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Crop Breeding and Applied Biotechnology
21(S): e386221S8, 2021
Brazilian Society of Plant Breeding.
Printed in Brazil
http://dx.doi.org/10.1590/1984-70332021v21Sa21

# Contribution of breeding to agriculture in the Brazilian Amazon. I. Açaí palm and oil palm

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**Abstract:** *Sustainable development in the Amazon involves moderate actions that combine technology-based agriculture with forest conservation. One of these actions is the genetic breeding of native species, which promotes cultural appreciation of the local society, and enables the opening of new markets. As an example, two breeding programs with solid results will be mentioned in this review: açaí palm (Euterpe oleracea Mart.) and oil palm (Elaeis guineensis Jacq. and E. oleifera (Kunth.) Cortés). Despite its importance, the prospects for breeding programs on Amazon are not optimistic. Factors intrinsic to plants, such as their incipient domestication, as well as their perennial nature and the difficulty linked to the improvement of plants in this category; and extrinsic factors, such as the lack of resources and specialized labour, in addition to the deficiency in logistics, are growing challenges that make it difficult to implementation of new programs and expansion of existing ones.*

**Keywords:** *Perennial species breeding, plant breeding, Euterpe oleracea, Elaeis guineensis, Elaeis oleifera.*

## INTRODUCTION

The Amazon basin corresponds to the entire territory containing water resources that culminate in the Amazon River, the largest water source in the world. This basin occupies around 6.9 million km², 4 million of which are filled by the Amazon biome (Lleras 2012). Brazil holds 60% of this biome, which occupies nearly half of the national territory (IBGE 2019a) (Figure 1A).

Cardoso et al. (2017) accounted for 14,003 species of vascular plants known throughout the basin, which corresponds to 5% of the world diversity of this plant category. Around 76% of these species are found in the Brazilian territory, which represents about 40% of the superior plants in Brazil. It is estimated that 13% of the total amount of species is endemic to the Brazilian Amazon area, and 111 species of this amount are currently useful to humans (Lleras 2012, Flora do Brasil 2020).

The Northern region of Brazil (Figure 1B), fully inserted within the Amazon biome, has just over 385.3 million ha, consisting of 40% of conservation units, 30% of indigenous areas, 17% dedicated to agriculture and livestock and 13% for other purposes. Most of the population of more than 18 million inhabitants have as their main occupation agriculture, livestock and extractivism, three of the main activities that most create jobs in the region, directly and indirectly (IBGE 2017, 2020).

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**Received:** 11 June 2021
**Accepted:** 14 June 2021
**Published:** 06 July 2021

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The aforementioned data highlight the importance of two occupational aspects: the conservation of natural resources, in particular, those related to the forest; and agriculture, an important activity for the local socioeconomic dynamics. Agriculture promotes the subsistence of the producer and food security for the community, while the forest, in addition to the obvious environmental benefits, encourages the aspects of local culture, linked to the lifestyle and especially to the products it offers (Hoelle 2018).

Rebello and Homma (2010) and Homma (2014) highlight the unfeasibility of extremes: while keeping the forest untouchable is not economically viable, despite being environmentally optimum, predatory agriculture, which aims to increase the planted area and profits, using harmful actions to the forest, is also unacceptable in a socio-environmental perspective. The authors recommend a series of temperance-based actions, that is, combining forest conservation with technology-based agriculture, aiming at sustainability. Among these actions is the breeding of species usually cultivated in the region.

Plant breeding, combined with environmental improvement, transcends the search for higher numbers (greater yield, greater resistance, etc.) and permeates the cultural appreciation of the local community, by allowing producers to continue offering the products traditionally accessible to the community. In addition to the maintenance of current markets, the bioeconomy promotes the risen of new markets, mainly due to the motto of the products' sustainable origin, generated in harmony with the environment.

