Macaw palm (Acrocomia spp.)

An opportunity for including smallholders in Brazil's biodiesel production

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Macaw palm (*Acrocomia* spp.): An opportunity for including smallholders in Brazil's biodiesel production

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ABSTRACT

Promoting inclusive development through public policies is a complex task that presents different challenges and even controversies. The National Program for Biodiesel Production and Use (PNPB) in Brazil is one example of an effort to promote sustainable development within an inclusive strategy with good intentions but many challenges. One of the PNPB goals is to diversify feedstocks for biodiesel production, and oils from the *Acrocomia spp.* palm genus have the potential to meet this goal. As acrocomia's value chain is under development in Brazil, particularly with a focus on the macaúba palm (*Acrocomia aculeata*), and in different regions of Latin America, we state that it is possible to develop it with the inclusion of smallholder farmers. In this sense, this paper focuses on analyzing the challenges and opportunities for smallholder productive inclusion in the value chain. Our main question is: How can the participation of smallholders in the cultivation of macaw palm be promoted? The answer to this question is based on literature and field research carried out by the authors. Our study finds opportunities for inclusion, but also four main challenges to be considered with caution: i) the shift from agroextractivism to commercial plantations, ii) the limited acreage available to some small farmers, iii) the slow pace in generating economic results, and iv) negative past experiences with other crops. We emphasize the importance of development strategies that offer incentives, mitigate risks, and guarantee greater security in decision-making for those involved. The available literature about the acrocomia value chain focuses mainly on technical and agronomic aspects, with few outputs on inclusion. In this sense, this paper calls attention to the development of the novel biobased value chains from the acrocomia palm without leaving social responsibility behind.

1. Introduction

Productive inclusion of smallholders in value chains can be used as a strategy towards poverty alleviation and resilient and inclusive development (Gupta et al., 2015). In developing countries, poverty is generally concentrated in rural areas and many smallholders are vulnerable and face socioeconomic exclusion (Barbier and Hochard, 2018). The productive inclusion of this group of farmers, especially when combined with social protection policies, may contribute to reducing poverty by generating employment and income opportunities (Vicol et al., 2018; Vollmer et al., 2017).

In Brazil, the National Program for Biodiesel Production and Use (PNPB) seeks to promote the diversification of feedstocks for biodiesel production combined with the productive inclusion of smallholders (Ribeiro et al., 2018). *Acrocomia* spp., also known as macaw palm, particularly the species *Acrocomia aculeata*, native to Latin America, emerged as a potential feedstock to meet these goals. Besides presenting the potential to reach similar oil productivity of the African oil palm

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(Elaeis guineensis),[1] and higher oil productivity compared to other oilseeds such as castor and soybeans (Colombo et al., 2018), the macaw palm is already part of the local culture in different regions of the country. Especially in the state of Minas Gerais, significant natural populations of *A. aculeata* are found in the Cerrado biome in the regions of Alto Paranaíba, Zona Metalúrgica, and Montes Claros (Motta et al., 2002). Macaw palm fruits are used in these regions for the production of animal feed, cooking oil, soap, and charcoal from the endocarp (Lobo et al., 2013). In this sense, promoting the use of this palm is a possibility for improving the already existing strategy of exploitation of the palm tree to meet the biodiesel market demands for oil with social responsibility.

This potential, however, is not naively addressed in the literature. Challenges related to the lack of technological packages and financing lines compatible with the crop were identified by Moreira and Souza (2010), for example. To make macaw palm viable to meet the biodiesel market demands, further studies and analyses are necessary (Faria, 2024). As the acrocomia value chain in Brazil is under development, there is room to shape it in an inclusive way, giving opportunities for smallholder farmers. Thus, this study aims to identify opportunities and challenges for the development of the acrocomia value chain for biodiesel production in Brazil with the inclusion of smallholder farmers.

The economic exploitation of this palm tree is fundamentally based on agroextractivism, which is the extraction of available resources from nature as a strategy to generate extra income[2] (Wunder, 1999). During agricultural off-seasons, farmers often seek alternative sources of income. In many areas, one alternative is agroextrativism (Zelt, 2018). In the north of Minas Gerais state in Brazil, for example, 400 families engage in collecting macaw palm fruits in natural forest areas, reaching 450 tons per year (CooperRiachão, 2024). This livelihood option is temporary and has certain limitations. First, it is impossible to predict the quantity of available fruits. Second, there are logistical difficulties, as long distances must often be covered. Third, quality can be compromised, as overripe fruit found on the ground and fruits that are not ready for harvest are collected. Fourth, land ownership in areas where the palm naturally grows can limit the access to fruit collectors.

Cultivations of acrocomia based on tailored agronomic practices, high-quality planting material and improved varieties have the potential to ensure more productive palm trees, more efficient cropping systems, standardization of row spacing, harvest scheduling, income security, and job generation for smallholders (Plath et al., 2016). In addition, the cultivation of macaw palm on the farmers' lands can reduce the logistical difficulties of agroextractivism. Nonetheless, commercial plantations in Brazil are at the initial stages of development, since the macaw palm is still being domesticated and improved (Colombo, 2018; Lobo, 2024; Vargas-Carpintero et al., 2021), and the shift from agroextractivism is a complex process. From 2018 to 2021, around 1750 hectares with acrocomia were established in Brazil, reaching 2000 hectares by 2022 in silvopastoral systems (Vargas-Carpintero et al., 2022; Favaro and Rocha 2022), with few initiatives including smallholder farmers. The challenges of this transition are discussed in this paper, since failure may affect the productive inclusion of smallholders in this value chain under development. Thus, the productive inclusion of smallholders in the biodiesel value chain based on acrocomia in Brazil is largely dependent upon the success of the transition from agroextractivism to cultivation and the farmer's adaptation to cultivation systems of this crop.

Moreover, the development of new and innovative value chains requires new governance structures involving different sectors and stakeholders. Thus, we pose the question: How can the participation of smallholders in the cultivation of macaw palm be promoted? The focus of this work is to analyze the challenges and opportunities for the productive inclusion of smallholders in the acrocomia value chain in Brazil based on the available literature and field research carried out by the authors. We state that the successful productive inclusion of smallholders in the acrocomia value chain is constrained by market incentives and strongly depends on governmental commitment and support to unlock structural constraints and offer incentives.

Public support is especially relevant for the development of the chain in at least four dimensions: i) research, ii) financing (credit and subsidies), iii) development of technologies for genetic improvement, harvesting, and processing, and iv) stable regulation. A tripartite governance model (Hatanaka et al., 2012), involving the state, entrepreneurs/investors, and smallholders, has the potential to develop these four dimensions and guarantee greater security in decision-making for those involved. Taking a multidimensional approach to meeting the needs of Brazilian smallholders is also key. Providing access to education, infrastructure, technical assistance, inputs, technologies, and markets must be complementary actions.

This paper is divided into seven sections, including this introduction. In the second section, we explain the methodology of this research. In the third section, we present our definition of productive inclusion and give some examples of smallholder inclusion in value chains. The characteristics of Brazilian smallholders are also presented. The fourth section presents the general characteristics of the macaw palm in Brazil. The fifth presents the main findings of the field research carried out by the authors. In the sixth section, we discuss the importance of distributing the economic risks between the stakeholders, based on the literature and field research. Concluding remarks are presented in the seventh section.

