

Chapter

Biotechnological Advances for the Propagation and Conservation of Nutraceutical and Oilseed Palm Tree Crops

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Abstract

The demand for nutraceutical foods and vegetable oils has promoted the development of the palm tree agroindustrial chain in the world. The production of açai and coconut is rapidly expanding. On the other hand, macaw palm and oil palm have fruits with a high oil content, a characteristic that makes them potential species for use in the food, cosmetics, and oleochemical industries, as well as for the production of biofuels. Palm trees are traditionally propagated by seeds, and the impossibility of cloning high-performance genotypes by conventional propagation methods makes it difficult to expand their cultivation. However, biotechnological tools such as somatic embryogenesis have recently been established, allowing the cloning of superior genotypes and accelerating the domestication and sustainable development of some palm tree production chains. In this chapter, we address recent advances and challenges in the *in vitro* propagation and conservation of five palm tree species: *Acrocomia aculeata* (macaw palm), *Cocos nucifera* (coconut palm), *Elaeis guineensis* (oil palm), and *Euterpe oleracea* and *E. edulis* (açai palm). We believe this chapter will contribute to understanding their domestication panorama and support studies on developing and optimizing propagation systems for these and other palm trees of agroindustrial interest.

Keywords: Arecaceae, micropropagation, palm trees, plant tissue culture, somatic embryogenesis

1. Introduction

Palms (Arecaceae) are among the main monocots in the world and comprise the most abundant vascular plants in the tropics [1]. The Arecaceae family is predominantly distributed across the Neotropics [2], encompassing 200 genera and 2500 species recognized worldwide [3]. South America is the main center of diversification of Arecaceae (palm trees), and species from this group can be found in almost all neotropical biomes [2].

Palm trees comprise key forest structure and functionality components in tropical ecosystems [4], exhibiting great ecological and socioeconomic relevance [5]. Indeed, their flowers and fruits encompass fundamental resources for pollinators and fruit-eating animal species [6]. Some palm species also have high economic and social value. Indigenous or traditional communities and agroindustrial industries exploit many of them for various purposes. Among their representatives, species from the genera *Acrocomia*, *Cocos*, *Elaeis*, *Euterpe*, and *Syagrus* attract attention due to their potential use. Their fruits and seeds are sources of oils, fibers, starch, carbohydrates, proteins, and functional biomolecules—raw materials for the most varied industrial sectors. In addition, solid waste from the destruction of raw materials can have equally or even more noble applications, adding value to production and making the production chain more sustainable [7]. However, while coconut (*Cocos nucifera* L.) and oil palm (*Elaeis guineensis* Jacq.) are recognized as agricultural commodities, other important palm species can be considered neglected or underutilized crops since the current exploitation model is based on inefficient extractivism, which may threaten biodiversity, as it can exhaust natural matrices and lead to uneven production, requiring efforts to form a sustainable chain.

Palm tree propagation is mainly carried out *via* seed [8]. Most palm trees have a single trunk, devoid of axillary buds along their stems or any specialized structure, which limits the use of conventional vegetative propagation methods for cloning and multiplication of high-performance genotypes. However, biotechnological tools such as somatic embryogenesis have recently been established, allowing *in vitro* cloning of superior genotypes and accelerating domestication and sustainable development of some palm tree production chains [9]. Somatic embryogenesis is one of the biotechnological tools used to achieve large-scale clonal propagation. This technique is based on the principle of cellular totipotentiality, in which somatic embryos are obtained from a plant explant (cell or any fragment of living tissue or organ), cultivated in an aseptic environment and in a nutrient medium under controlled temperature and light conditions, which, after germination, will give rise to new plants identical to the mother plant [10].

In this chapter, we address recent advances and challenges in the *in vitro* propagation of three nutraceuticals [*Cocos nucifera* (coconut palm), *Euterpe oleracea*, and *E. edulis* (açai palm)] and two oilseeds [*Elaeis guineensis* (oil palm) and *Acrocomia aculeata* (macaw palm)]. Here, nutraceutical palms refer to species in this group whose fruits have health benefits, such as improving physiological performance and/or effectiveness in treating diseases. In contrast, oilseed palms are recognized especially for their high vegetable oil production. We believe this report will contribute to understanding their domestication panorama and support studies on developing and optimizing propagation systems for these and other palm trees of agroindustrial interest.

2. Nutraceutical palms

2.1 *Cocos nucifera* (L.)

Cocos nucifera (L.) is a monotypic species widely recognized and considered one of the most economically important palms in the world. It stands out for the comprehensive utilization of all its parts, mainly for its nutritional and medicinal values [11]. Although the exact origin of the coconut remains debated, evidence suggests that it may have originated in the tropical regions of Southeast Asia, possibly along the coasts of India and Indonesia [12, 13]. Often referred to as the “tree of life,” the coconut palm is among the most valued palm crops globally, cultivated on 12 million hectares across more than 90 tropical and subtropical countries [14].

The coconut (*C. nucifera*) is the only genus *Cocos* member within the Arecaceae family [15]. It is a typical palm with a solitary, erect, or slightly curved stem, reaching up to 30 m in height and 20–35 cm in diameter, with irregular rings (**Figure 1a**). The leaves are pinnate, with 25–30 leaves present simultaneously, measuring 3–6 m long, and bearing 100–150 pinnae per side, arranged in the same plane. Inflorescences are interfoliar, with rachillae and a woody bract. The flowers are unisexual and may occur in triads, dyads, or singly, with pistillate flowers at the basal portion and staminate flowers in the apical portion. The fruit is large, oval to ellipsoidal (20–30 cm x 12–20 cm), with a thin epicarp, fibrous mesocarp, and woody endocarp; the endosperm is initially liquid, later becoming hardened and white [11].

There are three main varieties of coconut palms: the tall coconut (*C. nucifera* var. *typica*), the dwarf coconut (*C. nucifera* var. *nana*), and the hybrid coconut (*C. nucifera* var. *aurantiaca*). The tall coconut is notable for its robust stems, which can reach up to 30 meters in height, making it ideal for industrial use, such as copra and oil production. Conversely, the dwarf coconut typically does not exceed 10 meters in height and flowers earlier, which is more suitable for fresh consumption, such as coconut water. The hybrid coconut exhibits intermediate characteristics between these two varieties.

In 2019, the global coconut market moved approximately US\$ 13 billion, and projections indicate that this value could reach more than US\$ 31 billion by the end of 2026, with a Compound Annual Growth Rate (CAGR) of 13.6% [16]. Brazil is

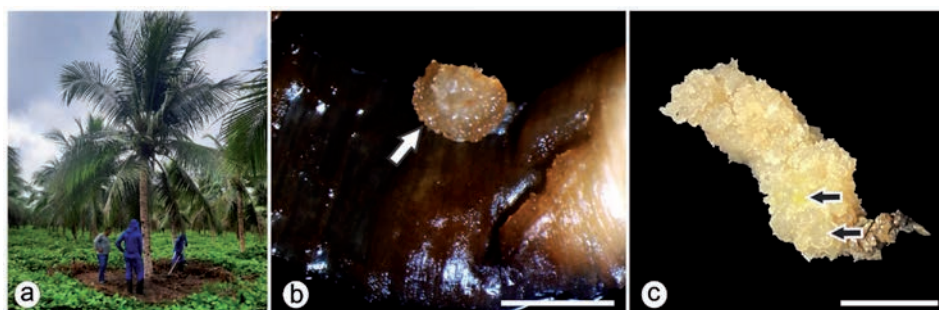


Figure 1. Somatic embryogenesis in coconut palm (*Cocos nucifera* L.). (a) Coconut palm, a plant of economic importance. (b) Embryogenic callus obtained by somatic embryogenesis from leaf explants (white arrows). (c) Embryogenic callus formed from inflorescence explants (black arrows). Scale bars, a = 150 μ m; b = 1 cm.

the fifth-largest coconut producer globally, with a 4.5% market share [17]. In 2023, Brazil produced 1,932,282 fruits, with a harvested area of 186,712 hectares and an average yield of 10,349 fruits/ha (2023) [18]. Advanced cultivation technologies, such as proper management of coconut plantations, intensive production systems, and improved varieties, such as dwarf and hybrid coconut trees, drive increased productivity and expand cultivation worldwide [19].

There is a wide variety of coconut-derived products that drive the global market and offer a range of uses for humanity, such as coconut water, coconut milk, grated coconut, coconut fiber, wood, coconut flour, coconut sugar, coconut powder, copra, shell, or pulp. Coconut fiber can make rugs, brushes, ropes, and threads. Its wood can be used for building houses and furniture. Fuel and charcoal can be produced from coconut shells, and even the leaves are utilized, being used for the production of brooms, baskets, and roof coverings. The high demand for this crop is mainly due to the beneficial properties of coconut, discovered through research conducted primarily by its most prominent producers, including Indonesia, the Philippines, India, and Brazil [20, 21].

2.1.1 Biotechnological tools for multiplication of *Cocos nucifera* (L.)

2.1.1.1 Somatic embryogenesis

The scarcity of suitable seedlings, extreme weather events, biotic and abiotic stresses, and low productivity caused by plant aging are the main problems coconut cultivation faces [22]. In this context, biotechnological techniques such as somatic embryogenesis are essential for propagating this species and its elite varieties.

Initial studies on somatic embryogenesis in *C. nucifera* used a variety of explants, each demonstrating the unique potential for embryogenic callus formation and plant regeneration. Among them, rachillae from immature inflorescences showed promising results, although they initially presented efficiency and reproducibility problems [23]. Plumules stood out as highly responsive explants, achieving higher callus and somatic embryo formation rates than rachillae [24]. Other explants tested include zygotic embryos, which presented better results when immature, with up to 58% embryogenic callus formation [25], in addition to unfertilized anthers and ovaries, both producing viable somatic embryos under optimized culture conditions [26, 27]. Other important studies on somatic embryogenesis in coconut are highlighted in **Table 1**.

Research is underway to obtain somatic embryos in coconut palms using explants from leaves and inflorescences. In the experiments performed, it was possible to observe the formation of embryogenic calluses from leaf explants, indicating the potential for clonal propagation of elite coconut plants (**Figure 1b**). In addition, embryogenic calluses from inflorescence explants were also obtained, reinforcing the viability of this approach (**Figure 1c**).

2.1.1.2 De novo shoot organogenesis

De novo shoot organogenesis is considered one of the alternative routes for *in vitro* clonal propagation of coconut, with direct organogenesis considered safe since callus formation can lead to the emergence of undesired somaclonal variations [22]. Recent studies conducted with shoot apices from germinated seeds, with sizes between 5 and 10 mm, cultivated in Y3 culture medium supplemented with 1 μ M of TDZ [34]

Phase	Explant	Culture medium	Response	References
Induction	Plumule	Y3–5 μM BAP and 600 μM 2,4-D	56.7% from embryogenic callus originating from juvenile fruits/embryos	[28]
Induction	Plumule	Y3 modified - 600 μM and 6 μM 2,4-D	Compact callus, somatic embryos and plantlets	[29]
Induction	Haustorium tissues	Y3–0,3 μM de 2,4-D + 150 ml L^{-1} of coconut water	61% somatic embryos	[30]
Induction	Inflorescences	Y3–300 μM de 2,4-D + calcium ionophore (A23187), 22(S) and 23(S)-homobrassinolide	Improvements in the proliferation of embryogenic callus	[31]
Induction	Inflorescences	Y3–4,54 μM 2,4-D	92% embryogenic callus	[32]
Induction	Zigotic embryos	Y3–100 to 250 μM of 2,4D + GA_3 , BAP and TDZ ↓ Induction of multi-buds - kinetin, BAP and NAA	16.7–100% (embryogenic callus) and 16.7–83.3% (embryos) - 100% survival in seedling acclimatization	[33]
Induction	Ovary	BM72–100 μM of 2,4-D + 5 μM of ABA and 10 μM of AgNO_3	41% embryogenic callus	[26]
Induction	Anthers	Y3–100 μM of 2,4-D and 100 μM of NAA	Formation of 123 calluses or embryos per 100 anthers	[27]
Induction	Plumule	Y3–100 μM of 2,4-D	57% of plumules formed callus	[24]

Note: Y3, Eeuwens medium; BM72, Karunaratne and Periyapperuma medium; BAP, Benzylaminopurine; 2,4-D, 2,4-Dichlorophenoxyacetic Acid; GA_3 , Gibberellic Acid; TDZ, Thidiazuron; NAA, 1-Naphthaleneacetic Acid; ABA, Absciscic Acid; AgNO_3 , Silver Nitrate.