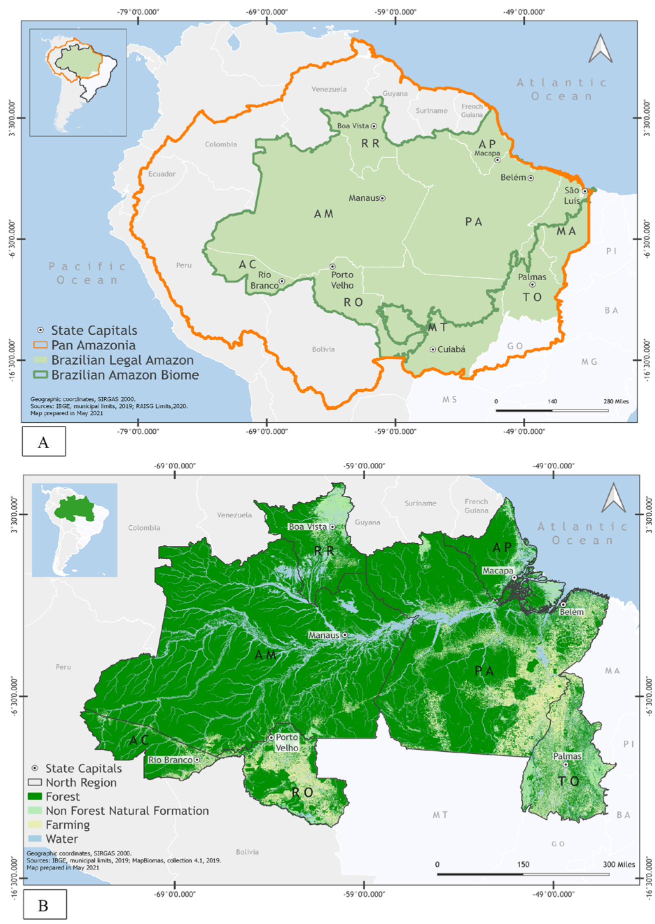


***Figure 1.*** Brazilian Amazon Biome (A) and Northern Region spatial division (B). Prepared by: Alexandra Alves.

Researches related to the breeding of Amazonian plant species are carried out mainly by public institutions such as Embrapa (Portuguese initials for Brazilian Agricultural Research Corporation), Ceplac (Portuguese initials for Executive Commission for the Cacao Crop Plan), Inpa (Portuguese initials for National Institute for Amazonian Research), among other public and private research institutes and universities, supported and fostered by research support foundations in the seven states of the North region, as well as research institutions from other regions (Souza et al. 2012).

Among Amazon native perennial species under research in regional institutions and which have a breeding program, the following stand out: açaí palm (*Euterpe oleracea* Mart.), cupuassu tree (*Theobroma grandiflorum* Willd (ex. Spreng) Schumm.), oil palm (*Elaeis guineensis* Jacq. and *Elaeis oleifera* (Kunth.) Cortés), guarana tree (*Paullinia cupana* Kunth. var. *sorbilis* (Mart.) Ducke) and cacao tree (*Theobroma cacao* L.). In addition to these, other species have been submitted to breeding and conservation of genetic resources, on a small scale, such as bacuri tree *(Platonia insignis* Mart.), açaí-do-amazonas palm (*Euterpe precatoria* Mart.), juçara palm (*Euterpe edulis* Mart.), muruci or murici tree (*Byrsonima crassifolia* (L.) Rich), achiote tree (*Bixa orellana* L.), camu-camu tree (*Myrciaria dubia* (Kunth) McVaugh), hog plum tree (*Spondias mombin* L.), peach palm (*Bactris gasipaes* Kunth), tucumã palm (*Astrocaryum vulgare* Mart.), paricá tree (*Schizolobium amazonicum* Herb.) and rubber tree (*Hevea spp.*). In an earlier stage, with small germplasm collections, there are patauá palm (*Oenocarpus bataua* Mart.), abiu tree (*Pouteira caimito* (Ruiz & Pav.) Radlk.), Brazil nut tree (*Bertholletia excelsa* Bonpl.) and mangaba tree (*Hancornia speciosa* Gomes), among others.

This study analyzes the main contributions from the breeding of two perennial species (açaí and oil palm) to agriculture in the Amazon, addresses the difficulties and outlines perspectives for this research line to continue contributing to the sustainable use of the natural resources of this region.

## AÇAÍ PALM (*EUTERPE OLERACEA* MART.)

### Socioeconomic relevance

Brazilian Northern region states have nearly 195,000 ha destined for açaí harvesting and are responsible for almost the whole national production (99%). Of this total, 40% is exported to other Brazilian states and/or other countries, and the remaining 60% is consumed in the Amazon market, showing a strong relationship between the fruit and local residents (IBGE 2019b). Açaí juice is an important food for the natives, contributing strongly to the food security of this population, as it is nutritionally rich and economically accessible (Yokomizo et al. 2012).

Despite not being the only producer, Brazil leads the world market for açaí. In 2019, more than 1.6 million tons of açaí were produced, considering the production from commercial plantations and extractivism (IBGE 2019b). There is a substantial growth in açaí production year after year, which is accompanied by the increase in prices per kilo, indicating the constant pressure of demand on supply (CONAB 2020).

The fruit of the açaí palm is currently the most commercially successful product from Amazon in the world. Açaí is an example of how a native fruit, until recently restricted to the Amazonian borders, can achieve prominence through efficient promotion, reaching even international markets. This is illustrated by the 10-fold increase in the amount of fruit exported from 2010 to 2019, a decade in which the profits of over US$935,000 reached US$9.5 million (Figure 2) (CONAB 2020).

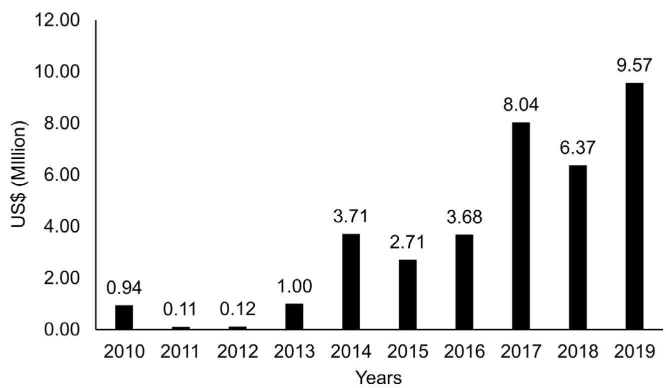


***Figure 2.*** Evolution of revenue generated by açaí exports. Adapted from CONAB (2020).

The appreciation of açaí as a source of fundamental biomolecules for human health began in the 1990s. This new approach made the fruit the main product, drastically reducing the number of plants felled to obtain the heart of palm, which was, until then, the main economic purpose (Homma 2014). Several current studies describe the numerous properties of fruit pulp, such as antioxidant, antidepressant, antiaging, antidiabetic, among others (Bem et al. 2018, Souza-Monteiro et al. 2019, Liz et al. 2020).