2. Material and methods

This research combines a literature review with qualitative interviews. This approach allowed us to gather perceptions and generate new insights on the development of an innovative value chain with the inclusion of smallholders. Interviewees were identified through purposive sampling, which is the selection based on criteria settled by the researcher (Jupp, 2006). The main goal of purposive sampling is to focus on particular characteristics of participants, which supports the comprehension of the research problem. Usually, the sample is small, mainly if compared with probability sampling (Guarte and Barrios, 2006). The research is approved by the Brazilian Research Ethics Committee under protocol number 44271321.4.0000.8142. To safeguard the rights of the participants and to comply with confidentiality obligations, neither the names of the initiatives visited nor the interviewees can be disclosed.

Eighteen interviews based on in-depth semi-structured questionnaires (Appendix A) were conducted in 2020.[3] This small, purposive sample, was chosen to focus on depth in the qualitative analysis rather than seeking statistical representativeness. The criteria for selection of stakeholders for interviews were: i) relevant research on the

[1] In Brazil, one hectare of African oil palm yields approximately 5 tons of oil/ha-[1] per year (Jardine, Barros, 2021). Colombo et al. (2018) presented a conservative and optimistic scenario where macaw palm with selection could be even more productive per hectare than African oil palm in Brazil.

[2] Agroextravism consists of the extraction of available resources from nature for subsistence, as in the case of non-timber forest products. Historically, agroextractivism in Brazil is a strategy employed by traditional populations to generate extra income (Wunder, 1999). We consider that the shift from agroextractivism to cultivation should not neglect the importance of this activity as a livelihood option, particularly in areas with abundant natural populations of acrocomia, where it can be used as a non-timber forest product and balance ecosystem conservation and livelihood diversification.

[3] The interview process was impacted by the Covid-19 pandemic. The field research was being performed and had to be halted to comply with sanitary regulations and ensure everyone's safety. Nevertheless, the purposive sampling remained effective for capturing diverse perspectives.

development of acrocomia value chain in Brazil, ii) participation/leadership in projects/business of acrocomia cultivation, iii) non-participation in projects/business of acrocomia cultivation, iv) interest and availability to participate in the research. The profiles of interviewees were: researchers, businessmen, representatives from public and private sectors, smallholders, and representatives from their organizations, such as cooperatives and unions (Appendix B). Each interview lasted an average of one hour, and questionnaires were adapted according to the profile of the participants. Questionnaires are available in the appendices.

One interview was conducted online, in the phase of testing questionnaires. The content of this pilot interview is included in this research. Seventeen interviews were performed face to face, in a field research. The field research was carried out by four researchers in March 2020, in the Brazilian state of Minas Gerais, home to native acrocomia palms and pioneering cultivation. Projects and businesses of acrocomia cultivation were characterized by the presence and absence of smallholder productive inclusion. The state also offered diversified business models, from cooperatives to strictly research-focused initiatives. The interviews were transcribed and analyzed using thematic analysis through the software MAXQDA, a qualitative data analysis tool that allows the encoding of excerpts from the interviews' transcripts.

The findings from the interviews are complemented by secondary data reported in scientific literature and Brazilian public institutions selected for the object of study. The literature research (Appendix C) was conducted using three scientific literature databases: Scopus, Scielo, and Web of Science. Secondary data were collected from the official sources of the Brazilian government, such as the Brazilian Institute of Geography and Statistics.

3. Smallholder productive inclusion in biobased value chains

There is potential to include smallholders in biobased value chains, developing roles such as producers, traders, processors, retailers, and consumers (Mishra and Dey, 2018). Most of these actors are poor, depend on outdated technology, and are excluded from dynamic value chains (Ma and Sexton, 2021; Ola and Menapace, 2020). For them, productive inclusion in value chains is an opportunity for poverty alleviation (Ros-Tonen et al., 2019; Vos and Cattaneo, 2021) and accruing higher income levels. Value chains can transform livelihoods, especially in developing countries (Asveld et al., 2021; FAO, 2021). However, due to structural challenges, smallholder inclusion in dynamic agro-industrial value chains is a major challenge (Manda et al., 2020).

The term productive inclusion is not directly addressed in the literature and the difficulty to define it is recognized (Souza, 2013). The few structured definitions available focus on tangential aspects such as employment, income, and poverty (Mariotti et al., 2016). In this sense, Vahdat et al. (2019) carried out a systematic literature review and, based on the main findings, developed a definition for productive inclusion: "promotion of stable and decent job and income generation for populations facing poverty and/or social vulnerability, in order to facilitate the overcoming of chronic processes of social exclusion" (Vahdat et al., 2019, p. 21). In this paper we adopted this definition, adding the importance of a fair distribution of economic risks (Asveld, 2021; Stern and Stiglitz, 2021). By productive inclusion, we therefore mean the promotion of stable and decent jobs and the creation of income generation, whereby the economic risks are distributed fairly among those involved.

Brazil has some examples of interventions developed to promote smallholder productive inclusion in biobased value chains. One example is the National Program for Biodiesel Production and Use (PNPB). Created in 2004, the objective was to include biodiesel in the energy matrix, promoting the development of vulnerable regions, diversifying feedstocks, and including smallholders in the value chain (Marcossi and Moreno-Pérez, 2018). The first projects carried out in the North and Northeast regions focused on developing the castor bean value chain by promoting its commercial cultivation (Conejero et al., 2017). Nevertheless, aspects such as low productivity, increasing irregular droughts, inadequate management, among other organizational issues constrained the production of castor beans in these regions (Conejero et al., 2017; César and Batalha, 2010).

The example of PNPB shows that interventions aimed at promoting productive inclusion and alleviating poverty may face several controversies. In the Northeast of Brazil, the pilot intervention in the state of Piauí focused on the cultivation of castor beans [*Ricinus communis* L.] faced resistance from local social movements, which did not approve the business models that were based on integration with private companies. In addition, castor beans were not traditionally grown by the farmers in the area and proved to be economically unviable for biodiesel production (Conejero et al., 2017). Castor bean produces a highly valued oil, which is expensive and not the most suitable for the biodiesel value chain. Besides, the limited scientific and technological development to promote large-scale commercial production and supply for the biodiesel market added several challenges to the intervention. Productivity was low and significant losses were generated. The intervention was controversial because it intensified the vulnerability of the smallholders involved (Flexor et al., 2011; Kato, 2012).

Therefore, the main reasons for the failure to develop the castor bean [*Ricinus communis* L.] value chain for biodiesel with the inclusion of smallholders relate to at least five dimensions: i) structural-historical problems in the regions, ii) fragile scientific-technological development, iii) economic viability, iv) limited availability of financial and human resources, and v) weak monitoring. Among the historical structural problems is the agrarian structure. In the Northeast, 65 % of the total establishments had less than ten hectares and were classified as smaller than the minimum size to support at least one family (IBGE, 2017). Furthermore, climatic risks, especially in the semi-arid region, resulted in major fluctuations in the total planted area between the different crops, such as castor bean and sunflower [*Helianthus annuus* L.] (Mattei, 2004). Scientific and technological development was unable to develop the necessary responses to face the climate risk and increase productivity (Sampaio, 2017). Regarding economic viability, low production scales and high production costs, logistical difficulties, and high price volatility were evident. The lack of cooperatives between farmers limited access to technologies, knowledge, inputs, and markets.[4] The presence of middlemen for market access imposed economic dependence. The Ministry responsible for the operationalization of the policy was newly created and had too few resources and employees to provide technical assistance services. This also resulted in weak monitoring, which hindered the consolidation of routines and knowledge building (Marcossi and Moreno-Pérez, 2018; Sampaio, 2017).