Table 1.
Studies on somatic embryogenesis in *Cocos nucifera*.

or 200 μM of TDZ [35], have shown promise as explants for large-scale production of elite coconut plantlets.

In a recent study conducted by Neema et al. [36], the electric current was employed in coconut calluses derived from plumules to induce a higher multiplication rate. In their study, the continuous application of weak electric current in the range of 1 and 2 μA induces a higher multiplication rate of the calluses, which can be used for plantlet propagation through somatic embryos (SE) or *in vitro* organogenesis.

2.1.2 Conservation

The genetic heritage of the coconut faces significant threats, and due to its great importance, *ex situ* conservation methods are necessary. *Ex situ* conservation occurs when genetic material is removed from its habitat, protecting it from pests and

diseases. Cryopreservation and *in vitro* cultivation are used among the *ex situ* conservation methods. Coconut seeds are recalcitrant [37], which makes *ex situ* conservation the most efficient and safe conservation method [38].

Cryopreservation is a method that enables the *ex situ* conservation of plant material for an indefinite period [39]. In coconut, cryopreservation studies have been successfully carried out using different types of explants, such as mature zygotic embryos [40, 41], pollen [42], plumules [43], and embryogenic calluses [44]. Furthermore, in studies conducted by Sisunandar et al. [45] and Sajini et al. [46] with zygotic embryos, plants regenerated after cryopreservation showed stable genetic, morphological, and cytological characteristics, which is one of the great advantages of this conservation method [39].

2.2 *Euterpe edulis* Martius

Euterpe edulis Martius, popularly known as juçara palm, is a native species to the Brazilian Atlantic Forest (**Figure 2a**) [47]. It is a key species within the forest ecosystem, as its fruiting powerfully attracts fauna. The species was the main palm tree producing palm hearts in this ecosystem, which made it the target of intense exploration from the 1960s, suffering a drastic reduction in its natural population since the extraction of its heart of palm (apical meristem) led to the death of the plant [48, 49], and its inclusion in the list of endangered species [50]. Currently, the species is also subject to the increasing effects of extractivism demanded by the pulp of its fruits, used locally as a substitute for açaí (**Figure 2b**) [51, 52].

2.2.1 Biotechnological tools for multiplication of *Euterpe edulis* Mart

Euterpe edulis reproduces exclusively by seeds. It does not have a natural vegetative propagation system (tillers or shoots) and does not respond to conventional vegetative propagation methods [51]. As an aggravating factor, its seeds have strong recalcitrance, with slow and irregular germination [53]. Over the past few years, several studies have been carried out seeking the development of propagation protocols that can provide high-quality and uniform seedlings in large quantities [54].

Somatic embryogenesis in *E. edulis* was first reported by [55]. Subsequently, the same authors carried out new studies indicating somatic embryogenesis as the most suitable method for *in vitro* regeneration of the juçara palm [56, 57]. Commonly used explants for this species include inflorescences, zygotic embryos, and leaves. In addition, juvenile explants have demonstrated more excellent responsiveness than those derived from adult tissues (**Figure 2c**) [55, 56]. Those authors used NAA and 2,4-D in 5–50 mg L⁻¹ and 2iP in 3–10 mg L⁻¹ concentrations to induce embryogenic calluses (**Figure 2d**). Somatic embryos in globular stages appeared after 80–200 days of inoculation. They were transferred to rooting media after the bipolar embryos detached from the matrix tissue, the stage at which the primary root begins to form. Plantlets' progression and formation occur with this material's transfer to a basic culture medium without plant growth regulators. The authors emphasize that somatic embryogenesis in this species occurs synchronously, allowing the visualization of all stages of embryogenesis on the same matrix tissue (**Table 2**).

Direct somatic embryogenesis protocol was subsequently determined using three types of explants: zygotic embryos (from mature and immature seeds), inflorescences of the adult plant, and leaves of seedlings grown *in vitro* [56]. The basal medium consisted of Ewens salts [62, 63] and vitamins, according to Morel and

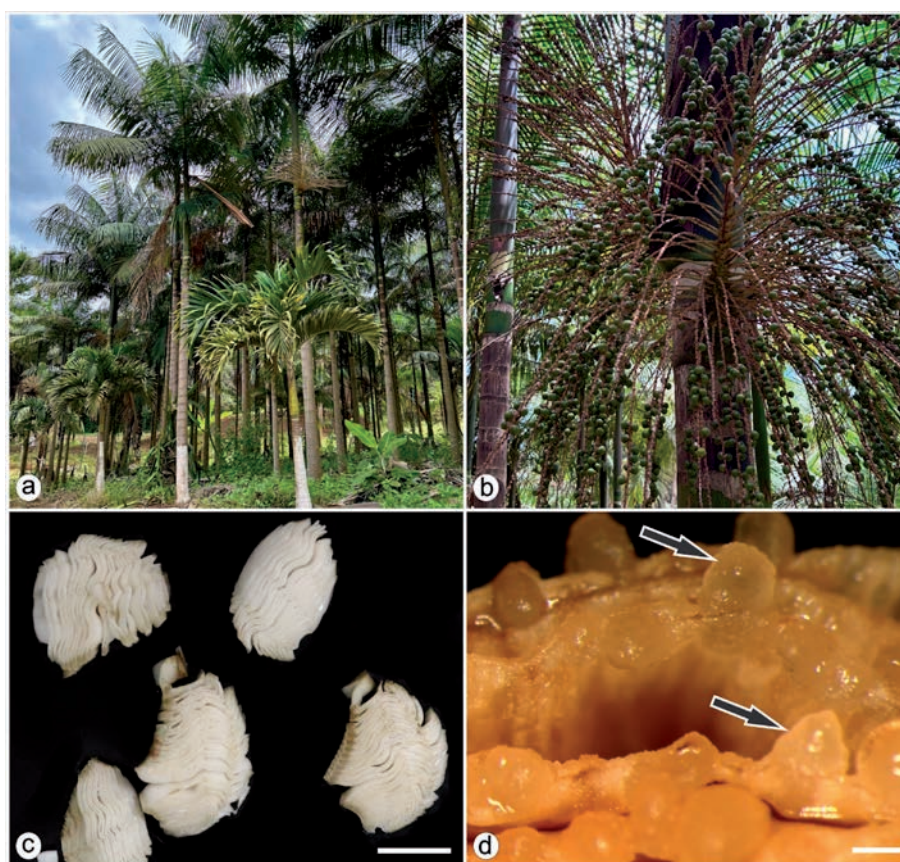


Figure 2.
 Somatic embryogenesis in *Euterpe edulis* Mart. (a) In situ plant. (b) Fruits of the species are used for pulp extraction and have various applications in the industry. (c) Juvenile explants obtained from leaf primordia. (d) Embryogenic callus formed in leaf explants. Scale bars, c = 1 cm; d = 200 μ m.

Wetmore [64], and the plant growth regulators used were 2,4-D, NAA, and 2iP. The results obtained from zygotic embryos were satisfactory at high concentrations of 2,4-D (50–100 mg L^{-1}). The somatic embryos were converted into plantlets after being transferred to a medium with sucrose and mineral salts reduced to half the strength of the basal medium. Embryogenesis was slower in mature embryos, taking 90 days after the cultures started, compared to 30 days in immature embryos. The inflorescences and young leaves were initially cultured in liquid medium before being transferred to the gelled medium. Embryogenesis in the inflorescences was induced with the addition of 2,4-D (50 mg L^{-1}) and 2iP (3.0 mg L^{-1}), while in the leaves, the authors obtained satisfactory results with 10–20 mg L^{-1} 2,4-D. The embryos that originated from these explants reached bipolar stages in a medium supplemented with 2iP (2.5 mg L^{-1}) and NAA (0.1 mg L^{-1}). The explants of zygotic embryos and inflorescences proved more appropriate for the induction of somatic embryogenesis in the species, especially those originating from immature tissues [65]. Structural analyses revealed that the embryogenic process in immature zygotic embryos originates from protodermal cells, while in mature embryos, it is formed from subepidermal cell clusters. In leaves, the division centers occurred adjacent to vascular bundles (Table 2) [66].

Phase	Explant	Culture medium	Response	References
Induction	Zygotic embryos and inflorescences	Y3 + NAA, 2,4-D and 2iP medium	Emergence of somatic embryos in the globular stage between 80 and 150 days	[55]
Induction	Zygotic embryos	Y3 + 2,4-D, NAA and 2iP medium	Satisfactory results at high levels of 2,4-D 50–100 mg L ⁻¹	[56]
	Inflorescences	Y3 + 2,4-D, NAA and 2iP medium	Embryogenesis was induced with the addition of 2,4-D at 50 mg L ⁻¹ and 2iP at 3.0 mg L ⁻¹	
	Leaves of seedlings grown <i>in vitro</i>	Y3 + 2,4-D, NAA and 2iP medium	Satisfactory results with 2,4-D between 10 and 20 mg L ⁻¹	
Induction	Zygotic embryos	Addition of CaCl ₂ H ₂ O to MS + 2iP and 2,4-D medium	Addition of calcium reduces the proliferation of embryogenic structures	[58]
Induction	Zygotic embryos	MS medium +2,4-D or picloram	Satisfactory results with 2,4-D at 125, 150 and 175 µmol L ⁻¹ and picloram at 250, 275 and 300 µmol L ⁻¹	[59]
Multiplication	Embryogenic callus	MS + 2iP and NAA medium	125 µmol of NAA proved to be more effective	
Germination	Somatic embryos	MS + GA3 and BAP medium	More effective results with BAP and GA ₃ without auxin pulses	
Induction	Zygotic embryos	Semi-solid MS medium +2,4-D, picloram, triclopyr and clopyralid	Greater efficacy of picloram at 150 µM and triclopyr at 100 µM	[60]
Maturation and germination	Zygotic embryos	MS + ABA medium	5 µm of ABA provided satisfactory results	
Differentiation and maturation	Zygotic embryos from immature fruits	Polyamines, spermidine and spermine in different concentrations	150 µM spermidine caused an effective stimulus in the differentiation of embryogenic callus	[61]

Note: Y3, Euwens medium; NAA, 1-Naphthaleneacetic Acid; 2,4-D, 2,4- dichlorophenoxyacetic acid; 2iP, Isopentenyladenine; CaCl₂H₂O, calcium chloride dihydrate; MS, Murashige & Skoog medium; GA₃, gibberellic acid; BAP, benzylaminopurine; ABA, abscisic acid.

Table 2.
Studies on somatic embryogenesis in Euterpe edulis.

The addition of calcium to the induction medium was tested by Saldanha and Martins-Corder [58]. The results showed that increasing the concentration of CaCl₂ H₂O in the culture medium reduced the average number of somatic embryos in 150-day-old palm seedlings. The MS medium supplemented with 2iP (3 mg L⁻¹) and

2,4-D (100 mg L^{-1}) without extra levels of Ca induced a more significant proliferation of embryogenic structures (**Table 2**).

Recently, a microscopy study evaluated the quality of the embryogenic calluses obtained in induction media supplemented with $25\text{--}300 \text{ }\mu\text{mol L}^{-1}$ 2,4-D or picloram [59]. Scanning electron microscopy analyses of somatic embryos obtained after 100 days of culture with $50\text{--}275 \text{ }\mu\text{mol L}^{-1}$ 2,4-D revealed tissues with embryogenic and non-embryogenic masses. Some calluses presented a compact and smooth surface formed by elongated cells without evidence of proembryo formation. Only the callus induced with $175 \text{ }\mu\text{mol L}^{-1}$ 2,4-D presented protuberances on the surface, indicating the formation of pre-embryogenic complexes. Anatomical sections of callus cultured in the 2,4-D induction medium revealed the presence of meristematic zones formed by groups of meristematic cells and embryogenic zones. Interestingly, recent results also demonstrated greater efficacy of picloram ($150 \text{ }\mu\text{M}$) and triclopyr ($100 \text{ }\mu\text{M}$) to induce somatic embryogenesis in *E. edulis* [60]. In this study, the maturation and germination of somatic embryos occurred in a medium supplemented with $5 \text{ }\mu\text{M}$ ABA. Picloram and triclopyr have similar chemical structures, presenting equivalent biological activity; therefore, plantlets treated with triclopyr obtained normal formation and acclimation (**Table 2**).