Therefore, açaí is a product whose nutritional potential is compatible with the market potential, both still to be better exploited. This goes beyond the goals of açaí palm breeding, which has already presented relevant results and may also offer other supports for the structuring of the species' production chain.


***Figure 3.*** Açai palm: flowers and typical pollinator (A); Orchard with 'BRS Pará' (B); and comparison between fruits from 'BRS Pará' (left) and 'BRS Pai D'Égua' (right) (C). Photos by: Ronaldo Rosa.

### Biology

The açaí palm tree produces raceme-type inflorescences, composed of the main rachis subdivided into 63 to 158 rachillae, which have sessile and unisexual flowers (Figure 3A) (Jardim and Macambira 1995). This is a monoecious species, with male and female flowers arranged in the same inflorescence, however with protandrous dichogamy, i.e., first there is the anthesis of staminate flowers (male phase) and, after these flowers dry, the pistillate flowers open (female phase) (Venturieri et al. 2014, Bezerra et al. 2020). Flowering occurs during the period of greater humidity and fruiting occurs during the period of lower precipitation (Moraes et al. 2020).

The plant is predominantly allogamous, that is, it uses cross-fertilization for reproduction, favoured by physical mechanisms such as protandry, and genetic mechanisms such as the self-incompatibility of some genotypes. However, it is common to observe cases of autogamy, caused by the overlapping of flowering stages, either in the same or different inflorescences on the same plant (Oliveira et al. 2000). Pollination may occur by wind and rain, but entomophily is the main method, performed by small beetles and hymenopterans (Bezerra et al. 2020).

The açaí palm also propagates asexually through tillering, which makes it a caespitose plant, unlike other species of the *Euterpe* genus that are also economically exploited, but on a small scale, such as *E. precatoria* and *E. edulis* (Solar-Guilhen et al. 2020, Ramos et al. 2021). The species has 2n = 2x = 36 chromosomes, most of which are classified as metacentric, with an average DNA content of 4.22 pg and an estimated genome size of 4.13 Gpb (Oliveira et al. 2016).

## Genetic resources

The putative centre of origin of the açaí palm is in the Amazon River estuary region, with wide interpopulation diversity, mainly in Pará State, Amapá State and a part of Maranhão State (Oliveira et al. 2000). These populations occupy mainly floodplain areas ("*várzea*"), subject to periodic flooding and may, however, be present in non-flooded areas ("*terra firme*") and flooded areas ("*igapó*") (Oliveira et al. 2012). The relationship between açaí and the native residents goes back to pre-Columbian peoples with a close relationship between their nomadism and the plant distribution. According to Clement (2001), the domestication of the species and the phenotypic selection of the best individuals began with these populations.

The *ex-situ* conservation of açaí palm began in the mid-1980s, with the collection of matrices in natural populations and in domestic and commercial orchards to form an Active Germplasm Bank (AGB). This AGB, managed by Embrapa Eastern Amazon (Embrapa Amazônia Oriental), has 212 accessions, eight of which are *E. edulis* and *E. precatoria*. Later, other AGBs were created, such as the one at Embrapa Amapá, with 175 accessions, and at the IAC (Agronomic Institute of Campinas), this one outside the Amazon region, with 90 accessions (Oliveira et al. 2012).

## Breeding

Açaí palm breeding brings with it all the difficulties of perennial species breeding, such as the long period of evaluation, motivated by the long juvenile period (up to four years after germination); and the expression of characteristics across different ages (Resende 2002). For the palm, there are still two aggravating factors: self-incompatibility, associated with strong protandry, and the difficulty for vegetative propagation without biotechnology.

The breeding methods applied range from mass selection, in the initial stages, to selection with progeny testing in the subsequent stages (Farias Neto et al. 2007), both as part of the recurrent selection for the formation of improved açaí palm populations. Species breeding programs in the region focus on fruit production rather than palm heart production. They aim to develop genotypes that follow an ideotype (Figure 4) (Oliveira et al. 2012).

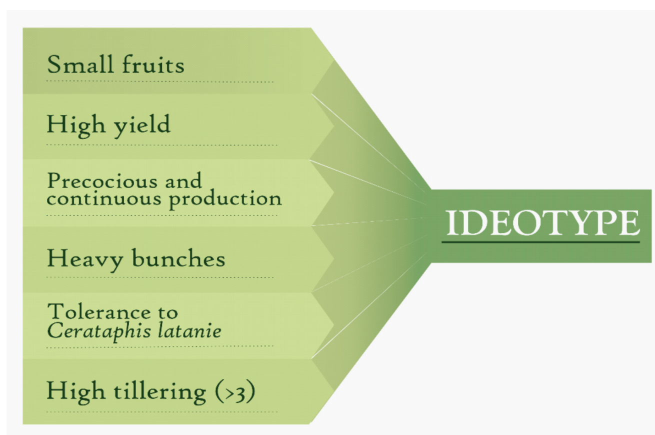


***Figure 4.*** Ideotype of *Euterpe oleracea* breeding programs. Adapted from Oliveira et al. (2012).

### *Cultivars*

Based on this ideotype, the first açaí palm cultivar was launched in 2004 by Embrapa Eastern Amazon, named 'BRS Pará' (Figure 3B). This cultivar was developed based on a mass selection of 25 individuals from the AGB accessions. Afterwards, the fruits of the selected individuals were collected, mixed and sown in isolated areas, for the production of commercial seeds. 'BRS Pará' has high productivity compared to native areas, with precocious production start (from the third year after planting) and low bunch insertion (from 112 cm). It produces fruits with good pulp yield (15-25 g of pulp per 100 g of fruit) and a good number of fruits per kilo (average of 625). It is recommended for crops in non-flooded areas and requires irrigation in Ami and Awi climate areas, but not in places with Afi climate, according to the Köppen classification (Oliveira and Farias Neto 2004).