Since, the PNPB goal to diversify feedstocks for biodiesel was not fully achieved, as soybean [*Glycine* max *(*L.*) Merr.*] oil dominated the biodiesel market. A dynamic soybean value chain with significant scientific and technological development was already established (Marcossi and Moreno-Pérez, 2018), which hampered the competitiveness of new feedstocks. This argument is related to the Theory of the Infant Industry (Shafaeddin, 2000), which posits that emerging industries may struggle to compete against well-established sectors without initial protection or support. In this context, nascent feedstock industries face difficulties in gaining market share due to the entrenched dominance of the soybean industry. The significance of soybean oil for biodiesel production is sustained through time, representing over 70 % of the raw material used for biofuel production (dos Santos Alves et al., 2017).

Despite the initial setbacks, the interest in the development of alternative feedstock as a long-term strategy must not be neglected. In this context, the acrocomia palm, locally known as "macaúba", was

[4] Those challenges were also identified by Mutonyi (2019) as barriers to smallholder inclusion.

prioritized and fostered in Minas Gerais through the "pro-macaúba law" (Law N° 19.485/2011) as a crop to contribute to the supply of renewable energy while benefiting agricultural diversification, local development, and inclusion of smallholder farmers in the acrocomia value chain (Minas Gerais, 2011). Given the risks and uncertainties involved in the development of a new value chain, it is necessary to look at the lessons learned from other interventions, such as those promoted by PNPB, and strengthen public policies. An important prerequisite for dealing with the associated risks and uncertainties is to understand the local context and involve local stakeholders (Asveld, 2021).

3.1. *Who are the smallholders in Brazil, and why is it relevant to include them?*

In Brazil, smallholders are mostly recognized as family farmers. In the international context, there is no single definition of family farming, although some general parameters are used to guide the delimitation of the concept, at least for public policy purposes (Guanziroli et al., 2020). Brazilian family farmers as a target group for public policies is a category defined by Law 11.326, created in 2006.

As a result, family farming in Brazil must follow four main parameters: i) the labor force employed in the establishment must be predominantly familiar; ii) the farm must be set up as a small property, with a maximum of four fiscal modules[5]; iii) the family's income must originate predominantly from the family farm; and iv) the management of the farm must be carried out by the family (Presidency of the Brazilian Republic, 2006). The table below presents some data on Brazilian family farming: (Table 1).

Brazilian family farmers constitute a heterogeneous group related to several dimensions, such as education, professional experience, access to technologies, capital, and markets. In addition, there are structural differentiations regarding organization (individual production, cooperative or associative) and access to land (Guanziroli et al., 2019). In this sense, some smallholders are integrated into dynamic and technologically demanding value chains, while others live in vulnerable situations with no access to basic resources. These heterogeneities also reflect the different levels of development between Brazilian regions and their historical-structural characteristics (Maia et al., 2020; Medina et al., 2021). Consequently, different solutions are required according to the characteristics of farmers.

Brazilian smallholders were historically excluded from policies and interventions, since the agricultural modernization process in the 1970s favored medium and large-scale farmers (Guanziroli et al., 2013; Gutberlet, 2010). With the strengthening of rural workers' unions and social movements after the end of the dictatorial period in the middle of the 1980s, smallholders began to voice their demands (Ghinoi et al., 2018). The first national program aimed at small-scale farmers was launched in 1996 (Flexor and Grisa, 2016; C. Guanziroli et al., 2013). Since then, many policies have been developed. However, the inclusion of such a large and heterogeneous group remains one of the main challenges for policymakers.

Table 1
Brazilian family farming in numbers.

Number of establishments	3897,408 (77 % of total rural establishments)
Area (hectares)	80,891,084 (23 % of the total area of agricultural establishments)
Average size of establishments	20.76 hectares*
Occupation of labor	10.1 million people (67 % of total occupation of rural labor)

* The average size of non-family farming establishments in Brazil is 229,95 hectares.

Source: (IBGE, 2017).

[5] Fiscal module is a unit of measurement, in hectares. The value of each module is determined by municipality considering the local characteristics, such as predominant and relevant type of exploitation (fruit and vegetable, permanent culture, temporary culture, livestock or forestry). The value of fiscal modules in Brazil ranges from 5 to 110 hectares (National Institute of Colonization and Agrarian Reform, 2021).

4. Acrocomia in Brazil

In Brazil, mainly *A. aculeata* is found. Acrocomia palms mostly appear in pastures and open forests, disturbed areas such as secondary forests, degraded grasslands, and tilled land, and along roads (de Lima et al., 2018). Advantages of this palm include its broad existing and potential broad product range, which allows multipurpose use, and the already existing traditional use by local communities (Cardoso et al., 2017; Vargas-Carpintero 2018; Vargas-Carpintero et al., 2021). As the properties of acrocomia oils, both from pulp and kernel, are similar to those of the African oil palm, it can be used as an alternative to these oils in various markets, such as biodiesel, cosmetic, food industries, and industrial applications (CIF, 2020). As mentioned previously, acrocomia is part of the diversification strategies for family farmers, who practice the agroextractivism of the fruits. The Brazilian Agricultural Census (IBGE, 2017) presents some data about acrocomia agroextractivism in the country, revealing that the total number of farms engaged in acrocomia agroextractivism in Brazil is 480. Of this total, 340 farms are classified as family farming establishments.

Regarding the regional distribution of farms engaged in acrocomia agroextractivism in Brazil, Fig. 1 shows that most are located in the North region (293), followed by the Central-West (84) and the Southeast (66). There are no records of farms engaged in acrocomia agroextractivism in the South (IBGE, 2017).

The table below presents data regarding the amount produced and sold by these farms:

The Minimum Price Guarantee Policy for sociobiodiversity products is an incentive for the agroextractivism of acrocomia in Brazil. Because of this policy, small-scale farmers can use sales invoices to receive the difference between the market price and the established minimum price. The minimum price established for acrocomia are 0.074 and 0.082 U.S. dollars per kg, according to the region (National Supply Company, 2021). This policy instrument aims to provide a market reference for extractivists and reduce variations in income. The Law 19.485 ("Pró-macaúba"), established by the government of the state of Minas Gerais, encourages the cultivation, extraction, commercialization, consumption, and transformation of acrocomia. It also encourages the

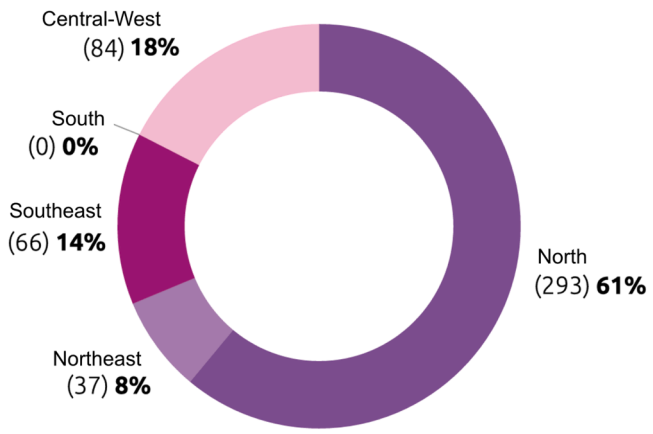

Fig. 1. Number of farms engaged in acrocomia agroextractivism in Brazil by region
Source: Favaro, Guiducci, 2023.

creation of joint cooperations between farmers and the industry, and technical improvement (Minas Gerais, 2011). Table 2 shows that in 2017 48.1 % of acrocomia production was sold, totaling 64 tons. The remaining 51.9 % (approximately 69 tons) may have been allocated for self-consumption, stored for future sales, or used in other forms of processing.