The impact of polyamines, spermidine, and spermine on the differentiation of embryogenic tissues and the maturation of somatic embryos of *E. edulis* was also evaluated [61]. It was observed that $150 \text{ }\mu\text{M}$ spermidine caused an effective stimulus in the embryogenic callus differentiation, facilitating the formation of several zones for the development of somatic embryos and inducing vigorous cell division. More than 80% of the somatic embryos formed at $150 \text{ }\mu\text{M}$ spermidine were regenerated into normal plantlets (**Table 2**).

Thus, we conclude that studies of somatic embryogenesis in *Euterpe edulis* have used zygotic embryos as a source of explants, the only possible source to obtain complete regeneration of plantlets. From zygotic embryos, it is possible to establish large-scale production of plants with high genetic quality, obtained from crosses between superior genotypes. However, the cloning of superior genotypes from somatic tissues of these matrices is still far from being a reality for the species.

2.3 *Euterpe oleraceae* Martius

Euterpe oleraceae Martius is commonly known as açai [67]. It is native to Central America and the Amazon region of northern South America [68]. In Brazil, it occurs spontaneously in the states of Amazonas, Maranhão, Amapá, and Pará [69]. The species stands out for the cultural, environmental, medicinal, nutritional, and antioxidant value of its fruits [70–76].

The açai is a palm tree with drupe-type fruit that is small, globose, and purple or dull green when ripe. It has a recalcitrant seed and a hard endocarp (**Figure 3a, b**) [77–79]. The palm is multi-stemmed (up to 25 stems per clump) with fasciculated and dense roots, which allow it to inhabit predominantly igapó and várzea forests [68, 69]. It has 10–12 pinnate leaves and reaches up to 30 m in height with a diameter of 12–18 cm (**Figure 3c–e**) [68]. At 3–4 years, it begins to flower. The racemose inflorescence (spadix) has small, unisexual, and sessile flowers. On the rachis, the flowers are arranged in triads, with one female flower flanked by two male flowers, and at the terminal part, only male flowers [69].

Açai is one of the main sources of raw materials for the palm heart agroindustry. However, research institutions holding germplasm of the species are focusing on

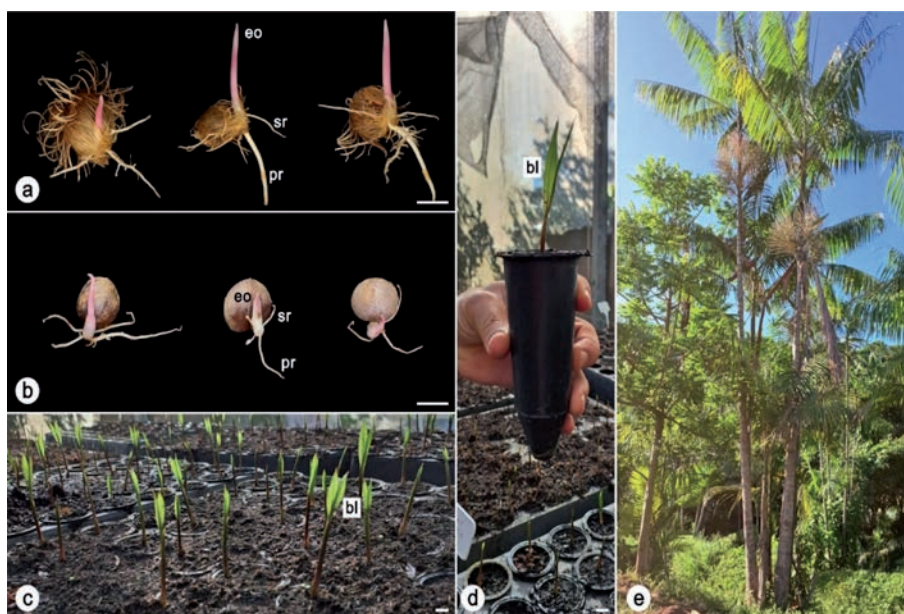


Figure 3. *Euterpe oleracea* Mart. Pre-germinated seeds: (a) with mesocarpic fibers; (b) core stone after removing the external fibers; (c), (d) acclimatized seedlings with 76 days showing leaves with characteristic patterns in the greenhouse; (e) palms, in loco, at the Federal University of Viçosa (UFV) orchard, Brazil (note the tillering). Bifid leaf (bl), eophyll (eo), primary roots (pr), and seminal roots (sr). Scale bars: a-d = 1 cm.

fruit agribusiness [80, 81]. In Brazil, the state of Pará leads national production with 1.7 million tons, representing 90.4% of the national production [82]. Likewise, Pará is considered the nation's largest producer of açaí fruit (66%). The United States has become the leading importer and processor of açaí-based products, followed by Australia, Japan, and European Union countries (Germany, Belgium, Portugal, and France) [83].

2.3.1 Biotechnological tools for multiplication of *Euterpe oleracea* Mart

2.3.1.1 Somatic embryogenesis

Açaí can be propagated *via* seeds (sexual propagation) and tillering (asexual propagation). However, due to plants' low production and survival rates *via* tillering, commercial-scale seedling production is limited to sexual propagation [84, 85]. At the same time, the recalcitrance of seeds makes it challenging to store them for long periods, in addition to presenting slow and uneven germination [84].

In this context, *in vitro* regeneration techniques, especially somatic embryogenesis, are seen as a promising alternative to the clonal propagation of açaí [86]. However, somatic embryogenesis is a complex, multifactorial, and multistep technique involving cell dedifferentiation, cell division activation, and reorganization of physiology, metabolism, and gene expression patterns [87–89]. Somatic embryogenesis protocols in palm trees are scarce, and few reach mass scale [90]. Thus, selecting the type and development stage of explants to be used *in vitro* açaí regeneration protocols becomes essential for the success and deepening of knowledge about the two most critical aspects of palm morphogenesis: callus initiation and induction of

somatic embryogenesis. The explant type and its development stage are probably the most critical factors in determining the embryogenic capacity of a culture [91].

Zygotic embryos have advantages, such as high responsiveness to *in vitro* culture, presumably because they still express many embryogenesis-related genes [92]. They are also generally pathogen-free and abundant in many species, making them easy to harvest with minimal damage to the mother plant [86]. Studies on somatic embryogenesis from zygotic embryos as an initial explant source have been conducted in açai (Table 3) [75, 76]. However, zygotic embryo regeneration protocols have the disadvantage of unpredictability, like the regenerants [94], due to cross-pollination.

Immature inflorescences have been studied as potential explants for palm due to the high embryogenic capacity of the callus they produce [95], as well as the additional advantages of low fungal and bacterial contamination [96, 97], minimal damage to the mother plant during harvest [94], and abundant inflorescence production in many species. Similarly, immature leaves are seen as potential explants to be used in the initiation of the technique, mainly because, like inflorescences, they allow the cloning of phenotyped individuals in the field without the influence of genetic material segregation after cross-fertilization [86].

Protocols for obtaining somatic embryos from immature leaves and inflorescences of açai have been developed at the Plant Tissue Culture Laboratory of the Federal University of Viçosa (UFV) in Brazil. However, the protocols are still under evaluation (unpublished data) (Figure 4).

2.3.1.2 De novo shoot organogenesis

Regeneration in palms through *de novo* shoot organogenesis has been considered relatively low and irregular compared to other monocots [98]. Açai embryos inoculated in semi-solid MS induction medium [99], with 30 g L⁻¹ of sucrose, 1.5 g L⁻¹ of activated charcoal (AC), MW vitamins [64], and 100 mg L⁻¹ of 2,4-D, produced callus. However, the plantlets did not regenerate [100].

2.3.2 Genetic breeding and conservation

Açai cultivars were developed by the Brazilian Agricultural Research Corporation (Embrapa) to increase the supply of fruit to the market. Traditionally, açai grows in flooded areas. However, in 2005, through a genetic breeding program based on phenotypic selection from its germplasm bank, Embrapa Western Amazonia (Belém, PA, Brazil) developed a cultivar 'BRS-Pará', suitable for growing on stable land, as a result of which the production system of this plant has now been modified, making it easier and more productive than the traditional system [101]. The release of this cultivar was key to the establishment of more productive crops, as the first açai plantations in upland areas were carried out amateurishly, using seeds of unknown genetic origin from açai harvesters, resulting in plantations with heterogeneous productivity and fruit qualities [102].

To address another challenge in açai fruit production, which is production seasonality, researchers from Embrapa Western Amazonia (Belém, PA, Brazil) developed the BRS Pai D'égua cultivar in 2019. The breeders selected native açai species produced in the off-season and, through crossbreeding, aimed to create genetic material capable of producing year-round. In addition to this characteristic, the researchers selected species with higher productivity and pulp yield. Thus, tests were conducted under different cultivation conditions to ensure the stability and adaptation of the

Phase	Explant	Culture medium	Response	References
Induction		MS supplemented with 0.6% agar, 0.25% activated charcoal, 3% sucrose, 500 mg/L hydrolyzed casein, 339.36 and 454.48 μ M of 2,4-D	80% and 61% of the explants subjected to concentrations of 339.36 and 454.48 μ M, respectively, showed yellowish embryogenic callus	
Multiplication	Mature zygotic embryos	MS supplemented with 0.6% agar, 2% sucrose, 0.537 μ M of NAA and 12.30 μ M of 2iP	The embryogenic calluses from the treatment with 339.36 μ M of 2,4-D progressed to SEs, while the others oxidize	[75]
Regeneration		MS supplemented with 0.6% agar and 1% sucrose in the absence of growth regulators	97% of the embryogenic callus from the treatment with 339.36 μ M of 2,4-D progressed to somatic embryos	
Induction		MS supplemented with 30 g sucrose, 1.5 g of activated charcoal, 6 g agar, 225 μ M of PIC, dark conditions	72% of the explants presenting embryogenic calluses formation	
Differentiation/ Maturation	Immature zygotic embryos	MS supplemented with 0.537 μ M NAA and 12.3 μ M 2ip with subcultures at 4-week intervals	100% of the explants that exhibited embryogenic calluses formation in the induction phase differentiated into SEs	[76]
Conversion		1/2MS supplemented with 20 g sucrose, 2.5 g of activated charcoal and light conditions	Plants were successfully regenerated from SE and acclimatized	
Induction		MS supplemented with 30 g/L sucrose, 2.5 g/L Phytigel, 2.5 g/L activated charcoal, 0.5 g/L L-glutamine and 450 μ M PIC	84% of the explants showed embryogenic calluses with a nodular appearance and yellowish coloration	
Multiplication	Immature and mature zygotic embryos	MS supplemented with 12.3 μ M 2iP, 0.6 μ M NAA and 300 mg/L of activated charcoal	100% of the explants that formed embryogenic calluses developed globular and compact somatic embryos	[93]
Regeneration		MS supplemented with 1.0 μ M of BAP, 0.5 μ M of GA ₃	The highest conversion rate of SEs into plants was 58.7%	

Note: NAA, 1-Naphthaleneacetic Acid; MS, Murashige & Skoog; 2,4D, 2,4-dichlorophenoxyacetic acid; 2ip, 2-isopentenyladenine; PIC, Picloram; BAP, N6-benzylaminopurine; GA3, gibberellic acid SEs, somatic embryos.

Table 3.
Studies on somatic embryogenesis in Euterpe oleracea Mart.

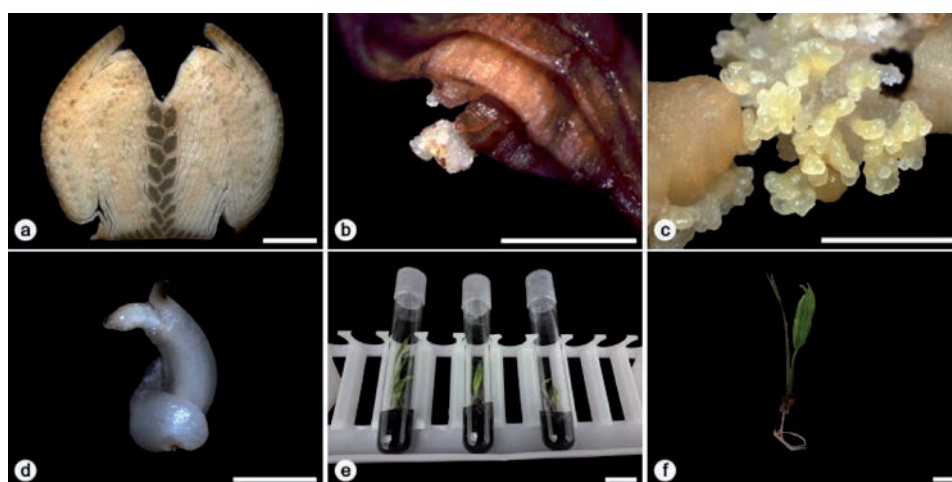


Figure 4.
 Somatic embryogenesis in açai (*Euterpe oleracea* Mart.) (a) Immature leaf explant obtained from palm offshoot; (b) primary callus development on the leaf margin in induction medium after 60 days; (c) polyembryonic mass in differentiation medium; (d) conversion of somatic embryos in regeneration medium; (e) *E. oleracea* seedlings regenerated from somatic embryos; and (f) shoot and root system of the regenerated seedlings ready for acclimatization. Scale bar: a-d = 0.3 cm; e-f = 2 cm.

cultivar, as the traditional açai production area is usually in floodplain regions [103]. Examples such as these are necessary for understanding the importance of further studies on the species, given that the açai palm has strong production potential and is a valuable resource for creating derivatives.