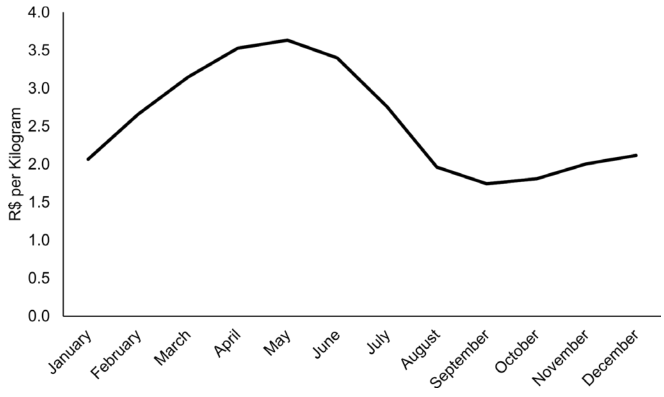


***Figure 5.*** Dynamics of the price paid to the producer per kilogram of açaí in the State of Pará, over the months of the year, represented by the average prices of the last five years. Adapted from CONAB (2020).

'BRS Pará' was widely accepted in the market, especially among producers who were starting to cultivate açaí palms on non-flooded lands. However, it failed to mitigate one of the biggest problems in the species' production chain: production seasonality. According to Dimenstein and Farias Neto (2008), 70 to 80% of açaí production occurs in the second half of the year, with a severe reduction in the supply of raw material in the first half. This makes the price paid to the producer in the off-season much higher than the rest of the year (Figure 5) (CONAB 2020). This fluctuation in the consistency of supply and price of raw material discourages the installation of new agribusinesses for processing the fruit in the region, as well as hinders the fruit export (Farias Neto 2019, CONAB 2020).

To meet this demand, a cultivar with capacity for greater production in the off-season period has been developed. Thus, in 2019, 'BRS Pai D'Égua' was released, with high productivity rates, small and lighter fruits (Figure 3C), higher pulp yield than 'BRS Pará', and up to 46% of the production occurring in the off-season, when water supplementation is executed (Farias Neto 2019). This cultivar was obtained from materials evaluated in progeny tests, in sequential trials conducted between 2003 and 2018, using materials from both AGBs in Pará and Amapá (Farias Neto et al. 2007, Farias Neto et al. 2008, Yokomizo et al. 2016).

## Perspectives

Although Brazil is the world's largest producer and exporter of açaí pulp, the processing capacity and product specialization is far short of demand, and the greatest dividends are earned by countries that manage to meet certain segments, such as the market for energy and vitamin drinks, and pharmaceutical and cosmetic products (CONAB 2019).

Therefore, the next challenges of the breeding program are related to the development of cultivars that meet these market segments, selecting genotypes with traits of interest for each sector. This approach should not be dissociated from the constant search for the reported ideotype, making the sustainable cultivation of the açaí palm more attractive to producers, thus relieving the pressure on native açaí groves. The use of interspecific hybridization with other euterpes is also promising to explore their different sensory and nutritional characteristics, as well as the peculiarities of each species. For example, *E. precatoria*, a palm in a lower stage of domestication and better adapted to non-flooded land ("*terra firme*") conditions (Ramos et al. 2021); and *E. edulis*, a palm tree native to the Atlantic Forest and, therefore, adapted to the milder climatic conditions in other regions of Brazil (Santos et al. 2020).

For this, breeding must be closely linked to biotechnological tools, such as proteome, transcriptome and genome sequencing, the latter already conducted by Lopes et al. (2021) using plastome. Another option is the use of molecular markers to assess the divergence and genetic variability of accessions, assisted breeding, QTL location, among other strategies to accelerate the breeding process.

## OIL PALM (*ELAEIS GUINEENSIS* JACQ. AND *ELAEIS OLEIFERA* (KUNTH) CORTÉS)

### Socioeconomic importance

Oils from the oil palm fruit are highly valued products in the market. Palm oil, from the pulp, and palm kernel oil, obtained from the almond, are used for culinary purposes and several products from the pharmaceutical, cosmetic and automotive industries, and is also suitable for conversion into biofuel (Mekhilef et al. 2011).

Two species of the *Elaeis* genus are used for oil extraction: *E. guineensis* and *E. oleifera* (Figure 6A and 6B). *E. guineensis* Jacq. is a perennial palm of African origin that, despite being exotic, has adapted well to Amazonian conditions. It is the oil crop with the highest yield capacity, lowest maintenance cost, and consequently, the main source of vegetable oil in the world (Lopes et al. 2012, Gomes Júnior et al. 2015). Since the mid-1970s, this palm has been cultivated in the Amazon region. This cultivation enhanced after the creation of government programs to encourage the production of biofuels, attracting the private sector (Brandão and Schoneveld 2015). Such interest was the driving force to expand researches on genetic and environmental improvement for the species in the region. However, the expansion of cultivation ran into a sanitary problem: lethal yellowing, a pathology of unknown cause that precludes entire plantations (Nascimento et al. 2018).