Besides the strategies to promote the productive inclusion of smallholders into the acrocomia value chain by fostering agroextractivism, cultivation strategies are also being developed. Brazil leads the plant genetic and agronomic research of this palm, mainly of *A. aculeata*, leading to relevant advances in seed germination, propagation, plant breeding, among other key areas that allow its semi-domestication and initial cultivation (Bergmann et al., 2013; Ribeiro et al., 2018; Vargas-Carpintero et al., 2021). Lopes et al. (2013) concluded that biodiesel plants based on acrocomia with integrated oil mill and alkaline transesterification are profitable. However, the complete domestication of the plant and improvements in industrial processes are fundamental. For at least the past two decades, Brazilian federal and state agencies, entrepreneurs, and large businesses supported the development of the acrocomia value chain as an alternative crop for the biodiesel sector (Lopes et al., 2013). Such support has been given to scientific research, the development of technological innovations, knowledge for domestication,[6] and the inclusion of different stakeholders. (Bhering, 2007; Franco and Zimpel, 2020; Paes et al., 2011; Pires et al., 2013). In 2009, a germplasm bank was created by the Federal University of Viçosa, in the state of Minas Gerais, containing genetic material of *Acrocomia* species from almost all regions of Brazil. This germplasm bank is one of the largest collections in South America (Vargas-Carpintero et al., 2021).

The species *A. aculeata* has great cultivation potential in regions with unfavorable climatic conditions or poor-quality soils, such as the Brazilian savanna (Cerrado biome). In the Brazilian savanna, which covers 24 % of the country's territory, the climate is usually dry, and the soil is largely nutrient-poor, affected by erosion with signs of poor fertility (Andrade et al., 2017). This biome contains the largest pasture area in the country and concentrates about 55 % of all Brazilian cattle production. Studies showed that at least 39 % of the biome's pastures are degraded (Fernandes et al., 2018; Pereira et al., 2018).

Hence, its cultivation in silvopastoral[7] systems shows promising potential, allowing local producers to maintain cattle farming as a dominant economic activity while contributing to the livelihoods of rural farmers and the recovery of the biome (Costa et al., 2018; Moraes et al., 2019). According to Fortini (2021), about 58 % of all family farms in Minas Gerais report livestock raising in their farms, representing almost 73 % of the total area of family farms.

The diversification of cropping systems can lead to a lower dependence on a single product market. In this sense, it is possible to earn extra income that will not harm the main business but may, in fact, benefit it (César et al., 2015). As the acrocomia harvest occurs after the coffee harvest, income opportunities are created in the off-season. Workers who chose to integrate the acrocomia harvest in the off-season earned more than twice the minimum wage and more than for alternative jobs (Averdunk et al., 2014; Moreira et al., 2018).

Table 2
Acrocomia agroextractivism in Brazil - amount produced and amount sold (2017).

	Family farming	Other farms (non-family)	Total
Amount produced* by the acrocomia agroextractivism practice (ton of fruits)	104	29	133**
Amount sold by the acrocomia agroextractivism practice*** (ton of fruits)	61	3	64

* IBGE considers the quantity produced or obtained during the period of reference, including the production delivered to partners and workers as payment for services provided to the farm.

** A number that may be underestimated due to the difficulty in accounting for fruit collection by extractivists (Favaro, Guiducci, 2023).

*** The amount sold takes into account the production transferred to other farms of the producer or amount delivered to partners and employees as payment for services rendered. The quantity transferred to other units of the producer for storage, which remained there as of the reference date, is not considered as amount sold.

Source: Brazilian Institute of Geography and Statistics, 2017, Table 6949.

5. Case study in Brazil: the potential of acrocomia for productive inclusion of smallholders

To answer the question "how can the transition with the inclusion of smallholders be accelerated?", a field study was performed and the perceptions of interviewed stakeholders analyzed. In the next subsections, we explore four critical topics to be taken into account. First, we explore the complex transition from agroextractivism to commercial cultivation of acrocomia. It sheds light on the challenges and opportunities associated with this transition. Other critical topics discussed include land size constraints, the extended time required for the palm tree to yield fruits, and the lingering skepticism of smallholders due to negative experiences with similar initiatives in the past. We also identify potential strategies to accelerate smallholder inclusion, such as involving local leaders, providing practical demonstrations, and offering purchase guarantees to instill trust.

5.1. From agroextractivism to cultivation

In Brazil, acrocomia is already exploited by smallholders in agroextractivist systems. As it is already part of their culture, some interviewees indicated that it would not be difficult to include cultivation into current business models, in public or private projects. However, other interviewees mentioned the difficulties in moving to cultivation. Agroextractivism in Brazil is characterized as an activity performed by low-income farmers, usually in regions with the greatest pockets of poverty and social inequalities in the country (Carvalho and Gomes, 2009). Generally, these farmers make low capital investments and use simplified technologies, relying predominantly on manpower to extract and transport the fruits (Pageù et al., 2015). Historically, agroextractivism has represented a source of extra income without added production costs, and thus is an activity rooted in the culture and tradition of these populations (Lôbo et al., 2013). This type of exploitation is suited to the production system of small-scale farmers, usually characterized by intense labor seasonality (Carvalho and Gomes, 2009). Thus, the opportunity cost of labor in agroextractivism is low.

A small-scale farmer can collect on average one ton of acrocomia fruits per day in an agroextractivist system in areas with dense populations of acrocomia (Franco and Zimpel, 2020). However, the daily collection capacity of small-scale farmers in agroextractivist systems can vary significantly. Vargas-Carpintero (2018) found that Paraguayan farmers collect approximately 33 kg per hour, totaling around 250 kg over an 8-hour workday. This result may be attributed to factors such as longer distances between palms and lower palm densities in Paraguay. The amount of time dedicated to collecting fruits by agroextractivism is

[6] Based on a systematic literature review, Vargas-Carpintero et al. (2021) presented the state-of-the-art in acrocomia's research worldwide and identified research gaps. The main research gaps are related to genotype and environment interaction, planting material, crop management, and sustainable cropping systems.

[7] One of the types of agroforestry systems. In this productive system, trees and pastures are placed in the same area (Lüdeke-Freund et al., 2012).

also directly influenced by the farming and livestock rearing demands in the establishments. In other words, during soil preparation, planting, cultural treatments, and harvesting, as well as activities related to livestock management such as feeding, herding, and ensuring animal health, acrocomia agroextractivism is not the focus of smallholders (Cardoso et al., 2020). In the field research, various interviewees affirmed that logistical issues in acrocomia fruits collection have implications for the quality of the oil. As native acrocomia is located out of the farmer's establishments, and often far away, in agroextractive harvesting, all available fruits are collected at once: including fruits that have fallen to the ground and those that are not yet ripe. Thus, the fruits do not pass through a selection process before harvesting. This compromises the quality for higher-value uses, such as for the cosmetic industry and biodiesel production.