3. Oilseed palms

3.1 *Acrocomia aculeata*

Macauba (*Acrocomia aculeata*) is a native palm to the tropics and subtropics, with occurrences in areas with high to medium precipitation and high solar irradiation in America, such as Brazil, Mexico, Colombia, Argentina, Bolivia, Paraguay, Venezuela, Suriname, French Guiana, and the Antilles [104]. This evergreen, heliophilous, and pioneering species can form extensive oligarchic populations, mainly occupying anthropized areas in different biomes of the American continent. The plants of this genus are generally arboreal, robust, and tall [105, 106]. Its remarkable resilience and resistance to water scarcity, easy adaptation to different climates, lower environmental impact, and versatility of uses make it an up-and-coming crop compared to palm oil, the world's primary source of vegetable oil [107]. Furthermore, macauba fits integrated cultivation systems, such as the Crop-Livestock-Forest Integration, which renders slow carbon emissions, representing a more sustainable alternative to conventional oilseed growing [107]. Commercial exploitation and plantation of macauba are still in their early stages, as previously reported. The existing value chains rely on fruits from natural populations gathered by smallholder farmers. The fruits are supplied to local small-scale oil extraction facilities, primarily driven to niche markets, or processed on-farm by local communities for their own consumption and short-chain market [108, 109].

Macauba is a palm tree with many attributes that have been exploited since the eighteenth century [110]. However, despite the tremendous economic potential of the species, exploitation of macauba was restricted to extractivism until 2007. One of the reasons the species had not yet been cultivated was its complex propagation, which was considered the bottleneck for the development of palm plantations until then [111]. It was only in 2007, with the development of technology for the production of pre-germinated macauba seeds [112], that seed propagation, the natural form of propagation of the species, could be applied in the large-scale production of macauba seedlings, allowing the beginning of agricultural exploitation of the species.

3.1.1 Seminiferous propagation

Macauba is described in the literature as one of the most challenging palm species to germinate [113]. This species' natural germination of seeds is generally slow and uneven, taking up to 4 years and rarely resulting in germination rates above 7% [111, 114]. This is due to the deep dormancy, the inherent characteristic of the seeds of palm species of the genus *Acrocomia* [115, 116]. The first method for overcoming the dormancy of macauba seeds was developed by [112]. The process described by the authors enabled the rapid and efficient germination of macauba seeds and the regularization of seedling production, which allowed the cultivation of macauba inside and outside its natural environment.

The process of overcoming dormancy and inducing germination of macauba seeds developed by [112] consists of seven treatments, applied in sequence to the seed, namely: (i) elimination of the endocarp, (ii) first disinfestation, (iii) soaking treatment, (iv) second disinfestation, (v) mechanical scarification, (vi) treatment with gibberellic acid, and (vii) germination of the almond in a semi-aseptic environment. The process described above allowed the germination of 60–80% of the treated macauba seeds, which were finalized and ready for planting in the nursery approximately 30 days after the beginning of the germination process. The final product of this process was called pre-germinated macauba seeds by the authors and should contain a defined plumule and radicle.

*3.1.2 Biotechnological tools for multiplication of *Acrocomia aculeata**

3.1.2.1 Somatic embryogenesis

In macauba, studies involving somatic embryogenesis have been reported as promising for its vegetative propagation [117–120], with these being recent and published just over a decade ago (**Table 4**). Moura et al. [117] were the pioneers in reporting the process, followed by Luis and Scherwinski-Pereira [118]. These authors used zygotic embryos to study somatic embryogenesis in macauba. Zygotic embryos are ontogenetically younger and consequently more responsive to the induction of somatic embryogenesis. Granja et al. [119] obtained in their study with zygotic embryos embryogenic lines with high multiplication capacity and a high degree of synchronization, enabling the control of all stages of somatic embryogenesis (multiplication, regeneration, and germination), thus achieving the cyclic production of seedlings over more than 2 years.

However, cloning protocols should be obtained from somatic tissues of properly tested elite matrices with proven agronomic performance. Recently, Meira et al. [121] demonstrated the development pathways of somatic embryogenesis in macauba from

Phase	Explant	Culture medium	Response	References
Induction	Zygotic embryo	Y3 + 9 µM Picloram	Embryogenic callus	[117]
Germination	Somatic embryos	Y3 + activated charcoal without growth regulator	Half of somatic embryos germinated	
Induction	Zygotic embryo	MS or Y3 with 0.5 mg/L or 1.0 mg/L of Dicamba or Picloram or 2,4-D	Embryogenic callus	[118]
Regeneration	Somatic embryos	MS or Y3 + activated charcoal without growth regulator	Plant regeneration	
Induction	Zygotic embryo	Y3 + 9 µM Picloram + 0,9 µM 2iP	Callus	[119]
Multiplication	Callus	Y3 + 18 µM Picloram	Embryogenic mass	
Maturation	Embryogenic mass	Y3 + 2.5 µM 2iP + 5.55 µM NAA + active charcoal + 1000 µM PUT	Somatic embryos	
Germination	Somatic embryos	Y3 + 0.25 µM 2iP + 0.55 µM GA ₃ + 1000 µM PUT	Plants	
Multiplication	Callus	Y3 + 9 µM Picloram + 1000 µM PUT	Somatic embryos	[120]
Regeneration	Somatic embryos	Y3 + 0.54 µM NAA + 1000 µM PUT + active charcoal	Plantlets	
Induction	Leaves	Y3 + activated charcoal + 450 µM Picloram	Callus	[121]
Multiplication	Embryogenic callus	Y3 + 450 µM Picloram + active charcoal	Somatic embryos	
Induction	Leaves	Y3 + 450 µM Picloram	Callus	[122]
Multiplication	Callus	Y3 + 450 µM Picloram	Somatic embryos	
Regeneration	Somatic embryos	Y3 without growth regulator	Germinated plants	
Induction	Aereo parts of <i>in vitro</i> plants (TCL)	Y3 + Morel's vitamins + 300 µM Picloram	Callus	
Multiplication	Callus	Y3 + Morel's vitamins + 25 µM BAP or 12.5 µM 2iP + 75 µM Picloram	Somatic embryos	[123]
Germination	Somatic embryos	Y3 + Morel's vitamins without growth regulator	Plants	
Induction	Zygotic embryo	Y3 + activated charcoal + 9 µM Picloram or Y3 + 9 µM Picloram	Nodular callus	[124]
Multiplication	proembryos	Y3 + charcoal active + 9 µM Picloram or Y3 + 9 µM Picloram	Somatic embryos without germination	

Note: NAA, 1-Naphthaleneacetic Acid; PUT: putrescine; 2iP: isopentenyladenine; BAP: benzylaminopurine; MS: Murashige & Skoog medium; Y3: Eeuwens medium; 2,4-D: dichlorophenoxyacetic acid; GA₃: gibberellic acid.

Table 4.
Studies on somatic embryogenesis in *Acrocomia aculeata*.

leaf explants of adult plants. According to the authors, the process generated hundreds of somatic embryos, indicating a possible application of *in vitro* propagation in the clonal production of macauba, although plantlets were not obtained. Immature leaflets are excellent sources of explants for initiating somatic embryogenesis in species of the Arecaceae family, as they are protected within the heart of the plant and consequently show low levels of microbial contamination. In studies conducted by Andrade et al. [120], immature leaves of macauba showed responsiveness to the induction of somatic embryogenesis. In this study, the authors obtained embryogenic lines comparable to those obtained by Granja et al. [119], producing numerous plants. However, leaflets from adult plants did not respond to the somatic embryogenesis induction treatments. Protocols for obtaining somatic embryos from immature leaves and inflorescences of adult macauba plants have been developed at the Plant Tissue Culture Laboratory of the Federal University of Viçosa (UFV) in Brazil (Figure 5). However, the protocols are still under evaluation (unpublished data).



Figure 5. Somatic embryogenesis in macauba (*Acrocomia aculeata*). (a) embryogenic callus. (b-c) embryogenic callus with somatic embryos in a regeneration medium. (d) somatic embryo germination. (e) *in vitro* macauba plantlet obtained from somatic embryogenesis. (f) Acclimatization. (g-h) one-year-old plants obtained somatic embryos. (i-j) Planting of macauba clonal plants. Scale bars, a and b = 5 mm. c, d and e = 1 cm; f = 5 cm; g and h = 10 cm; i and j = 20 cm.

The different culture media used in the somatic embryogenesis process essentially differ in the concentration of macro and micronutrients, vitamins, organic compounds, carbon sources, and other complex substances, typically specific to each stage of the process and the species used. The most commonly used culture media formulations for somatic embryogenesis in macauba include the MS medium from [99, 118, 119] and the Y3 medium from Eeuwens [117, 119–121]. The induction of somatic embryogenesis is associated with the use of auxins and cytokinins, the main growth regulators involved in controlling cell division and tissue differentiation [88]. Among the auxins most commonly used in the induction of somatic embryogenesis in macauba, 2,4-D can be cited [118, 121, 122]. However, other auxins such as Picloram and Dicamba have proven efficient [117–119, 121, 123]. The use of cytokinins in the induction medium for callus formation in macauba is not very common. Still, interesting results were reported in the work of Granja et al. [119] and Andrade et al. [120], where isopentenyl adenine (2iP) allowed the generation of embryogenic lines when combined with Picloram or Dicamba.

3.1.3 Genetic breeding and conservation

The ex situ conservation of macauba is more recent, starting at Embrapa Cerrados in December 2008 and later implemented in other Brazilian research institutions, such as the Federal University of Viçosa (UFV) and the Agronomic Institute of Campinas (IAC). UFV is responsible for the first collection registered by the Brazilian Genetic Heritage Management Council (registration no. 084–2013/CGEN/MMA). The Active Germplasm Bank (AGB-MACAUBA) of macauba from the Macauba Research Network of the Federal University of Viçosa (REMAPE/UFV) was established in 2009 at the Unit for Teaching, Research, and Extension in Genetic Improvement and Palm and Other Oilseed Production Systems (UEPE-MGPO) in the city of Araponga, Minas Gerais, Brazil (latitude –20.6686 and longitude –42.51785). The repository comprises more than 300 maternal families of the species *A. aculeata*, from the sclerocarpa and totai ecotypes, with around 1500 accessions from various Brazilian regions. The AGB-MACAUBA has been intensively used in studies for genetic breeding and domestication of the species. In addition to the AGB-MACAUBA, the first *A. aculeata* clones developed by UFV were established at UEPE-MGPO (Figure 5i, j).

3.2 *Elaeis guineensis* Jacq

Elaeis guineensis Jacq., commonly known as the African oil palm or oil palm, is a perennial, monoecious, oil-producing plant and has a long life cycle, playing an essential role in the production of vegetable oils for human consumption and other agro-industries [125, 126]. It is a palm tree that can reach up to 15 meters in height, with an erect, unbranched stem of the stipe type and a fibrous root system. Its leaves are pinnate, measuring 5–7 meters, and its inflorescences form in the leaf axils as spadices composed of spikes protected by two fibrous bracts, classifying it as a monoecious plant [127, 128].

It is considered an oil-producing palm native to Africa, widely cultivated in regions with a humid tropical climate. The main product of the oil palm is the oil

extracted from the fruit pulp, known internationally as palm oil. This oil stands out in global production and consumption, with applications in food, medicine, and oleochemistry [127, 129].

Its oil stands out for its versatility, oxidation resistance, and functionality in the food industry as an essential ingredient in a wide range of products. Additionally, it contains bioactive compounds that offer added benefits, such as nutritional functionality, cardiovascular health, and antioxidant protection [125, 130]. It serves as a strategic component in formulating healthy, high-quality foods, enhancing its importance to the global food industry and human health [125].