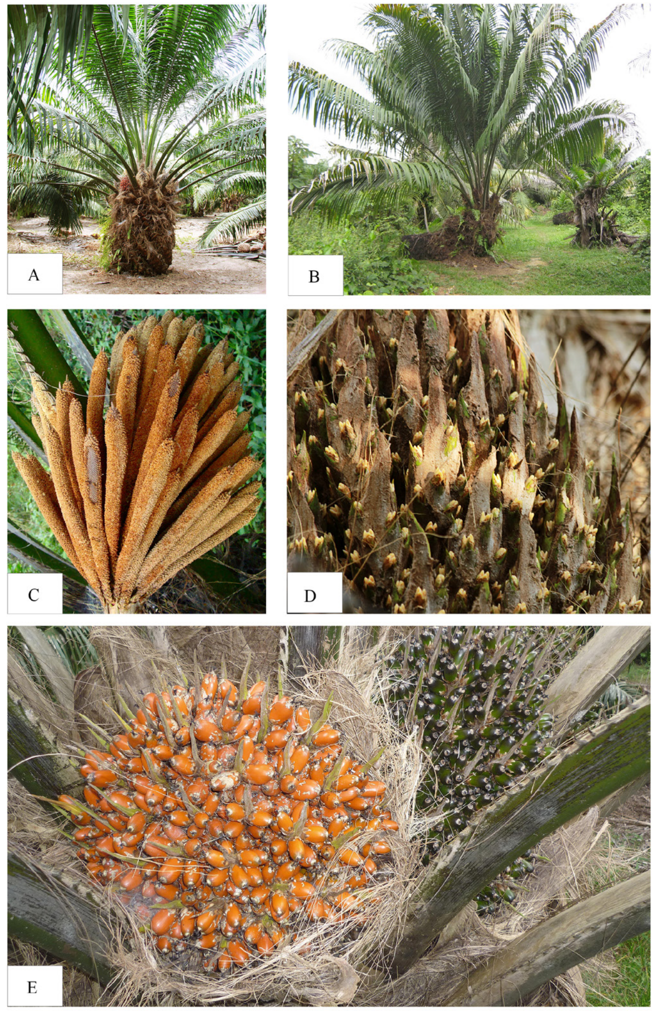

***Figure 6.*** Oil palm: *Elaeis oleifera* (A) and *Elaies guineensis* (B); male (C) and female (D) inflorescences; and bunches of 'BRS Manicoré' (E). Photos by: Julceia Camillo (A), Ronaldo Rosa (B, C and D) and Ricardo Lopes (E).

To overcome this problem, new sources of resistance were sought in the germplasm of related species, native to the Amazonian flora. *E. oleifera*, a palm in the initial phase of domestication (Clement 1999), is inserted in this context, with considerably lower yield rates, but resistance to lethal yellowing and other pests and diseases, in addition to advantages such as lower growth rate and more unsaturated oil (Cunha et al. 2012). In this study, the name "oil palm" refers to both species and scientific names will be used when the intention is to specify one of them.

Brazil is currently the ninth-largest producer of oil palm in the world (FAO 2019). In 2019, about 2.6 million tons of bunches were produced in the Brazilian territory, 98% of which came from the Northern region, distributed over 164,000 ha, with Pará State as the largest producer, responsible for practically all of this amount (IBGE 2019b). Brandão and Schoneveld (2015) estimated the creation of more than 16,000 jobs related only to the primary level of the production chain. Therefore, it is a crop of worldwide interest, in full expansion and with wide marketing potential, which must necessarily be accompanied by breeding programs.

### Biology

The flowering of the oil palm inherits common characteristics of its family (Arecaceae), such as raceme inflorescences and monoecia. However, the plant does not produce same-sex flowers in the same bunch, as the açaí palm does. The oil palm produces male and female inflorescences in different structures and alternating sexual cycles (Figures 6C and 6D).

This formation will depend on intrinsic factors, such as genetics and health, and extrinsic factors, such as environmental conditions. This mechanism favours the allogamy of the species (Adam et al. 2005, Adam et al. 2007).

In *E. guineensis*, the male inflorescence is composed of a rachis with up to 300 rachillae, with more than 1000 staminate flowers in each rachilla. The female one has up to 150 rachillae, with up to 30 floral triads per rachilla, with nearly the same size as the male inflorescence (Adam et al. 2007). These triads are composed of a central female flower and two peripheral sterile male flowers. The main difference in the *E. oleifera* inflorescence is the amount and density of rachillae, reaching 200 with up to 1600 flowers in the male structure, and 170 rachillae with 35 flowers in the female structure (Farias et al. 2018).

In both species, there is also a third structure with intermediate characteristics between the male and female inflorescences. In this structure, the male flowers are sterile and, in some cases, the female ones can be fertilized (Adam et al. 2005). Pollination is entomophilous, mainly carried out by beetles of the genus *Elaeidobius* (Coleoptera: Curculionidae), in addition to other visiting insects (Meléndez and Ponce 2016).