One of the visited initiatives from the private sector started cultivating acrocomia in 2007, without including small-scale farmers.[8] Acrocomia cultivation in smallholdings has been associated with potential socioeconomic advantages and opportunities for income generation (Mössinger, 2020; Averdunk et al., 2014; Vargas-Carpintero 2018; Vargas-Carpintero et al., 2022). Interviewees corroborated this potential adding that it is possible to include resource-poor farmers in acrocomia cultivation. These farmers are considered vulnerable due to limited access to resources such as land, capital, and/or technology. Acrocomia cultivation is particularly suitable for these contexts because the crop requires little maintenance, low technology, presents high resistance, and grows in poor-quality soils. However, the shift from agroextractivism to cultivation is not simple. First, it requires a change in the smallholders' usual exploitation system. It implies production costs, use of part of the land, time, and work processes. Second, the size of some smallholdings reduces economies of scale, and integration with pastures may affect the viability of integrating acrocomia with livestock production in properties that do not have sufficient space to isolate livestock from newly planted palms. Four interviewees highlighted those challenges. In the literature, a study conducted in South-East Paraguay demonstrated that smallholders face considerable obstacles when cultivating acrocomia due to land constraints and the need for substantial changes in land-use practices (Mössinger, 2021).

5.2. Size of the plot of land

Feasibility analysis strongly recommends integrating the cultivation of acrocomia with pastures (Averdunk et al., 2014; Cardoso et al., 2017). Two of the interviewees, however, explained that in the first three years of planting, the palm tree is extremely palatable to the herd. Thus, it is necessary to isolate the cattle until the fourth year. The five interviewed small-scale farmers did not have cattle on their lands. They were planting food between the rows of plantations, intercropping mainly with corn, watermelon, and peanuts. However, a very small property that survives exclusively on livestock[9] would probably lack the space to isolate cattle in the first years of macaúba growing. In this sense, acrocomia cultivation in consortium with pastures can be constrained in smallholders' farms.[10] Possibilities to enable this integration include the partial cultivation of macaúba on the farm, ensuring space for cattle.

5.3. Beginning of the plant's production phase

There is an important implication for acrocomia cultivation at the beginning of the production phase of the palm tree. Newly planted acrocomia trees only produce fruit after five years and reach full production in the tenth year (Visconti and Watson, 2013). The slow pace in generating economic results was one of the reasons highlighted by two interviewees for decreasing smallholders' interest in planting the palm tree. We also identified in the field research that due to the palm's maturation period, contracts with partners and financiers are long-term. In the interviews, we identified that many of the smallholders in the studied region, in general older farmers, would not commit to these long contracts. One of the initiatives from the private sector promoting the cultivation of acrocomia and that was involved in the study applied a 20-year contract to guarantee an adequate internal rate of return. As part of the contract, the necessary inputs and technical advice are provided by the company to farmers for the start and development of acrocomia cultivation. Among the small-scale farmers in the negotiation process with one of the private sector initiatives included in this study, 16 % did not commit to the partnership because of the long-term contract. The maturation period of the palm tree also impacts the financing of initiatives. In addition to the need for first movers to invest in a future market in the present (Poetsch et al., 2012), capital gains are long-term. A suitable and stable regulation is therefore required that offers guarantees to all parties involved.

Subsidies and assistance offered to family farmers during the plant's non-productive period could mitigate the risk of having no income, particularly in cases where there are no other economic activities within the establishment. In addition to technical assistance, one of the private sector initiatives visited provided a symbolic financial incentive for smallholders to take care of the cultivation. In another case, an interviewee from the public sector planned to attract small-scale farmers by offering financial subsidies and infrastructure for properties, such as access to water during acrocomia's non-productive period. In this second case, the benefits to producers would be provided by the government, while in the first case, the responsibility lies with the private sector, financed by resources from an international development institution.

5.4. Past experiences

Several interviewees mentioned one particular negative experience in the region, in which an outside enterprise stimulated the production of castor beans but faced problems when outsourcing the processing. The enterprise abandoned the municipality and many farmers suffered losses. Because of experiences such as this, new initiatives stimulating acrocomia cultivation, especially from companies, cause distrust among farmers. Negative past experiences were also a barrier identified by Palmeros Parada et al. (2017).

To deal with small-scale farmers' reluctance to adhere to acrocomia cultivation due to negative past experiences, two interviewees from the private sector and one from the public sector who were promoting inclusion were considering and/or applying the following strategies: i) gather support from local leaders, ii) provide examples in the form of prototype farms, which were described as a way to showcase best practices and potential benefits in real-world scenarios, iii) utilize processing plants owned by farmers' cooperatives, public or private initiatives, iv) implement purchase guarantees. The most important strategy identified was the involvement of local leaders, such as presidents of agricultural cooperatives, heads of community associations, or highly experienced and influential farmers, given the communities' trust in them. Two interviewees leading acrocomia cultivation projects pointed out the high initial cost of identifying the leadership and forming partnerships. This initial effort, however, was seen to facilitate the adhesion process of smallholders from the surrounding areas, generating a snowball effect.

[8] When the field research was performed, only one initiative included smallholders in cultivation projects. Another initiative was planning to start acrocomia cultivation with the inclusion of smallholder farmers.

[9] Brazilian family farming holds 31% of the number of cattle and is responsible for 64.2% of milk production. These farmers are concentrated in the South and Southeast regions of the country, particularly in the states of Minas Gerais, Paraná, Rio Grande do Sul, and Santa Catarina (IBGE, 2017).

[10] The average size of the properties of the interviewed farmers who planted macaúba was 57.5 hectares. Establishment sizes of the interviewed farmers varied from between 2 and 100 hectares.

6. Distribution of economic risk

As previously discussed, the development of new value chains poses a number of challenges (some of which are associated with risks), and the productive inclusion of smallholders brings new challenges (and can increase risks). This section analyzes the risks identified in the transition from agroextractivism to inclusive acrocomia cultivation in Brazil. The interviews showed that stakeholders have different perceptions of the risks involved. Some of these perceptions are presented and supported by the literature. The key stakeholders in this discussion are the smallholders, entrepreneurs/investors, and local governments. On the one hand, the distribution of economic risks in acrocomia's value chain may provide more security for smallholders. Thus, the distribution of economic risks may encourage small-scale farmers to be included in the chain. On the other hand, the distribution of economic risks and tax incentives may make the financing of inclusive projects in this innovative value chain more attractive to entrepreneurs/investors.

Risk is a dimension that cannot be underestimated and is seldomly overlooked in opportunity cost or economic feasibility analyses. Risk is a measurable uncertainty which considers that the actual result may differ from expected risk due to random and unforeseen factors (Buainain and Silveira, 2017). Risks in agriculture are traditionally high and increasing due to climate change and socioeconomic factors (World Bank Group, 2016). Agriculture is intensive in capital, inserted in complex value chains, and involves an extensive network of heterogeneous stakeholders (Manda et al., 2020). The distribution of economic risks provides opportunities to mitigate the usual and rising risks in agriculture (Stern and Stiglitz, 2021).