It is one of the most economically valuable oil-producing plants due to its high oil yield per bunch, plant, and productive area. As a perennial species, it can reach up to 6000 kg per hectare, with high quality and low production costs [131, 132]. Its cultivation is one of the main sources of vegetable oil production worldwide [133]. By 2022, its global production was nearly 74 million tons annually, representing 4% of global agricultural production [134].

3.2.1 Biotechnological tools for multiplication of *Elaeis guineensis* Jacq

3.2.1.1 Somatic embryogenesis

Somatic embryogenesis is considered a promising and efficient technique for multiplying elite genotypes of *Elaeis guineensis* (Table 5) [124, 135–138, 142, 143, 147]. Furthermore, it has been recognized as an ideal approach for mass clonal propagation associated with genetic improvement, particularly for perennial and long-cycle species [147].

Figure 6 presents the somatic embryogenesis of oil palm. The embryogenesis process in oil palm occurs indirectly, initially through the development of a pro-embryogenic mass, followed by its multiplication, which differentiates to form somatic embryos [127]. In oil palm, the induction of somatic embryogenesis has been achieved from different explants, such as root segments, immature leaves, and immature inflorescences [90–134].

Plant growth regulators, particularly 2,4-dichlorophenoxyacetic acid (2,4-D) and picloram, are essential in this process [135, 137]. Other growth regulators, such as naphthaleneacetic acid (NAA), gibberellic acid (GA_3), and benzylaminopurine (BA), are also frequently used in the various phases of somatic embryogenesis in this plant [138, 142, 143]. Additionally, polyamines have been commonly used in the somatic embryogenesis of the species, with a particular emphasis on putrescine [141, 145].

The somatic embryogenesis induction can be performed in culture media supplemented with a high auxin concentration. The subsequent proliferation of calluses and regeneration of somatic embryos is achieved by reducing the auxin levels or completely removing them, as well as adding other growth regulators, such as cytokinins, abscisic acid, and polyamines [145, 148].

Despite the various published protocols, many factors can interfere with the somatic embryogenesis process, making the repeatability of the protocols challenging, with uncertainty remaining regarding the best procedures. In oil palm, due to the advantages offered by the use of elite clones, research on the multiplication processes of oil palm is primarily conducted by private companies, and many important details for the success of embryogenesis are not made available [127].

Phase	Explant	Culture medium	Response	References
Induction	Leaf primordia	Y3 medium + Picloram or 2,4-D	1.0 mg L ⁻¹ of picloram allows calluses formation with higher embryogenic potential	[135]
Induction	Root primordia	Y3 medium + different regulators	1.0 mg L ⁻¹ of picloram provides better results	[136]
Induction	Male inflorescences	Modified Y3 medium + regulators	The use of picloram provides better responses in male inflorescences	[94]
Induction	Leaf primordia	MS medium + 2,4-D + Activated charcoal	Higher concentrations of 2,4-D (450 µM) + activated charcoal provide better responses	[137]
Induction	Leaf primordia	MS medium + NAA + 2,4-D	The best responses were achieved using 6 mg L ⁻¹ of NAA + 0.5 mg L ⁻¹ of 2,4-D	[138]
Multiplication	Friable callus	Different immersion systems and culture media	The use of modified MS (MSA9) in a shaker or MSD in a temporary immersion system with intervals of 3 hours for 3 minutes	[139]
Induction and multiplication	Leaf primordia of 32 superior genotypes	Y3 medium	Occurrence of genetic control in the formation and multiplication of embryogenic lines, being genotype-dependent	[140]
Induction and regeneration	Mature zygotic embryos and Friable callus	MS medium and Blaydes medium + different regulators	The addition of polyamines allows an increase in the somatic embryogenesis rate	[141]
Regeneration	Somatic embryos	Suspension culture in modified MS medium + BA	The application of BA increases the responsiveness of somatic embryos	[142]
Regeneration and germination	Friable callus and somatic embryos	Modified MS medium + CaCl ₂ and GA ₃	880 mg L ⁻¹ of CaCl ₂ allows for a higher regeneration rate, as well as higher concentrations of GA ₃ (4.0 mg L ⁻¹), while for germination, lower values of GA ₃ are ideal	[143]
From multiplication to germination	Leaf primordia, friable callus and somatic embryos	Modified MS medium in different cultivation and immersion systems	The use of RITA-type bioreactors enables multiplication, as well as a higher yield of viable seedlings at the end of the process	[144]

Phase	Explant	Culture medium	Response	References
From induction to acclimatization	From leaf primordia to clonal seedlings	Modified Y3 medium + putrescine	Putrescine can be an important substitute for cytokinins, reducing somaclonal variations. Additionally, the response to somatic embryogenesis is genotype-dependent	[145]
Conservation	Friable callus	Successive subcultures in modified MS medium for 20 years	It is possible to conserve for more than 20 years; however, its success is genotype-dependent, and attention is required to somaclonal variations	[146]

Note: Y3, Eeuwens medium; 2,4-D, 2,4-Dichlorophenoxyacetic acid; MS, Murashige and Skoog medium; NAA, 1-Naphthaleneacetic Acid; BA, Benzylaminopurine; GA₃, Gibberellic acid; CaCl₂, Calcium chloride.

Table 5.
Studies on somatic embryogenesis in *Elaeis guineensis*.

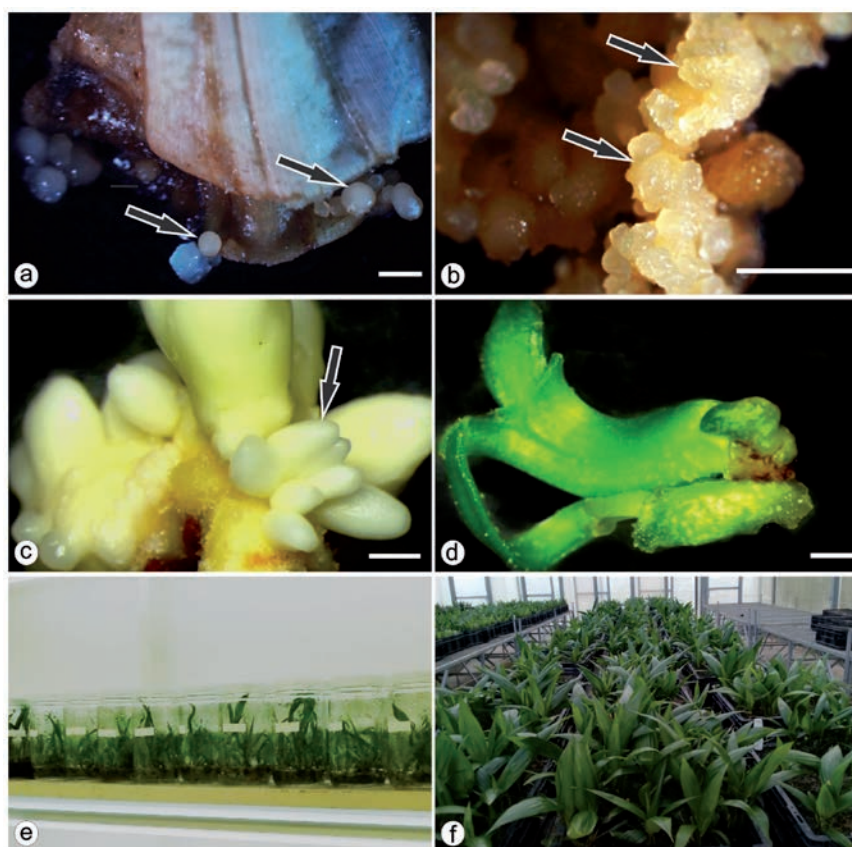


Figure 6.
Somatic embryogenesis in oil palm (*Elaeis guineensis* Jacq.). (a) Formation of friable callus—Induction; (b) Multiplying friable calluses; (c) Differentiation of somatic embryos—regeneration; (d) clonal seedling in development—germination; (e) Large-scale germination; and (f) Acclimatization of *E. guineensis* seedlings arising from somatic embryogenesis. Scales bars: a = 1000 μm; b = 2500 μm; c, d = 500 μm.

However, it is possible to obtain seedlings derived from somatic embryogenesis on a large scale.

4. Conclusions

Combining agricultural traditions with biotechnological innovations is crucial to ensure the sustainability and growth of palm crops, meeting the growing global demand for their products and beneficial properties. In this context, *in vitro* regeneration techniques, such as somatic embryogenesis, have proven crucial for the multiplication and cloning of superior genotypes. This technique not only allows the regeneration of uniform, pathogen-free, and genetically superior plants but also helps in the conservation of germplasm, in addition to subsidizing and accelerating genetic breeding programs. However, for some palm tree species, the established protocols are still inefficient, which requires continuous effort to optimize them, enabling the application of this biotechnological tool on a commercial scale to ensure the constant supply of high-quality plantlets, aligned with the sustainability demands of the production chain of these important palm tree plant species.

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Conflict of interest

The authors declare no conflict of interest.

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References

- [1] Dransfield J, Uhl NW, Lange CBA, Baker WJ, Harley MM, Lewis CE. Genera Palmarum: The Evolution and Classification of Palms. London: Kew Publishing; 2008. 732 p. DOI: 10.34885/92
- [2] Muscarella R, Emilio T, Phillips OL, et al. The global abundance of tree palms. *Global Ecology and Biogeography*. 2020;**29**:1495-1514. DOI: 10.1111/geb.13123
- [3] Pintaud JC, Baker WJ. A revision of the palm genera (*Arecaceae*) of New Caledonia. *Kew Bulletin*. 2008;**63**(1):61-73. DOI: 10.1007/s12225-007-9009-3
- [4] Lieberman M, Lieberman D, Hartshorn GS, Peralta R. Small-scale altitudinal variation in lowland wet tropical forest vegetation. *The Journal of Ecology*. 1985;**73**:505-516. DOI: 10.2307/2260490
- [5] Henderson A. Evolution and Ecology of Palms. New York: New York Botanical Garden Press; 2002. 259 p
- [6] Genini J, Galetti M, Morellato LPC. Fruiting phenology of palms and trees in an Atlantic rainforest land-bridge island. *Flora-Morphology, Distribution, Functional Ecology of Plants*. 2009;**204**:131-145. DOI: 10.1016/j.flora.2008.01.002
- [7] Cerqueira AF, Benchimol M, Sousa-Santos C, Bezerra IM, Santana dos Santos M, Dalmolin ÂC, et al. Trends and gaps in the literature on native palms of the Brazilian Atlantic Forest. *Austral Ecology*. 2024;**49**:e13322. DOI: 10.1111/aec.13322
- [8] Meerow AW. Palm seed germination: BUL274/EP238, rev. 6/2004. EDIS. 2004;**2004**(9). DOI: 10.32473/edis-ep238-2004
- [9] Ree JF, Guerra MP. Palm (*Arecaceae*) somatic embryogenesis. *In Vitro Cellular & Developmental Biology - Plant*. 2015;**51**:589-602. DOI: 10.1007/s11627-015-9722-9
- [10] Rocha DI, Kurczyńska E, Potocka I, Steinmacher DA, Otoni WC. Histology and Histochemistry of somatic embryogenesis. In: Loyola-Vargas V, Ochoa-Alejo N, editors. *Somatic Embryogenesis: Fundamental Aspects and Applications*. Cham: Springer; 2016. pp. 471-494. DOI: 10.1007/978-3-319-33705-0_26
- [11] Vianna SA. Cocos in Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro [Internet]. 2024. Available from: <https://floradobrasil.jbrj.gov.br/FB80541> [Accessed: October 25, 2024]
- [12] Harries H. The evolution, dissemination and classification of *Cocos nucifera* L. *The Botanical Review*. 1978;**44**:265-319. DOI: 10.1007/BF02957852
- [13] Purseglove JW, editor. *Tropical Crops Monocotyledons*. 1 & 2nd ed. London: Longmans; 1972. 607 p
- [14] Adkins S, Foale M, Bourdeix R, Nguyen Q, Biddle J, editors. *Coconut Biotechnology: Towards the Sustainability of The 'Tree of Life'*. St Lucia, QLD, Australia: Springer International Publishing; 2021. p. 5. DOI: 10.1007/978-3-030-44988-9
- [15] Nayar NM. The coconut: Phylogeny, origins, and spread. In: Nayar NM, editor. *Taxonomy and Intraspecific Classification*. Amsterdam, Netherlands: Academic Press; 2016. pp. 25-51