According to Ngoot-Chin et al. (2021), the oil palm has 2n = 2x = 32 chromosomes, and the occurrence of euploidy (presence of triploids) is reported. Madon et al. (2008) estimated an absolute DNA content of about 3.96 pg for *E. guineensis*, 2.06 pg for *E. oleifera* and 4.17 pg for the interspecific hybrid.

### Genetic resources

The conservation of genetic resources of *E. oleifera* began in the early 1980s, when Embrapa and CIRAD (French initials for Agricultural Research Centre for International Development) carried out surveys and sample collections in the Amazon basin, especially along the Solimões, Negro and Madeira Rivers, as well as representative areas of Roraima State. Subsequently, two more expeditions were carried out, in 1998 and 2006, covering other populations not yet sampled. These collections were the basis for the formation of the *E. oleifera* AGB from Embrapa Western Amazon (Embrapa Amazônia Ocidental), the largest in the world for this species, which today has 237 accessions represented by 4,300 plants (Moretzsohn et al. 2002, Cunha et al. 2012). Despite the wide availability of genetic resources, the AGB's genetic diversity is only moderate, probably due to the prospecting strategy adopted (Pereira et al. 2020).

This Unit also has a collection of *E. guineensis* with around 3,600 plants from 330 accessions, with contributions from CIRAD, PORIM (Palm Oil Research Institute of Malaysia), in addition to collections in sub spontaneous populations in Bahia State, Northeastern Brazil. The accessions in this collection are representative of the main genotypes already used in other countries, besides to other promising ones (Krug et al. 2013). Some private companies have their own collections. Despite a large number of materials, the cost of phenotyping makes it difficult to characterize the accessions, which do not have all samples typified (Krug et al. 2013).

### Breeding

Breeding is carried out both individually with *E. guineensis* and jointly with *E. oleifera*, exploiting the genetic resources contained in the AGB. Among the perennial species native to the Amazon, only the oil palm has breeding programs maintained by public and private, national and international institutions with an emphasis on Embrapa, CIRAD, through PalmElit; Agricultural Services and Development, a Costa Rican institution; and La Cabaña, a Colombian company; besides the companies that maintain genetic resources in Brazilian territory: Biopalma da Amazônia, Palmaplan, Agropalma, Palma Tech and Marborges (Cunha et al. 2010, Brasil 2021).

In Embrapa's breeding program for *E. guineensis*, the reciprocal recurrent selection is the most applied method, in which the progenies from crosses of dura (homozygote) and tenera (intraspecific hybrid) genotypes are evaluated, also measuring the general and specific combining ability. After selecting the best crosses, the genitors are self-fertilized to maintain the genotypic integrity of dura type and obtain pisifera genotypes from the teneras' self-fertilization (25% dura, 50% tenera and 25% pisifera). Next, pisiferas are crossed with duras for evaluation in progeny tests. Once selected, the genitors are again recombined to re-establish genetic variability, closing a recurrent selection cycle (Cunha et al. 2007, Rivas et al. 2012). There may be variations in the procedure adopted between *E. guineensis* breeding programs in different institutions, but they share the same goal: obtaining intraspecific hybrids, or teneras, with high productivity and resistance to the main pests and diseases.

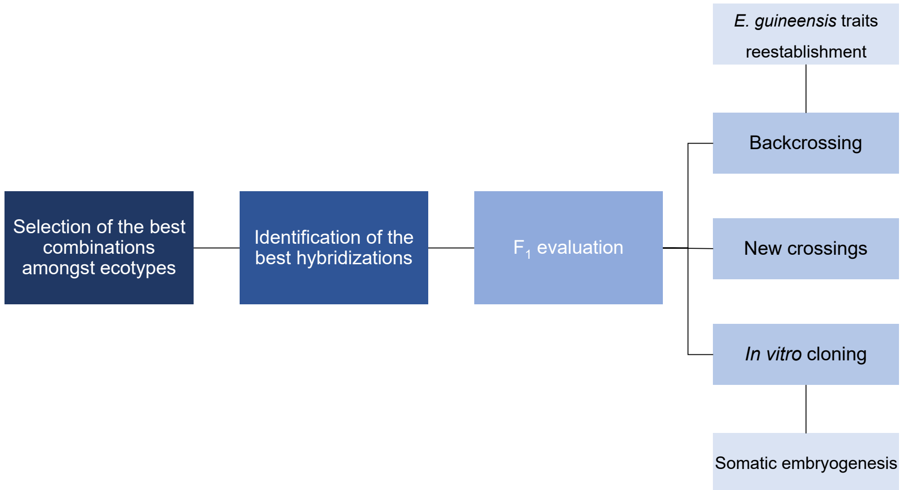


***Figure 7.*** General scheme for the breeding of interspecific oil palm hybrids. Adapted from Cunha et al. (2012).

The *E. oleifera* accessions evaluated have significant intra- and interpopulation diversity, which makes the collection a material to be worked on by breeding (Pereira et al. 2020). However, according to Cunha et al. (2012), isolated studies with the species are not justifiable due to its low production rates compared to *E. guineensis*, which has been improved for decades. Therefore, the breeding of native *Elaeis* in the Amazon region was based on interspecific hybridization with the African species. These crosses aimed to obtain genotypes that maintained the high productive indexes of *E. guineensis* and some *E. oleifera* characters such as resistance to lethal yellowing, slow growth and greater oil unsaturation (Cunha et al. 2012, Lopes et al. 2012).

