA 2024), however, these records do not distinguish cocoa production between traditional systems and the new CEPLAC agroforestry models. The microregion of Lower Tocantins (Pará), covering five municipalities (Table 1), also known as the Region of the Islands, has a cocoa cultivation area of 8,158 ha, cultivated by approximately 890 families (9.2 ha/family), and a production of 3,820 t/year of dry cocoa seeds.

Table 1 Harvested area, production, and productivity of "wild" and cultivated cocoa in floodplain areas in the municipalities of the states of Amazonas and Pará, in 2022

State/Municipality[a]	Harvested area (ha)	Production (t)	Productivity (kg/ha)
Amazonas			
Apuí	50	30	600
Autazes	40	17	425
Boca do Acre	240	125	521
Borba	145	87	600
Coari	170	120	706
Codajás	20	12	600
Fonte Boa	30	10	333
Humaitá	20	14	700
Itapiranga	10	4	400
Jutaí	60	25	417
Manicoré	150	52	347
Nova Olinda do Norte	55	19	345
Novo Aripuanã	85	51	600
Pauini	7	4	571
Tefé	19	14	737
Urucará	22	16	727
Urucurituba	80	56	700
Total	1,203	656	545*
Pará			
Baião	500	200	400
Cametá	6,396	2,885	451
Igarapé-Miri	462	164	355
Limoeiro do Ajuru	100	46	460
Mocajuba	700	525	750
Total	8,158	3,820	468*

[a]IBGE/SIDRA (2024)

*Média

The regional average productivity is 468 kg/ha with municipal average productivity ranging from 355 to 750 kg/ha (Table 1). In Amazonas, areas with "wild" plus cultivated cocoa are located on the banks of the Amazonas/Solimões River and their tributaries, distributed across 17 municipalities in the state (Table 1). The harvested area is approximately 1,200 hectares, cultivated by 2,200 families (0.5 ha/family), production of around 700 tons of dry cocoa seeds, and regional average productivity of 545 kg/ha, with municipal averages varying from 333 to 727 kg/ha (Tables 1 and S1). The municipalities of Borba, Coari, Novo Aripuanã and Urucurituba, which represent 40% of the harvested area and 48% of the state's production, have average yields above 600 kg/ha, which represents, in comparison, a 30% superiority with the national average (464 kg/ha) (Tables 1 and S2).

Cocoa marketing

Due to its geographic isolation, farmgate sales prices for ribeirinho cocoa are lower than in other cocoa-producing regions of the country (Almeida et al. 2012). Ribeirinhos barter their production to the community trader, who generally has a grocery store with basic goods, known as "*dry and wet products*", where he sells his goods in exchange for the delivery of cocoa and other regional products, such as fish, rubber, Brazil nuts, parsley, copaíba oil, guaraná, cinnamon, cloves, sarsaparilla, piassava, açaí, and taperebá. This system of advances of goods on credit is locally known as—"*aviamento*" (McGrath 1999; Brito et al. 2002a; Mende and Mussói 2005), and is the traditional economic system of Amazonia (Mendes 2018). In this "*aviamento*" system, extractive producers are routinely penalized. The community trader also has rustic facilities to process cocoa seeds, whose fermentation is carried out for a few days in burlap bags inserted in a rustic wooden trough that is typically used for preparing manioc flour, while waiting for space to dry the cocoa seeds. In this way, the seed curing process is not completed properly. Seeds can be dried on tarps, plastic sheets, or barges. After that, the cocoa is sold to a middleman, who then passes it on to larger cocoa traders.

Challenges and recommendations

The ribeirinho community faces cultural and anthropological challenges, such as low education levels and a strong tradition of extractive practices. In floodplain cocoa cultivation, the current agronomic practices often reflect an extractive condition that is difficult to change using conventional rural extension methods (Almeida et al. 2012). To address these challenges, combining the ribeirinho community's knowledge with technical and scientific expertise is essential to enhance management strategies for the caboclo cocoa agroforestry system. Additionally, geographical isolation and navigation difficulties on the Amazon River prevent access to riverside areas. These factors hinder communication and increase the financial costs of rural extension services (Mendes and Mussói 2005). Other challenges include the inconsistent presence of the State in the region and the lack of appropriate public policies.

Development of cooperative organizations among cocoa farmers. Many ribeirinho communities already have social groups focused on improving their socio-economic status. One example is the Agroextractive Cooperative of Mapiá and Médio Purus (COOPERAR) in Boca do Acre, state of Amazonas, which involves 21 cocoa communities with approximately 400 families (30 ha/family) (Table S3). This cooperative has successfully positioned "wild" cocoa from the region in the European market, where it is sold as *Wild Cocoa de Amazonas* (COOPERAR 2024). Strengthening these ribeirinha associations along with raising awareness about sustainable practices will enhance local development.

The sustainability of cocoa agroforests in floodplains has been questioned due to the lack of studies on carbon and nutrient stocks in the plant-soil system, and the impact of management practices to increase production without harming the conservation of agrobiodiversity and the provision of environmental services (Gama-Rodrigues et al. 2021). The intensification of açaí cultivation in floodplains over the past 20 years, driven by its high market value, has had a negative impact on the density and diversity of tree species, including cocoa (Freitas et al. 2021; Damasco et al. 2022).

Conclusions

"Caboclo" cocoa agroforests in the Amazon floodplains are a unique agroforestry system that integrates food production with agrobiodiversity conservation. Rooted in the traditions of ribeirinho, indigenous, and quilombola communities, these sustainable management practices have preserved genetic diversity and, with proper management, can achieve productivity levels above the national average. Beyond its economic importance, this system has also contributed to the cultural-ecological heritage of cocoa cultivation in the region.

The Amazon floodplains harbor a rich genetic diversity of cacao, shaped by geographic isolation, natural selection, and human migration and settlement patterns. The high genetic variability both between and within river basins underscores the role of waterways in the dispersal and differentiation of cocoa genotypes. This diversity highlights the importance of conservation efforts that recognize and protect the genetic heritage of floodplain cocoa while promoting its sustainable use.

Cocoa-based agroforestry systems in the Amazon floodplains provide a sustainable alternative to deforestation. Despite their diversity and resilience, these systems face challenges such as limited technical assistance, market constraints, and insufficient institutional support. Strengthening cooperatives and improving marketing networks can enhance economic returns and ensure long-term sustainability. Since cocoa cultivation in the floodplains is organic, public policies can add value to riverine products and expand their market opportunities.

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Ethics approval Not applicable.

Consent to participate Not applicable.

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