- [16] Allied Market Research [Internet]. 2019. Available from: <https://www.prnewswire.com/news-releases/coconut-products-market-to-garner-31-1-bn-globally-by-2026-at-13-6-cagr-says-allied-market-research-300975188.html> [Accessed: October 26, 2024]
- [17] Brainer MSDCP, Ximenes LF. Produção de coco: soerguimento das áreas tradicionais do Nordeste. Caderno Setorial ETENE. 2020;127:1-15
- [18] Instituto Brasileiro de Geografia e Estatística (IBGE) [Internet]. Produção de Coco-da-baía (*Cocos nucifera* L.) no Brasil. 2023. Available from: <https://ibge.gov.br/explica/producao-agropecuaria/coco-da-baia/br> [Accessed: October 21, 2024]
- [19] Martins CR, Jesus Júnior LA. Produção e comercialização de coco no Brasil frente ao comércio internacional: panorama. [Internet]. 2014. Embrapa Tabuleiros Costeiros. Available from: <http://www.bdpa.cnptia.embrapa.br> [Accessed: October 26, 2024]
- [20] Rethinam P, Krishnakumar V. Coconut water: A promising natural health drink-distribution, processing and nutritional benefits. In: Rethinam P, Krishnakumar V, editors. Global Scenario of Coconut and Coconut Water. Cham: Switzerland; 2022. pp. 17-35. DOI: 10.1007/978-3-031-10713-9_2
- [21] Ramírez JFG, Muñoz RC, Sossa JWZ. Innovations and trends in the coconut agroindustry supply chain: A technological surveillance and foresight analysis. Frontiers in Sustainable Food Systems. 2023;7:1048450. DOI: 10.3389/fsufs.2023.1048450
- [22] Kong EY, Biddle J, Foale M, Panis B, Adkins SW. The potential to propagate coconut clones through direct shoot organogenesis: A review. Scientia Horticulturae. 2021;289:110400. DOI: 10.1016/j.scienta.2021.110400
- [23] Jain SM, Pramod K, Gupta RJ, Ronald JN. Somatic embryogenesis in Woody plants. In: Blake J, Hornung R, editors. Somatic embryogenesis in coconut (*Cocos nucifera* L.). 2nd ed. Dordrecht: Springer Netherlands; 1995. pp. 327-340. DOI: 10.1007/978-94-011-0491-3_18
- [24] Chan JL, Saenz L, Talavera C, Hornung R, Robert M, Oropeza C. Regeneration of coconut (*Cocos nucifera* L.) from plumule explants through somatic embryogenesis. Plant Cell Reports. 1998;17:515-521. DOI: 10.1007/s002990050434
- [25] Oropeza C, Verdeil JL, Ashburner GR, Cardña JM. Curre. Current plant science and biotechnology in agriculture: Current advances in coconut biotechnology. In: Adkins SW, YMS S, Godwin ID, editors. Control of Environmental Conditions and the Use of Polyamines Can Optimise the Conditions for the Initiation and Proliferation of Coconut Somatic Embryos. Dordrecht, Holanda: Springer; 1999. pp. 321-340. DOI: 10.1007/978-94-015-9283-3_24
- [26] Perera PI, Hoche V, Verdeil JL, Doubeau S, Yakandawala DM, Weerakoon LK. Unfertilized ovary: A novel explant for coconut (*Cocos nucifera* L.) somatic embryogenesis. Plant Cell Reports. 2007;26:21-28. DOI: 10.1007/s00299-006-0216-4
- [27] Perera PI, Yakandawala DMD, Hoche V, Verdeil JL, Weerakoon LK. Effect of growth regulators on microspore embryogenesis in coconut anthers. Plant Cell, Tissue and Organ Culture. 2009;96:171-180. DOI: 10.1007/s11240-008-9473-y

- [28] Mu Z, Yang S, Xu H, Yang Z, Haque MM, Tran BM, et al. The influence of maturity, storage, and embryo size on coconut callus induction success. *Forests*. 2024;**15**:764. DOI: 10.3390/f15050764
- [29] Kong EY, Biddle J, Kalaipandian S, Adkins SW. Coconut callus initiation for cell suspension culture. *Plants*. 2023;**12**:1-22. DOI: 10.3390/plants12040968
- [30] Agbidinoukoun A, Somakpe E, Houngue J, Houedjissin S, Ahanhanzo C. Response of haustorium tissues and coconut water in somatic embryos induction for the coconut palm (*Cocos nucifera* L.) variety PB121. *Journal of Advances in Biotechnology*. 2022;**10**:6-14. DOI: 10.24297/jbt.v10i.9195
- [31] Jayarathna SPNC, Balasooriya JOS, Vidhanaarachchi VRM, Perera D. Enhanced coconut somatic embryogenesis of unfertilized ovary derived callus through improved media composition. *COCOS*. 2023;**24**:13-21. DOI: 10.4038/cocos.v24i1.5825
- [32] Shareefa M, Thomas RJ, Sreelekshmi JS, Rajesh MK, Karun A. In vitro regeneration of coconut plantlets from immature inflorescence. *Current Science*. 2019;**5**:813-820
- [33] Bett CC, Mweu CM, Nyende AB. In vitro regeneration of coconut (*Cocos nucifera* L.) through indirect somatic embryogenesis in Kenya. *African Journal of Biotechnology*. 2019;**18**:1113-1122. DOI: 10.5897/AJB2019.16867
- [34] Wilms H, De Bièvre D, Longin K, Swennen R, Rhee J, Panis B. Development of the first axillary in vitro shoot multiplication protocol for coconut palms. *Scientific Reports*. 2021;**11**:18367. DOI: 10.1038/s41598-021-97718-1
- [35] Rohith S, Kavibalan S, Thangaraj K, Suresh J, Ananthan M, Renuka R. Characterization of mother palms and novel techniques to produce elite seedlings of coconut var. chowghat orange dwarf. *Electronic Journal of Plant Breeding*. 2023;**14**:867-875. DOI: 10.37992/2023.1403.112
- [36] Neema M, Hareesh GS, Aparna V, Chandran KP, Karun A. Electrical induction as stress factor for callus growth enhancement in plumular explant of coconut (*Cocos nucifera* L.). *International Journal of Bio-resource and Stress Management*. 2022;**13**:921-927. DOI: 10.23910/1.2022.3126
- [37] Oropeza C, Verdeil JL, Ashburner GR, Cardña JM. Current plant science and biotechnology in agriculture: Current advances in coconut biotechnology. In: Engelmann F, editor. *Criopreservation Coconut Germoplasm*. Dordrecht, Holanda: Springer; 1999. pp. 289-296. DOI: 10.1007/978-94-015-9283-3_24
- [38] Sopade PA, Samosir Y, Rival A, Adkins SW. Conservation of coconut (*Cocos nucifera* L.) germplasm at sub-zero temperature. *CryoLetters*. 2012;**33**:465-475
- [39] Benelli C. Plant cryopreservation: A look at the present and the future. *Plants*. 2021;**10**:1-5. DOI: 10.3390/plants10122744
- [40] Assy-Bah B, Engelmann F. Medium-term conservation of mature embryos of coconut. *Plant Cell, Tissue and Organ Culture*. 1993;**33**:19-24. DOI: 10.1007/BF01997593
- [41] Wilms H, Rhee JH, Rivera RL, Longin K, Panis B. Developing coconut cryopreservation protocols and establishing cryo-genebank at

- RDA; a collaborative project between RDA and bioversity international. In III International Symposium on Plant Cryopreservation. 2018;**1234**:343-348. DOI: 10.17660/ActaHortic.2019.1234.45
- [42] Karun A, Sajini KK, Niral V, Amarnath CH, Remya P, Rajesh MK, et al. Coconut (*Cocos nucifera* L.) pollen cryopreservation. CryoLetters. 2014;**35**:407-417
- [43] Léo ADS, Santana FV, Oliveira ACAD, Oliveira LARD, Silva AVCD. Cryopreservation of Brazilian green dwarf coconut plumules by droplet-vitrification. Ciência Rural. 2019;**50**:e20190020. DOI: 10.1590/0103-8478cr20190020
- [44] Welewanni I, Perera C, Jayasekera A, Bandupriya D. Recovery, histological observations and genetic integrity in coconut (*Cocos nucifera* L.) embryogenic calli cryopreserved using encapsulation-dehydration procedure. Journal of the National Science Foundation of Sri Lanka. 2020;**48**:175-186. DOI: 10.4038/jnsfsv48i2.9538
- [45] Sisunandar RA, Turquay P, Samosir Y, Adkins SW. Cryopreservation of coconut (*Cocos nucifera* L.) zygotic embryos does not induce morphological, cytological or molecular changes in recovered seedlings. Planta. 2010;**232**:435-447. DOI: 10.1007/s00425-010-1186-x
- [46] Sajini KK, Karun A, Amarnath CH, Engelmann F. Cryopreservation of coconut (*Cocos nucifera* L.) zygotic embryos by vitrification. CryoLetters. 2011;**4**:317-328
- [47] Carvalho CS, Galetti M, Colevatti RG, Jordano P. Defaunation leads to microevolutionary changes in a tropical palm. Scientific Reports. 2016;**6**:1-10. DOI: 10.1038/srep31957
- [48] Reis MS, Conte R, Fantini AC, Guerra MP. O palmito (*Euterpe edulis* Martius) como recurso da Mata Atlântica. In: Simões LL, Lino CF, editors. Sustentável Mata Atlântica a exploração de seus recursos florestais. 2nd ed. Senac: São Paulo; 2002. pp. 103-117
- [49] Martinelli G, Moraes MA, editors. Livro vermelho da flora do Brasil. 1st ed. Rio de Janeiro: CNCFlores; 2013. 1100 p
- [50] Ministério do Meio Ambiente. Instrução Normativa N°6. Lista Oficial das Espécies da Flora Brasileira Ameaçadas de Extinção. Diário Oficial da União. 2008;**185**:75-83
- [51] Schulz M, Borges G, Gonzaga SC, ACO LVC, Fett R. Juçara fruit (*Euterpe edulis* Mart.): Sustainable exploitation of a source of bioactive compounds. Food Research International. 2016;**89**:14-26. DOI: 10.1016/j.foodres.2016.07.027
- [52] LAOP G, Souza RG, editors. Palmeira juçara: patrimônio natural da Mata Atlântica no Espírito Santo. 1st ed. Vitória: Incaper; 2017. 68 p
- [53] Jaganathan GK. Ecological insights into the coexistence of dormancy and desiccation sensitivity in Arecaceae species. Annals of Forest Science. 2021;**78**:1-14. DOI: 10.1007/s13595021010329
- [54] Saldanha CW. Conservação in vitro de *Euterpe edulis* Martius através da embriogênese somática [Dissertação (Mestrado em Geomática)]. Brazil: Universidade Federal de Santa Maria; 2007; 110 p
- [55] Guerra MP, Handro W. Somatic embryogenesis in tissue cultures of *Euterpe edulis* Mart. (Palmae). In: Ahuja RM, editor. Wood Plant Biotechnology. New York: Plenum Press; 1991. pp. 189-196