For smallholders, there are basic risks related to contracts. Contracts are important to enable productive inclusion, but many farmers are reluctant to sign them. One of the reasons for this reluctance is the long-term nature of the acrocomia plantation contracts, as discussed in the previous section. Five interviewees (two from the private sector, one from the public sector, and two researchers) revealed that many farmers consider long-term contracts too risky. Most farmers are used to temporary annual crop systems and agroextractivist systems and are afraid to commit to long-term obligations with unclear consequences. We see a relation between the resistance, the level of education, age, and the number of family members involved in production. One of the private sector interviewees indicated that the lower the education levels and the number of family members supporting the farm, and unsurprisingly the older the farm's decision-maker, the greater the resistance.

Production risks are perceived as relevant by both farmers and entrepreneurs/investors, albeit in different ways. In the field research, we identified that acrocomia is not covered by rural insurance in Brazil.[11] For farmers, the existence of insurance could mitigate this type of risk (Junker and Schütz, 2011). This would not be the case for entrepreneurs/investors (Guanziroli and Basco, 2008). The production risks for these stakeholders are greater and involve at least two additional dimensions: i) the risk of production deviation, when fruits are redirected to alternative markets or uses, potentially breaking contract terms, and ii) the difficulty in monitoring how well the plantations are taken care of. Even with the existence of contracts, production deviations can occur, arising from factors such as inadequate contract enforcement, or logistical challenges. This information was gathered during interviews with two stakeholders from the private sector, one businessman and one researcher. To deal with the risk of product deviation, one of the private sector initiatives visited implemented a contractual arrangement whereby smallholder farmers are required to allocate 50 % of their output to the company at no cost. The remaining 50 % of the output is purchased by the company, providing payment to the farmers for this portion. This indicates a market dependency of farmers with one single buyer of macaw fruits.

In Brazil, there are cases of production deviations by intermediaries even in value chains in which contractual integration is highly disseminated, as in the tobacco value chain (Buainain et al., 2009). In this case, the companies concerned were not in a position to compensate for the economic losses caused by these deviations. In addition, acrocomia cultivation requires care of the plants that is not necessary in agroextractivism and that can be determinant for cultivation and productivity, also influenced by the quality of planting material and plant performance. In the interviews, it was possible to identify that the incentive for farmers to take care of production is low. Also, in addition to operational and methodological difficulties, effective monitoring implies high costs for both entrepreneurs and the public sector (Guanziroli and Basco, 2008).

Market/price oscillations were not perceived by the interviewed farmers as risks, thus are not considered in their decision-making process. This may be related to the fact that agroextractivism generates extra income at a low cost. Moreover, the amount of fruits sold by the acrocomia agroextractivism practice was recorded at 64 tons in 2017 (IBGE, 2017), indicating a market under development. This context might also contribute to the farmers' perception of market stability. Despite the existence of a minimum price program, these oscillations were identified by three interviewed researchers as posing a risk. Entrepreneurs/investors are aware of this risk, largely because of Brazil's experience with ethanol production, which was strongly stimulated in the early 2000s (La Rovere et al., 2011; German et al., 2020). Many companies invested heavily in the sector, but with the emergence of the pre-salt and the gasoline price control policy, incentives to produce ethanol weakened (Salles-Filho et al., 2017). In the acrocomia value chain, which is in the initial stages of development, interviewed entrepreneurs/investors mentioned the difficulties in anticipating scenarios and predicting the market price of the plant's products in the future.

The interviewees from private sector and a businessman highlighted that the initial investments in acrocomia cultivation are high and the financial returns are long-term. One of the interviewees stated that private investors are mainly interested in the industrial segment, such as setting up processing mills. According to the businessman, the agricultural part is of little interest to the private sector since it involves more risk, is capital-intensive, and the results are only reaped long term. This also highlights the high financial risk of these investments. In addition, one of the interviewees from the private sector mentioned that many investors only agree to promote acrocomia cultivation with the inclusion of smallholder farmers' initiatives if they have the contractual rights to intervene. In other words, if farmers did not reach the goals set, investors could intervene, and if necessary replace smallholders with large-scale farmers. This scenario would disrupt the commitment to the productive inclusion of smallholders.

There are also institutional risks for farmers and companies directly related to environmental laws. One interviewee from the private sector and one businessman indicated that acrocomia cultivation is being registered as an agricultural crop in official environmental or rural cadastres, to facilitate the removal of these cultives from small-scale farmers' properties in the future if desired. Acrocomia is a native Brazilian palm, and under current environmental laws, removing native or endemic species is already restricted. Registering acrocomia cultivation as an agricultural crop may provide a legal framework that ensures flexibility for small-scale farmers, even if environmental regulations were to become stricter in the future. This risk, therefore, depends directly on environmental policy decisions, which are unstable in Brazil. For entrepreneurs/investors, the changes in the biodiesel market are indicative of institutional risks. The reduction in the mandatory percentage of biodiesel blended with diesel is one of the changes introduced

[11] A situation that may soon change, as the first version of the Climate Risk Zoning (ZARC) for acrocomia in Brazil was published in February 2024. The ZARC helps minimize risks related to adverse climatic events, supports the delimitation of cultivation areas and the adoption of production systems, and provides more security for new investments. However, this first version of the ZARC is still limited by the low availability of information (Melo, 2024).

in 2020. The target blend dropped from 13 to 10 %, despite the sector's objective to reach 15 % of the blend by 2023 (De Oliveira and Coelho, 2017).

In this field research, it was possible to identify that the 15 % target goal encouraged several enterprises to increase their production capacity. It also encouraged the diversification of feedstock sources in the sector, such as acrocomia. Although the commercial use of acrocomia is still limited in Brazil, initiatives such as the target blend goals are driving the development of this value chain. Another example is the Growth Acceleration Program (PAC, for its initials in Portuguese), which includes the Ecological Transformation Plan launched in 2024 by the Brazilian federal government (Brasil, 2024). Aimed at transitioning to a more sustainable economy, this plan offers a range of incentives and financing opportunities that can accelerate the development of the acrocomia value chain, boosting its growth and market integration (Acelen, 2024). This is an opportunity that must be approached responsibly. Risks need to be carefully assessed and considered, especially when smallholder farmers are involved. Public and private initiatives should reflect on how they can collaborate with diverse stakeholders to address potential risks and challenges effectively.

The field research identified that municipal governments, mainly small municipalities, have little power to decisively intervene in the acrocomia value chain, and that this is one of their main limitations. Despite this, farmers and companies tend to consider municipal governments as relevant, since they are responsible for the provision of local road infrastructure and technical assistance services to farmers. These services must be provided by the federal government and operationalized by city halls, which often do not have sufficient resources and technicians to meet the farmers' demands (Sette and Ekboir, 2013). While institutions such as the Rural Technical Assistance and Extension Company (EMATER, for its initials in Portuguese) play an important role in providing technical assistance to farmers, challenges persist. This is a challenge and risk not only related to the acrocomia value chain but also to Brazilian agriculture in general (de Oliveira Lucas, 2023).

None of the identified risks can be measured at the current stage of development of the acrocomia value chain. Attempts to measure risks may also hinder the development of the value chain, as we identified a possibly exacerbated perception of the risks in some interviewees' narratives (mainly researchers, private sector and businessmen). The types of risks related to the different stakeholders are presented in Table 3. These risks do not necessarily reflect the perceptions of the stakeholders themselves. For example, market/price risks associated with farmers were not perceived by the farmers interviewed. The authors categorized the risks to provide a comprehensive understanding of the content discussed above.