Hybrid breeding consists of three stages (Figure 7). After these stages, $F_1$ hybrids from various crosses will have great variability among them, which can be exploited through selection, whether for cloning, the constitution of new hybrids or backcrossing (Gomes Júnior et al. 2016). Short-term gains can be achieved by selecting male genitors in *E. guineensis*, while medium- and long-term gains are obtained by selecting both genitors, as well as by cloning *in vitro* $F_1$ hybrids (Gomes Júnior et al. 2019). The cloning protocol is at an advanced stage of development, where the process is carried out mainly via somatic embryogenesis, with differential response of genotypes to callus induction, being a character that can be improved (Santos et al. 2018, Almeida et al. 2019, Almeida et al. 2020)

Two limiting factors stand out in oil palm breeding: the need for large areas to evaluate a significant number of genotypes and progenies; and the long period of each selection cycle, about 20 years to close a single cycle (Wong and Bernardo 2008, Rivas et al. 2012).

## Cultivars

There are 32 cultivars of *E. guineensis* registered in the National Cultivar Registry (RNC - Registro Nacional de Cultivares) and, therefore, have permission and aptitude for cultivation in Brazilian territory. Except for cultivars developed by Embrapa, all others are maintained by private companies (Brasil 2021).

Using the procedure mentioned in the previous topic, Embrapa Western Amazon launched, in 2006, seven intraspecific hybrids of *E. guineensis*, results of crossings between Deli and La Mé origin genotypes: BRS C2001, BRS C2301, BRS C2328, BRS C2501, BRS C2528, BRS C3701 and BRS C7201. These cultivars have high productivity, around 15 to 30 t $ha^{-1}$ $year^{-1}$, with 22% oil extraction and average oil production of 4 to 6 t $ha^{-1}$ $year^{-1}$. On average, the growth is 45 cm per year and the economic exploitation of the cultivars remains viable until, at most, 30 years after planting in the permanent location (Cunha et al. 2007).

Despite excellent productivity indexes, the available cultivars remained vulnerable to lethal yellowing, as they are unispecies (*E. guineensis)*. In 2010, 'BRS Manicoré' (Figure 6E), an interspecific hybrid cultivar of *E. guineensis* and *E.*

*oleifera*, was released. This cultivar resulted from crossings of African accessions originating from La Mé with Brazilian accessions of *E. oleifera* (Cunha and Lopes 2010). BRS Manicoré is resistant to lethal yellowing, has slow growth, which may increase the useful life of the planting, and offers oil with a higher proportion of unsaturated fatty acids, an interesting character for the food industry. Moreover, it has similar or slightly lower productivity to previously launched intraspecific hybrids, with lightly inferior oil extraction (Cunha and Lopes 2010, Krug et al. 2013). According to Krug et al. (2013), 'BRS Manicoré' is promoting regional crop revitalization through the reestablishment of plantations in areas devastated by lethal yellowing and is even being adopted in other Latin American countries.

After 'BRS Manicoré', another interspecific hybrid cultivar was registered for use in the Brazilian territory. This is Marborges Inducoari 1, developed by the company La Cabaña, from Colombia, and maintained by Marborges Agroindústria, a Brazilian company with private capital. It has some differential characteristics concerning BRS Manicoré, reported in Table 1.

***Table 1.*** Characteristics of two cultivars of oil palm interspecific hybrids: BRS Manicoré and Marborges Inducoari 1

| Characteristics | BRS Manicoré | Marborges Inducoari 1* |
|---|---|---|
| Origin | La Mé (*E. guineensis*) *vs* Manicoré (*E. oleifera*) | La Mé (*E. guineensis*) *vs* Coari (*E. oleifera*) |
| Average trunk growth (cm $year^{-1}$) | 20.5 | 22 |
| Resistance to Lethal Yellowing | Yes | Yes |
| Palm oil extraction rate (%) | 18 to 20 | 18 to 19 |
| Palm kernel oil extraction rate (%) | 3 to 4 | 3.5 |

* Source: Cunha et al. (2010).

### Perspectives

On the one hand, 'BRS Manicoré' cultivar enabled the implantation of orchards in places with an incidence of lethal yellowing, but on the other hand, it created new demand, adding around 15% of extra cost: manual pollination. According to Cunha and Lopes (2010), the hybrid produces pollen in smaller amounts and with low viability, in addition to the low attractiveness of the inflorescences to pollinators. Furthermore, it has a greater tendency to present anomalous inflorescences at the early stages, with the simultaneous presence of male and female structures (Krug et al. 2013).

Therefore, the next challenge for species breeding is to mitigate these nonconformities by developing cultivars with lower rates of inflorescence anomalies and greater fertility, thus reducing the need and, consequently, the costs of manual pollination. For this purpose, the program must intensify the production of backcrosses, aiming at fixing the interesting characteristics of each species in the hybrid.