- [56] Guerra MP, Handro W. Somatic embryogenesis and plant regeneration in different organs of *Euterpe edulis* Mart. (Palmae): Control and structural features. Journal of Plant Research. 1998;**111**:65-71. DOI: 10.1007/BF025 07151
- [57] Guerra MP, Nodari RO, Peixoto ML, Quinta M. Embriogênese somática e micropropagação do palmitero. Sellowia. 2000;**49**:150-162
- [58] Saldanha CW, Martins-Corder MP. In vitro germination and acquisition of embryogenic competence *Euterpe edulis* Martius immature zygotic embryos. Crop Breeding and Applied Biotechnology. 2012;**12**:171-178. DOI: 10.1590/S1984-70332012000300002
- [59] Oliveira LB, Mello T, Araujo CP, Oliveira JPB, Ferreira A, Zanardo EC, et al. Morphoanatomical aspects of auxinic herbicides-induced somatic embryogenesis in *Euterpe edulis* Martius - a symbol and threatened species of the Atlantic Forest. Scientia Horticulturae. 2022;**299**:111-051. DOI: 10.1016/j.scienta.2022.111051
- [60] Mello T, Taliuli YS, Silva TD, Zanardo TEC, Hegedus CEN, Anjos BB, et al. Optimization of somatic embryogenesis in *Euterpe edulis* Martius using auxin analogs and atomic force microscopy. Scientia Horticulturae. 2024;**331**:113-164. DOI: 10.1016/j.scienta.2024.113164
- [61] Costa JS, Mello T, Fagundes DP, Silva TD, Araujo CP, Simões IM, et al. The spermidine promotes maturation and tissue differentiation of somatic embryos of *Euterpe edulis* Martius, an endangered Atlantic Forest species. In Vitro Cellular & Developmental Biology-Plant. 2024:1-12. DOI: 10.1007/s11627-024-10473-6
- [62] Euwens CJ. Mineral requirements for growth and callus initiation of tissue cultures. Physiologia Plantarum. 1976;**15**:473-497
- [63] Linsmaier EM, Skoog F. Organic growth factor requirements of tobacco tissue cultures. Physiologia Plantarum. 1965;**18**:100-127. DOI: 10.1111/j.1399-3054.1965.tb06874.x
- [64] Morel G, Wetmore RH. Fern callus tissue culture. American Journal of Botany. 1951;**38**:141-143. DOI: 10.2307/2437837
- [65] Oliveira LB, Mello T, Araujo CP, Oliveira JPB, Ferreira A, Zanardo TÊC, et al. Morphoanatomical aspects of auxin herbicides-induced somatic embryogenesis in *Euterpe edulis* Martius, a symbol and threatened species of the Atlantic Forest. Scientia Horticulturae. 2022;**299**:111051
- [66] Saldanha CW, Martins-Corder MP, Steinmacher DA, Guerra MP. In vitro morphogenesis of the zygotic embryos and leaf sheaths of *Euterpe edulis* Martius (*Arecaceae*). Crop Breeding and Applied Biotechnology. 2006;**6**:228-235. DOI: 10.12702/1984-7033.v06n03a07
- [67] Oliveira MSP, Carvalho JEU, Nascimento WMO. Açaí (*Euterpe oleracea* Mart.). Série Frutas Nativas. Jaboticabal, Brasil: Funep; 2000. 52 p
- [68] Henderson A. The genus *Euterpe* in Brazil. In: Reis MS, Reis A, editors. *Euterpe edulis* Martius (Palmitero) - Biologia, Conservação e Manejo, Herbário Barbosa Rodrigues. Itajaí, Brasil; 2000. pp. 1-22
- [69] Cymerys M, Shanley P. Açaí. In: Shanley P, Medina G, editors. *Frutíferas e Plantas úteis na vida Amazônica*. Belém, Brasil: CIFOR/Imazon; 2005. pp. 163-170
- [70] Rambo MKD, Schmidt FL, Ferreira MMC. Analysis of the

- lignocellulosic components of biomass residues for biorefinery opportunities. *Talanta*. 2015;**144**:696-703. DOI: 10.1016/j.talanta.2015.06.045
- [71] Cedrim PCA, Barros EMA, Nascimento TGD. Antioxidant properties of acai (*Euterpe oleracea*) in the metabolic syndrome. *Brazilian Journal Food Technology*. 2018;**21**:e2017092. DOI: 10.1590/1981-6723.09217
- [72] Lima LR, Costa OF, Alves BSF, Dantas KDGF, Lemos VP, Pinheiro MHT. Remoção de Cu (II), Zn (II) e Ni (II) utilizando resíduo de açaí (*Euterpe oleracea* Mart.) como biossorvente em solução aquosa. *Revista Virtual de Química*. 2020;**12**:1066-1078. DOI: 10.21577/1984-6835.20200086
- [73] Laurindo LF, Barbalho SM, Araújo AC, Guiguer EL, Mondal A, Bachtel G, et al. Açaí (*Euterpe oleracea* Mart.) in health and disease: A critical review. *Nutrients*. 2023;**15**:989. DOI: 10.3390/nu15040989
- [74] Nascimento WMO, Euterpe A, oleracea Mart. Informativo Técnico Rede de Sementes da Amazônia. Vol. 18. Belém, Brasil: Embrapa Amazônia Oriental; 2008
- [75] Ledo AS, Lameira OA, Menezes IC. Embriogênese somática e regeneração de plantas em açaizeiro. Vol. 34. Rio Branco: Boletim de Pesquisa-Embrapa; 2002. 22 p
- [76] Scherwinski-Pereira JE, Guedes RS, Silva RA, Fermino JR, Luis ZG, Freitas EO. Somatic embryogenesis and plant regeneration in açaí palm (*Euterpe oleracea*). *Plant Cell, Tissue and Organ Culture*. 2012;**109**:501-508. DOI: 10.1007/s11240-012-0115-z
- [77] MSP O, Lemos MA, Santos EO, Santos VF. Variação fenotípica em acessos de açaizeiro (*Euterpe oleracea* Mart.) para caracteres relacionados à produção dos frutos. *Boletim de Pesquisa e Desenvolvimento*. 1998;**209**:6-19
- [78] Dos Santos BLG, Gama JRV, Da Silva Ribeiro RB, Dos Anjos RKF, Gomes KMA, Ximenes LC, et al. Estrutura e valoração de *Euterpe oleracea* em uma floresta de várzea na Amazônia. *Advances in Forestry Science*. 2018;**5**:391-396. DOI: 10.34062/afs.v5i3.5701
- [79] MSP O. Biologia floral do açaizeiro em Belém do Pará. *Boletim de Pesquisa e Desenvolvimento*. 2002;**8**:26
- [80] Da Silva AO, De Lima Mera WYW, Santos DCR, De Souza DP, Silva CGN, Raiol LL, et al. Estudo da produção de açaí (*Euterpe oleracea* Mart): aspectos econômicos e produtivos baseados nos anos de 2015 a 2017. *Brazilian Journal of Development*. 2020;**6**:1629-1641. DOI: 10.34117/bjdv6n1-112
- [81] Maciel-Silva FW, Buller LS, Gonçalves MLMBB, Rostagno MA, Forster-Carneiro T. Sustainable development in the legal Amazon: Energy recovery from açaí seeds. *Biofuels, Bioproducts and Biorefining*. 2021;**15**:1174-1189. DOI: 10.1002/bbb.2222
- [82] Instituto Brasileiro de Geografia e Estatística (IBGE) [Internet]. Pesquisa Agrícola Municipal. Rio de Janeiro: PAM; 2022. Available from: <https://sidra.ibge.gov.br/tabela/5457> [Accessed: November 26, 2024]
- [83] Companhia Nacional de Abastecimento (CONAB) - Açaí - Análise Mensal - Dezembro 2020 [Internet]. Available from: <https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuário-e-extrativista/analises-do-mercado/historico-mensal-de-acai> [Accessed: November 26, 2024]

- [84] WMO N, JEU C, MSP O. Produção de mudas de açaizeiro a partir de perfílios. Comunicado Técnico. 2011;231:4
- [85] Martins CC, Nakagawa J, Bovi MLA, Stanguerlim H. Teores de água crítico e letal para sementes de açaí (*Euterpe oleracea* Mart.–Palmae). Revista Brasileira de Sementes. 1999;21:125-132. DOI: 10.17801/0101-3122/rbs.v21n1p125-132
- [86] Freitas EO, Silva-Cardoso IMA, Ferreira JCB, Costa FHS, Scherwinski-Pereira JE. Somatic embryogenesis in Açaí palm (*Euterpe oleracea* Mart.). In: Jain SM, Pramod G, editors. Step Wise Protocols for Somatic Embryogenesis of Important Woody Plants, Forestry Sciences. 2nd ed. Cham, Switzerland: Springer International Publishing; 2018. pp. 267-290. DOI: 10.1007/978-3-319-79087-9_22
- [87] Emons AMC. Somatic embryogenesis: Cell biological aspects. Acta Botanica Neerlandica. 1994;43:1-14. DOI: 10.1111/j.1438-8677.1994.tb00729.x
- [88] Fehér A, Pasternak TP, Dudits D. Transition of somatic plant cells to an embryogenic state. Plant Cell, Tissue and Organ Culture. 2003;74:201-228. DOI: 10.1023/A:1024033216561
- [89] Fehér A. Callus, dedifferentiation, totipotency, somatic embryogenesis: What these terms mean in the era of molecular plant biology? Frontiers in Plant Science. 2019;10:536. DOI: 10.3389/fpls.2019.00536
- [90] Silva-Cardoso IMA, Scherwinski-Pereira JE. Somatic embryogenesis as a tool for propagation of palm trees (Arecaceae): Principles, strategies and challenges. In: Bettaieb T, editor. Micropropagation of Ornamental Plants: Research and Practice. 1st ed. New York: Nova Science Publishers; 2018. pp. 139-194
- [91] Gaj MD. Factors influencing somatic embryogenesis induction and plant regeneration with particular reference to *Arabidopsis thaliana* (L.) Heynh. Plant Growth Regulation. 2004;43:27-47. DOI: 10.1023/B:GROW.0000038275.29262.fb
- [92] Isah T. Induction of somatic embryogenesis in woody plants. Acta Physiologiae Plantarum. 2016;38:118. DOI: 10.1007/s11738-016-2134-6
- [93] Freitas EO, Monteiro TR, Nogueira GB, Scherwinski-Pereira JE. Somatic embryogenesis from immature and mature zygotic embryos of the açaí palm (*Euterpe oleracea*): Induction of embryogenic cultures, morphoanatomy and its morphological characteristics. Scientia Horticulturae. 2016;212:126-135. DOI: 10.1016/j.scienta.2016.09.044
- [94] Jayanthi M, Susanthi B, Nandiganti MM, Mandal PK. In vitro somatic embryogenesis and plantlet regeneration from immature male inflorescence of adult dura and tenera palms of *Elaeis guineensis* (Jacq.). Springer Plus. 2015;4:1-7. DOI: 10.1186/s40064-015-1025-4
- [95] Fki L, Masmoudi R, Kriaâ W, Mahjoub A, Sghaier B, Mzid R, et al. Date palm micropropagation via somatic embryogenesis. In: Jain SM, Al-Khayri JM, Johnson DV, editors. Date Palm Biotechnology. Dordrecht: Springer; 2011. pp. 47-68. DOI: 10.1007/978-94-007-1318-5_4
- [96] Teixeira JB, Söndahl MR, Kirby EG. Somatic embryogenesis from immature inflorescences of oil palm. Plant Cell Reports. 1994;13:247-250. DOI: 10.1007/BF00233313

- [97] Abul-Soad AA. Micropropagation of date palm using inflorescence explants. In: Jain S, Al-Khayri J, Johnson D, editors. Date Palm Biotechnology. Dordrecht: Springer; 2011. pp. 91-117. DOI: 10.1007/978-94-007-1318-5_6
- [98] Rabéchault H, Martin JP. Multiplication végétative du palmier à huile (*Elaeis guineensis* Jacq.) l'aide de cultures de tissus foliaires. Comptes Rendus de l'Académie des Sciences. Vol. 283. Série D: Sciences Naturelles; 1976. pp. 1735-1737
- [99] Murashige T, Skoog F. A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiologia Plantarum*. 1962;15:473-497
- [100] Yokoo EY, Ramos LCS, Bovi MLA. Cultura de tecidos de híbridos e espécies de palmito no instituto agrônomo. *Boletim científico*. 1992;25 24 p
- [101] Oliveira MSP, Farias NJT. Cultivar BRS-Pará: açaizeiro para produção de frutos em terra firme. Comunicado Técnico. Vol. 114. Embrapa Amazônia Oriental: Belém; 2005. 4 p
- [102] Homma AKO. Extrativismo vegetal ou plantio: qual a opção para a Amazônia? *Estudos Avançados*. 2012;26:167-186. DOI: 10.1590/S0103-40142012000100012
- [103] Farias NJT. BRS Pai d'Égua: cultivar de açaí para terra firme com suplementação hídrica. Comunicado Técnico. Vol. 317. Embrapa Amazônia Oriental: Belém; 2019. 7 p
- [104] Plath M, Moser C, Bailis R, Brandt P, Hirsch H, Klein AM, et al. A novel bioenergy feedstock in Latin America? Cultivation potential of *Acrocomia aculeata* under current and future climate conditions. *Biomass and Bioenergy*. 2016;91:186-195. DOI: 10.1016/j.biombioe.2016.04.009
- [105] Henderson A, Galeano G, Bernal G. Field Guide to Palm of the Americas. New Jersey: Princeton University; 1995. 502 p
- [106] Lorenzi H, Noblick L, Kahn F, Ferreira E. Flora Brasileira: Arecaceae (Palmeiras). Nova Odessa: Instituto Plantarum; 2010. 384 p
- [107] Sorita GD, Favaro SP, Gambetta R, Ambrosi A, Di Luccio M. Macauba (*Acrocomia* spp.) fruits: A comprehensive review of nutritional and phytochemical profiles, health benefits, and sustainable oil production. *Comprehensive Reviews in Food Science and Food Safety*. 2025;24:e70097. DOI: 10.1111/1541-4337.70097
- [108] Pires PCL, César AS, Cardoso AN, Favaro SP, Conejero MA. Strategies to improve the competitiveness of an agroindustrial system for a macauba based oil production in Minas Gerais state, Brazil. *Land Use Policy*. 2023;126:106552. DOI: 10.1016/j.landusepol.2023.106552
- [109] Vargas-Carpintero R, Hilger T, Mössinger J, Souza RF, Barroso Armas JC, Tiede K, et al. *Acrocomia* spp.: Neglected crop, ballyhooed multipurpose palm or fit for the bioeconomy? A review. *Agronomy for Sustainable Development*. 2021;41(6):75. DOI: 10.1007/s13593-021-00729-5
- [110] Motoike SY, Nacif AP, Paes JMV. Macaúba: história do nascimento de uma cultura. *Informe Agropecuário*. 2011;32:6
- [111] Tabai SA. Propagação da palmeira macaúba *Acrocomia aculeata* (Jacq.) Loddiges. através de métodos in vitro [Dissertação]. Piracicaba: Universidade de São Paulo; 1992