Risk management helps promoting a balance between the distribution of risks and benefits (Lund et al., 2020), which is often unbalanced among stakeholders. Entrepreneurs/investors are still relatively unprepared to take on the risks for these new plantations of acrocomia, despite the strengthening of the Environmental, Social, and Governance (ESG) discussion in Brazil (Miralles-Quirós et al., 2018). Moreover, the existing incentives are not enough to encourage investments in production chains that involve productive inclusion (Zapata et al., 2010). One interviewee attributed the disinterest of the entrepreneurs in investing in these initiatives to the existence of less risky and simpler alternatives. We argue that the success in the development of this new value chain with productive inclusion of smallholders and allocation of risks could be enabled by governmental action combined with support from entrepreneurs/investors. Institutional arrangements, such as the formation of cooperative groups between different stakeholders have the potential to contribute to economic development, overcoming poverty, and empowerment for group members (Robaey et al., 2022).

Table 3
Risks related to different categories of stakeholders.

Stakeholder	Risks	Risk implications
Farmers	Associated to the contracts	The long-term nature of acrocomia cultivation contracts is considered too risky.
	Production	Acrocomia is not covered by rural insurance in Brazil.
	Market/price	Agroextractivism generates extra income at a low cost, so market/prices oscillations were not perceived by farmers as risks.
	Institutional/legal	Environmental policy decisions are unstable in Brazil, so it is possible to be forbidden to remove the crops from the lands in the future.
Entrepreneurs/ investors	Production	Acrocomia is not covered by rural insurance; There is possibility of production deviation by intermediaries; There is difficulty in monitoring how well the plantations are taken care of.
	Market/price	It is difficult to anticipate scenarios and predict the market price of acrocomia's products in the future.
	Institucional/ legal	The changes in the biodiesel market are indicatives of institutional risks.
	Financial	Initial investments in acrocomia cultivation are high and the financial returns are long term.
Municipal governments	Management/ operational	City halls often do not have sufficient resources and technicians to provide services they are responsible for (such as technical assistance for farmers).

Source: Own elaboration based on interviews.

6.1. *A three-part route: the state, entrepreneurs/investors, and smallholders*

The development of new value chains in countries of the Global South generally requires strong governmental support and guidance. Without this support, markets and entrepreneurs/investors may neither be able nor interested in providing the conditions necessary to develop alternative crops, combined or not with inclusion (Millard, 2017). A tripartite governance model, involving the smallholders, entrepreneurs/investors, and the state as a conciliator, has been suggested as a solution to guarantee both the distribution of risks among stakeholders and greater security in decision-making for entrepreneurs/investors and smallholders (Bathfield and Gasselin, 2016).

Tripartite governance is a complex model that "consists of a standards setting sub-system and conformity assessment sub-system, both of which are characterized by three tiers of authority and oversight" (Hatanaka et al., 2012, p. 66). This type of governance model could support the domestication of the palm tree and the shift to acrocomia cultivation. State resources are scarce and allocations to science and research have suffered cuts in recent years (Petherick, 2017). Important research on acrocomia development has been carried out by universities and research centers (Vargas-Carpintero et al., 2022), but with a major lack of funding.[12]

In terms of stimulating cultivation and productive inclusion, certain financial innovations can be explored. One example is blended finance, which is a finance model involving resources from public, private, and multilateral organizations (Tonkonogy et al., 2018). These resources are characterized by low interest rates and can count on philanthropic capital. Blended finance aims to expand the resources available for sustainable projects in developing countries. This strategy is strongly recommended as a measure to contribute to the Sustainable

[12] Diagnosis based on interviews.

Development Goals (SDGs) financing gap (Basile and Dutra, 2019). The development of the acrocomia value chain with productive inclusion of smallholders fits into several of these goals, including poverty eradication (SDG 1), decent work and economic growth (SDG 8), reduction of inequalities (SDG 10), and action against global climate change (SDG 13).

In addition, the federal government can guide existing public policies, policy instruments, and institutions to foster an acrocomia value chain with the inclusion of small-scale farmers. The National Program for Strengthening Family Farming (Pronaf) is the main credit policy for smallholders and could grant productive and investment credit for them, as well as providing subsidies during the plant's maturation period. The National Program for Biodiesel Production and Use (PNPB), considered to be the instrument for the inclusion of small-scale farmers - the Social Biofuel Seal - could encourage initiatives under development to include these stakeholders. Institutions such as the Brazilian Agricultural Research Company (EMBRAPA), The Agronomic Institute of Campinas (IAC), and universities that have been studying acrocomia for years can continue providing major support to the research and development of technologies for acrocomia. State leadership and collaboration from entrepreneurs/investors could also contribute to developing and strengthening the value chain as well as the inclusion of smallholders.

The inclusion of smallholders into larger farmer associations, such as cooperatives, also facilitates risk sharing and pooling of resources, enabling collective learning in farm management and providing the opportunity to operate as a group to develop a balance of power vis-à-vis other stakeholders, thus increasing their bargaining power[13] (Gupta et al., 2015; ILO, 2021). In the state of Minas Gerais, where we carried out the field research, Watanabe & Zylbersztajn (2012) concluded that the main obstacle to the development of a local biodiesel agro-industrial system is the lack of horizontal organization among small-scale farmers. We confirmed the lack of horizontal organization between smallholders in our field research. To change this, incentives are needed. The government could take this responsibility by promoting cooperativism through public policies and effective incentives.

7. Conclusions

Productive inclusion is presented as an adequate concept to identify shortcomings and conditions needed for a beneficial transition from acrocomia's agroextractivism to acrocomia cultivation in Brazil. The concept was not directly addressed in the literature, so we developed our own definition, combining stable and decent jobs and income generation with the importance of a fair distribution of economic risks. Although general, this was an effort to delimit and express a possible meaning of the concept.

Despite existing research on acrocomia and its productive potential, the species is still exploited in agroextractivist systems by smallholders in Brazil. Initiatives to promote acrocomia cultivation are increasing in Brazil, besides the complexity of shifting from agroextractivism to the cultivation of acrocomia. It requires a change in the smallholders' usual exploitation system and implies production costs, use of part of the (often limited) land, with long return on investment expectations, and changes in work processes for farmers. Moreover, cultivation associated with pastures can be unsuitable for small farms, since small-scale farmers would lack the needed space to isolate cattle in the first years of macaúba growing.

After planting, the production phase of the palm tree takes at least five years, reaching full production in the tenth year. The slow pace in generating economic results means that long contracts are required, which is perceived by many smallholders as a risk. Previous negative experiences with private-oriented planting of castor beans are another reason that farmers are wary of planting acrocomia on their land. In the field research, we identified that the involvement of local leaders is key to instilling confidence in smallholders' decision-making.

The initial investments in acrocomia cultivation are high, and the financial returns are long-term because of the maturation period of the palm tree. This demands up-front capital and can discourage private investors. In addition, changes in the Brazilian environmental legislation and ongoing changes in the biodiesel market increase uncertainty for stakeholders. It is also possible that these stakeholders overestimate the risks involved. Therefore, a transition to inclusive farming of acrocomia can only be established if the state takes the responsibility to mitigate some of the barriers and improve regulatory and institutional guarantees to facilitate stakeholder decision-making.