Reducing hybrid breeding cycle time is another big challenge. In this sense, evaluations of both vegetative and productive characters should guide the early selection of genotypes with greater potential (Gomes Júnior et al. 2015). Added to this is the selection of genotypes capable of responding to *in vitro* propagation via somatic embryogenesis (Almeida et al. 2019). Moreover, the use of biotechnology, through the identification of QTLs and genome-wide association studies (Osorio-Guarín et al. 2019, Babu et al. 2021), will allow the determination of gene loci associated with characters of interest, which will enable the development of markers and, therefore, assisted selection.

BRS Manicoré and Marborges Inducoari 1 are the first interspecific hybrid cultivars, resulting from the initial studies of a work still in progress. Therefore, oil palm breeding programs are expected to develop increasingly productive materials, adapted to growing conditions and resistant to other pests and diseases, including lethal yellowing.

## DIFFICULTIES AND PERSPECTIVES OF BREEDING PROGRAMS IN THE AMAZON

The species discussed in this study are among the most advanced in the breeding of native species in the Amazon. However, the region has numerous plants of great economic and environmental relevance that also have the potential for breeding, such as andiroba (*Carapa guianensis* Aubl.), copaiba (*Copaifera langsdorffii* Desf.), rosewood (*Aniba* *rosaeodora* Ducke), Brazilian or Big-leaf mahogany (*Swietenia macrophylla* King) and Brazil nut (*Bertholletia excelsa* Bonpl.), among many others.

Breeding of native forest species virtually does not exist in the region. This action has the potential to relieve anthropogenic pressure on remaining forest populations, by providing producers with competitive improved materials to be cultivated (Alves et al. 2020). Furthermore, the *ex-situ* collection and conservation of accessions, a pre-breeding phase, would be greatly important for the maintenance of genetic resources, as the habitats of these species have been threatened by large agricultural projects, illegal logging, as well as the advance of urbanization (Iriarte et al. 2020, Xu et al. 2020).

The difficulties in the improvement of perennial species in the Amazon region can be classified into two categories: intrinsic and extrinsic factors to plants, with a close relationship between them (Figure 8). Intrinsic factors are related to the early domestication stages or even none domestication whatsoever, as well as to the inherent difficulties in the breeding of perennials species, detailed by Resende (2002), which involves the peculiarities that prevent immediate results, making the dynamics of breeding and adoption of cultivars slower, if compared to annual crops.

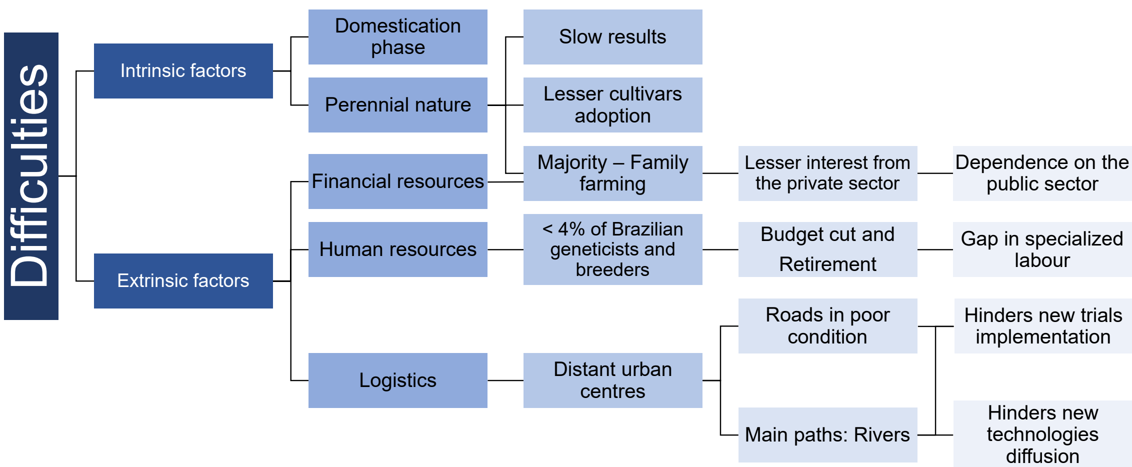


***Figure 8.*** Overview of the difficulties in plant breeding in the Brazilian Amazon.

The extrinsic factors are related to issues of financial and human resources, logistics, as well as the individualities of the region. The cultivation of native perennial species is traditionally carried out by family farmers with limited purchasing power (Levis et al. 2018, Iriarte et al. 2020), with some exceptions like the oil palm and cacao tree. Joining this fact with the intrinsic factors described above, the reduced interest of the private sector in the breeding of these species is explained, causing the public sector to be the only one involved in it and, consequently, to depends on resources allocated by the government, which have been drastically decreasing in recent years.

Another factor is the small number of specialized professionals involved in the research on native perennial species. According to Teixeira (2009), in 2008, the last year of this data collection, only 4% of Brazilian breeders worked in the Amazon region. Due to the cut in funds and the retirement of several professionals, which were not replaced, it is assumed that this estimate is even lower today.

Furthermore, the region has serious logistical problems, such as urban centers far from each other and roads in poor conditions, leading to take rivers as the main routes (Sathler et al. 2010). This hinders the implementation of experiments and data collection, as well as slows down the adoption of new technologies by producers.

Despite the complications, the breeding programs under development have significantly contributed to local and national society, breaking paradigms and placing native species at levels only recently reached. Therefore, breeding, directly and indirectly, provides a valuable service to the Brazilian society, contributing to food security, employment and income generation, conservation of natural resources and maintenance of cultural aspects of the Amazon region.

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