- [112] Motoike SY, Lopes FA, Sá Junior AQ, Carvalho M, Oliveira MAR. Processo de germinação e produção de sementes pré-germinadas de palmeiras do gênero *Acrocomia*. Brasília, Brazil: Patent: PI0703180-7. Industrial; 2007
- [113] Pinheiro CUB. Germinação de sementes de palmeiras. Teresina: Embrapa-UEPAE; 1986. 102 p
- [114] Ribeiro LM, Souza PP, Rodrigues Junior AG, Oliveira TGS, Garcia QS. Overcoming dormancy in macaw palm diaspores, a tropical species with potential for use as bio-fuel. *Seed Science and Technology*. 2011;**39**:303-317
- [115] Ellis RH, Hong TD, Roberts EH. Handbook of Seed Technology for Genebanks: Volume 2: Compendium of Specific Germination Information and Test Recommendations. International Board for Plant Genetic Resources; Rome, Italy. 1985. 456 p
- [116] Bicalho EM, Pintó-Marijuan M, Morales M, Müller M, Munné-Bosch S, Garcia QS. Control of macaw palm seed germination by the gibberellin/abscisic acid balance. *Plant Biology*. 2015;**17**:990-996
- [117] Moura EF, Motoike SY, Ventrella MC, Sá Júnior AQ, Carvalho M. Somatic embryogenesis in macaw palm (*Acrocomia aculeata*) from zygotic embryos. *Scientia Horticulturae*. 2009;**119**:447-454
- [118] Luis ZG, Scherwinski-Pereira JE. An improved protocol for somatic embryogenesis and plant regeneration in macaw palm (*Acrocomia aculeata*) from mature zygotic embryos. *Plant Cell, Tissue and Organ Culture*. 2014;**118**:485-496
- [119] Granja MMC, Motoike SY, Andrade APS, Correa TR, Picoli EAT, Kuki KN. Explant origin and culture media factors drive the somatic embryogenesis response in *Acrocomia aculeata* (Jacq.) Lodd. Ex Mart., an emerging oil crop in the tropics. *Industrial Crops and Products*. 2018;**117**:1-12
- [120] Andrade AP, Motoike SY, Kuki KN, Queiroz V, Madeira DDC, Granja MMC, et al. Explant age and genotype drive the somatic embryogenesis from leaf explants of *Acrocomia aculeata* (Jacq.) Lodd. Ex Mart. (*Arecaceae*), an alternative palm crop for oil production. *Trees*. 2024;**38**:315-326
- [121] Meira FS, Luis ZG, Silva-Cardoso IMA, Scherwinski-Pereira JE. Developmental pathway of somatic embryogenesis from leaf tissues of macaw palm (*Acrocomia aculeata*) revealed by histological events. *Flora*. 2019;**250**:59-67
- [122] Meira FS, Luis ZG, Silva-Cardoso IMA, Scherwinski-Pereira JE. Somatic embryogenesis from leaf tissues of macaw palm [*Acrocomia aculeata* (Jacq.) Lodd. Ex Mart.]. *Anais da Academia Brasileira de Ciência*. 2020;**92**:e20180709
- [123] Padilha JHD, Ribas LLF, Amano E, Quoirin M. Somatic embryogenesis in *Acrocomia aculeata* Jacq. (Lodd.) ex mart using the thin cell layer technique. *Acta Botanica Brasilica*. 2015;**29**:516-523
- [124] Moura EF, Ventrella MV, Motoike SY, Sá Júnior AQ, Carvalho M, Manfio CE. Histological study of somatic embryogenesis induction on zygotic embryos of macaw palm (*Acrocomia aculeata* (Jacq.) Lodd. Ex Martius). *Plant Cell, Tissue and Organ Culture*. 2008;**95**:175-184. DOI: 10.1007/s11240-008-9430-9
- [125] Tenorio MLO, Prieto CMC, Univio NCL, Díaz DAR, Carvajal MXQ,

- Perez LNT, et al. Bioactive compounds in palm oil: A comprehensive review of recent advances in physicochemical characteristics, health-promoting properties and Technologies for Extraction, concentration, fractionation, encapsulation and functional food applications. *Journal of Food Composition and Analysis*. 2024;**132**:106306. DOI: 10.1016/j.jfca.2024.106306
- [126] Morcillo F, Gallard A, Pillot M, Jouannic S. EgAP2-1, an AINTEGUMENTA-like (AIL) gene expressed in meristematic and proliferating tissues of embryos in oil palm. *Planta*. 2007;**226**(6):1353-1362. DOI: 10.1007/s00425-007-0574-3
- [127] Carvalho M. Embriogênese Somática a Partir de Folhas Imaturas e Flores Desenvolvidas in vitro de Dendzeiro (*Elaeis guineensis* Jacq.) [thesis]. Viçosa: Universidade Federal de Viçosa; 2009
- [128] Ferwerda JD. Ecophysiology of the African oil palm. In: *Ecophysiology of Tropical Crops*. Elsevier; 1977. pp. 351-382
- [129] Brazilio M, Bistachio NJ, Silva VC, Nascimento DD. O Dendzeiro (*Elaeis guineensis* Jacq.)-Revisão. *Bioenergia em Revista Diálogos*. 2012;**2**(1):27-45
- [130] Barbour JA, Howe PRC, Buckley JD, Bryan J, Coates AM. Cerebrovascular and cognitive benefits of high-oleic peanut consumption in healthy overweight middle-aged adults. *Nutritional Neuroscience*. 2017;**20**(10):555-562. DOI: 10.1080/1028415X.2016.1204744
- [131] Benjumea P, Agudelo J, Agudelo A. Basic properties of palm oil biodiesel–diesel blends. *Fuel*. 2008;**87**(10-11):2069-2075. DOI: 10.1016/j.fuel.2007.11.004
- [132] Thuzar M, Vanavichit A, Tragoonrun S, Jantasuriyarat C. Efficient and rapid plant regeneration of oil palm zygotic embryos cv. ‘Tenera’ through somatic embryogenesis. *Acta Physiologiae Plantarum*. 2011;**33**:123-128. DOI: 10.1007/s11738-010-0526-6
- [133] Hasen SB, Padfield R, Syayuti K, Evers S, Zakariah Z, Mastura S. Trends in global palm oil sustainability research. *Journal of Cleaner Production*. 2015;**100**:140-149. DOI: 10.1016/j.jclepro.2015.03.051
- [134] FAO. World Food and Agriculture Statistical Yearbook 2022. Rome: Food and Agricultural Organisation; 2022. 382 p. DOI: 10.4060/cc2211en
- [135] Pádua MS, Paiva LV, Labory CRG, Alves E, Stein VC. Induction and characterization of oil palm (*Elaeis guineensis* Jacq.) pro-embryogenic masses. *Anais da Academia Brasileira de Ciencias*. 2013;**85**:1545-1556. DOI: 10.1590/0001-37652013107912
- [136] Vilela MSP, Andrade JC, Santos RS, Stein VC, Paiva LV. Histological analysis of indirect somatic embryogenesis induced from root explants of oil palm (*Elaeis guineensis* Jacq.). *Revista árvore*. 2019;**43**:e430106. DOI: 10.1590/1806-90882019000100006
- [137] Yusnita Y, Hapsoro DWI. In vitro callus induction and embryogenesis of oil palm (*Elaeis guineensis* Jacq.) from leaf explants. *HAYATI Journal of Biosciences*. 2011;**18**(2):61-65. DOI: 10.4308/hjb.18.2.61
- [138] Sulaksono G, Hasmeda M, Hanum L, Wendra F, Santika B. Effect of media and plant growth regulator on proliferation of somatic embryogenic callus of oil palm (*Elaeis guineensis* Jacq.). *Agrivita: Journal of Agricultural Science*. 2024;**46**(2):367-379. DOI: 10.17503/agrivita.v46i2.4234

- [139] Marbun CLM, Marbun CLM, Toruan-Mathius N, Reflini UC, Liwang T. Micropropagation of embryogenic callus of oil palm (*Elaeis guineensis* Jacq.) using temporary immersion system. *Procedia Chemistry*. 2015;**14**:122-129. DOI: 10.1016/j.proche.2015.03.018
- [140] Corrêa TR, Motoike SY, Coser SM, Silveira G, Resende MDV, Chia GS. Estimation of genetic parameters for in vitro oil palm characteristics (*Elaeis guineensis* Jacq.) and selection of genotypes for cloning capacity and oil yield. *Industrial Crops and Products*. 2015;**77**:1033-1038. DOI: 10.1016/j.indcrop.2015.09.066
- [141] Rajesh MK, Radha E, Karun A, Parthasarathy VA. Plant regeneration from embryo-derived callus of oil palm—the effect of exogenous polyamines. *Plant Cell, Tissue and Organ Culture*. 2003;**75**:41-47. DOI: 10.1023/A:1024679910085
- [142] Aberlenc-Bertossi F, Noirot M, Duval Y. BA enhances the germination of oil palm somatic embryos derived from embryogenic suspension cultures. *Plant Cell, Tissue and Organ Culture*. 1999;**56**(1):53-57. DOI: 10.1023/A:1006241215717
- [143] Saptari RT, Sinta MM, Riyadi S I. Enhancing the regeneration of TIS-derived somatic embryos of oil palm (*Elaeis guineensis* Jacq.) with CaCl₂ and GA3. *IOP Conference Series: Earth and Environmental Science*. 2024;**2024**:1308. DOI: 10.1088/1755-1315/1308/1/012005
- [144] Gomes HT, Machado LG, Bartos PMC, Balzon TA, Costa F, Azevedo V, et al. Somatic embryogenesis in oil palm from immature leaves with emphasis on leaf position, sequential callus re-collection, use of temporary immersion system, and assessment of genetic and epigenetic fidelity of the resulting clones. *Plant Cell, Tissue and Organ Culture*. 2024;**156**(2):32. DOI: 10.1007/s11240-023-02630-3
- [145] Corrêa TR, Motoike SY, Andrade APS, Coser SM, Queiroz V, Granja MMC, et al. Accelerated in vitro propagation of elite oil palm genotypes (*Elaeis guineensis* Jacq.) by substituting cytokinin with putrescine. *African Journal of Biotechnology*. 2016;**15**(50):2767-2775. DOI: 10.5897/AJB2016.15670
- [146] Konan KE, Durand-Gasselin T, Kouadio YJ, Flori A, Rival A, Duval Y, et al. In vitro conservation of oil palm somatic embryos for 20 years on a hormone-free culture medium: Characteristics of the embryogenic cultures, derived plantlets and adult palms. *Plant Cell Reports*. 2010;**29**:1-13. DOI: 10.1007/s00299-009-0787-y
- [147] Pais MS. Somatic embryogenesis induction in woody species: The future after OMICs data assessment. *Frontiers in Plant Science*. 2019;**10**:1-18. DOI: 10.3389/fpls.2019.00240
- [148] Parthasarathy U, Parthasarathy VA, Karun A. Oil palm. *Biotechnology of Horticultural Crops*. 2001;**1**:595-608