This does not mean that the Brazilian government must provide all the solutions. On the contrary, the state does not have the capacity to develop the acrocomia value chain alone but must equip itself with the skills and necessary partnerships to leverage this objective. Despite the existence of the National Policy for Biodiesel Production and Use, no specific governmental action is in place to promote new and inclusive value chains. Brazil is moving towards exclusion, and the pandemic has intensified and accelerated this process. A successful and inclusive acrocomia value chain could alleviate this problem and then should be a governmental objective, but this has yet to appear on the agenda.

Changing this trajectory requires commitments and political choices. A tripartite governance model for small-scale farmer inclusion led by the state, with support from entrepreneurs/investors and the involvement of smallholders, could potentially drive the development of this crop in at least four dimensions: i) research, ii) financing (credit and subsidies), iii) development of technologies, and iv) stable regulation.

CRediT authorship contribution statement

Gabriela Solidario de Souza Benatti: Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Antônio Márcio Buainain:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Pedro Gilberto Cavalcante Filho:** Validation, Methodology, Investigation, Data curation. **Ricardo Vargas-Carpintero:** Writing – review & editing. **Lotte Asveld:** Writing – review & editing, Supervision, Conceptualization. **Patricia Osseweijer:** Writing – review & editing, Supervision, Resources, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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[13] Some authors identified that the poorest farmers are not included in cooperatives (Bijman & Wijers, 2019). In some cases, the inclusion of the most vulnerable smallholders may not be viable and compromise the efficiency of the cooperative as a business (Fischer & Qaim, 2014). For the smallholders, the transaction costs of participating in cooperatives are sometimes excessive (Thorp et al., 2005). It is important to recognize whether this is a social assistance or productive inclusion issue. Combined and systemic solutions may also be a possibility. In Brazil, approximately 5% of smallholders are members of agricultural cooperatives (Herrera et al., 2018a). The culture of cooperativism is strong in the South, where smallholders have greater access to capital, technologies, and public policies when compared to other regions. Cooperativism in the North and Northeast regions, which are more vulnerable, is still weak and under-explored by public policies (Herrera et al., 2018b)

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Appendices

A. Questionnaires

We utilized four main semi-structured questionnaires, which were adapted according to the context of each interview. These adaptations were made to better capture the specificities of the different stakeholders involved. Each questionnaire focused on a distinct group of participants. Prior to the start of each interview, respondents were asked to provide information on their background, education, profession, age, and gender, as part of an introductory section.

Questionnaire 1

1. How do you see the integration of acrocomia in the market? What role does acrocomia play?
2. Is biodiesel essential to support and be the foundation of this business model?
3. Are large acrocomia plantations feasible (similar to palm oil)?
4. Are there other Brazilian companies in the market that cultivate acrocomia?
5. How are the procedures being carried out to go downstream (develop other products in the chain)?
6. What are the main benefits and challenges of including smallholders in the plantations?

Questionnaire 2

1. Tell us about the history and characterization of the initiative.
2. What are the benefits of including family farming?
3. What are the main challenges?
4. What are the risks involved?

Questionnaire 3

1. What is the farm size (ha)?
2. What is the land tenure status?
3. How long have you been living on the property?
4. What is the number of family members that work on the farm?
5. What are the main activities and primary products of the farm?
6. In which partnerships do you take part? describe them and their benefits/challenges.
7. How long have you been planting acrocomia? (skip to question 9 if the smallholder is not planting)
8. What is the quantity of planted seedlings?
9. What are the main motivations for choosing acrocomia plantation? Describe the main benefits, risks, and challenges. (If the smallholder is not planting, what was the motivation for this decision?)
10. Describe the contract of plantations you have with the partner. (Skip to question 11 if the smallholder is not planting)
11. Are you a member of any association or cooperative?
12. What public policies do you access?
13. If you haven't accessed support policies, what was the reason?

Questionnaire 4

1. What is the average profile of acrocomia producers in the region? (age, property size, land tenure status, main production, level of organization, etc.)
2. How important is the income generated by acrocomia production to the total income of smallholders?
3. How did you meet the partner who supports the plantations?
4. Was this how smallholders in the region also got to know the company?
5. What are the motivations for choosing acrocomia cultivation?
6. Do you believe that the choice of other producers in the region was motivated by these factors mentioned earlier?
7. What are the main barriers/challenges faced in acrocomia cultivation?
8. What type of contract do you have with the company that supports the acrocomia plantation?
9. What are the most challenging aspects of the contract?
10. What are the benefits of the contract?
11. Have you ever felt disadvantaged by complying with this contract? Describe.
12. Are there any regulations that must be complied with for acrocomia production on your property (such as environmental, labor, or organic certification)? If yes, describe the actions taken to meet them.

13. What are the most challenging aspects of the regulations?
14. What are the main benefits of association with the cooperative for farmers?
15. What are the main public policies accessed? How do they assist in acrocomia cultivation?

B. Profile of interviewees and number of interviews

Profile	Number of interviews
Researcher	4
Businessman	2
Representative of the public sector	3
Representative of the private sector	3
Smallholder	5
Representative of smallholder organizations	1

C. Literature research

A literature research was conducted on the Scopus, Scielo, and Web of Science platforms from June to December 2022. The following keywords were used: macaw palm; acrocomia; macaw palm AND inclusion; acrocomia AND inclusion; macaw palm AND smallholder; acrocomia AND smallholder. The research was also performed in Portuguese: macaúba; macaúba AND inclusão; macaúba AND agricultura familiar; macaúba AND pequenos produtores.

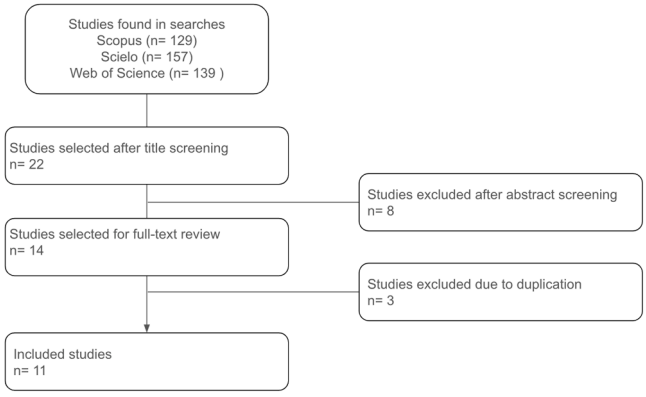
Studies were selected based on these criteria:

Inclusion criteria: literature reviews, case studies, and evaluations focused on the development of the macaw palm value chain in Brazil.
Exclusion criteria: technical studies on fruit/oil composition and/or physico-chemical properties; nutrient cycling, and related studies.

Study selection was performed in three stages:

Stage 1: Reading the titles and excluding those that did not meet the inclusion criteria.
Stage 2: Reading the abstracts of studies selected in Stage 1 and excluding those that also did not meet the inclusion criteria.
Stage 3: Full reading of all remaining studies from the previous stages and selecting those that met the inclusion criteria.

Duplicate studies were excluded.
The flowchart below provides a detailed outline of the process:



The small number of studies included highlights the need for more research on the development of a macaw palm value chain that includes smallholder farmers. Most found studies were technical, underscoring the gap in research that addresses broader development and inclusion aspects.

Data availability

The authors do not have permission to share data.

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