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RESEARCH ARTICLE OPEN ACCESS

Overview of the establishment and uses of *Ricinodendron heudelotii* (Euphorbiaceae): focus on the central and southern regions of Ivory Coast☆

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Abstract – *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel is a plant species present in the high-biodiversity areas of Central, West and East Africa. It has a considerable potential for development as a non-timber forest product (NTFP). The crushed seeds of this species have traditionally been used by local populations and those of certain large African cities as a spice or thickening agent for foods. In the face of strong and potentially growing demand, not only for nutritional purposes but also for new outlets, efforts are being made in Ivory Coast to domesticate this species with a view to increasing production. A number of actions are underway for the development of *R. heudelotii*: improvement of its availability; development of seed and kernel production; creation of markets for the seeds and their proteins and oil; development of industrial uses of this oil. This study carried out an inventory of *R. heudelotii* cultivation in Ivory Coast, and highlighted the levers available for promoting its integration into the economy of the country. The development of outlets for the kernels, oil and proteins of *R. heudelotii*, the improvement and control of product quality, and the modernization of seed crushing and oil extraction methods are essential conditions for increasing production and for the structuring and expansion of the market. This contributes to both the economic development of this crop and those involved in its cultivation — local communities, and women in particular — and the preservation of the environment through the development of an activity favoring regeneration and sustainable forest protection.

Keywords: *Ricinodendron heudelotii* / CLnA / oilseeds / agroforestry / valorization of natural resources

Résumé – État des lieux du développement et des usages de *Ricinodendron heudelotii* (Euphorbiaceae) : focus sur les régions centrales et méridionales de la Côte d'Ivoire. *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel est une espèce végétale présente en Afrique Centrale, de l'Ouest et de l'Est, zones de haute biodiversité et qui présente un bon potentiel de valorisation parmi les produits forestiers non ligneux (PFNL). Les amandes broyées de cette espèce sont utilisées depuis toujours par les populations locales et celles de certaines grandes villes africaines comme aromates ou épaississants culinaires. Pour répondre à une forte demande potentiellement grandissante, notamment pour des besoins nutritionnels, mais aussi concernant de nouveaux débouchés, des efforts sont menés en Côte d'Ivoire pour développer sa domestication en vue d'augmenter la production. Ainsi, certaines actions se multiplient pour le développement du *R. heudelotii* : amélioration de sa biodisponibilité; développement de la production des graines et des amandes; création de marchés des amandes et de leurs protéines et huile; développement d'usages industriels de cette huile. Cette étude a réalisé un inventaire de la culture de *R. heudelotii* en Côte d'Ivoire, et a mis en évidence les leviers disponibles pour favoriser son intégration dans

☆ Contribution to the Topical Issue "Creating new oil & protein crop value chains / Construire de nouvelles filières oléoprotéagineuses".

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l'économie du pays. Le développement des débouchés pour les amandes, l'huile et les protéines de *R. heudelotii*, l'amélioration et le contrôle de la qualité des produits, ainsi que la modernisation des méthodes de trituration des graines et d'extraction de l'huile sont des conditions essentielles à l'augmentation de la production et à la structuration et à l'expansion du marché. Cela contribue à la fois au développement économique de cette culture et des acteurs qui la cultivent – les communautés locales, et les femmes en particulier – et à la préservation de l'environnement à travers le développement d'une activité favorisant la régénération et la protection durable des forêts.

Mots clés : *Ricinodendron heudelotii* / CLnA / oléoprotéagineux / agroforesterie / valorisation des ressources naturelles

Highlights

- *Ricinodendron heudelotii* shows significant potential as a non-timber forest product in Ivory Coast.
- Cultivating it in agroforestry could drive economic growth and enhance plant cover.
- To enhance production and economic growth, it's crucial to broaden markets, upgrade quality, and modernize processing of *R. heudelotii* products.

1 Introduction

There has been considerable development of oilseed and protein crops in tropical Africa in recent years, with increasing needs for oil and oilcake due to population growth, improvements in living standards and the globalization of markets (OECD/FAO, 2016). This development of oilseed and protein crops is designed to meet the fat and oil needs of the food industry, to generate products for domestic consumption, the cosmetics and pharmaceutical industries and the chemical industry. Nutrient-rich oilcakes from these plants are also a source of protein for domestic animal and livestock feed. Furthermore, agroforestry systems integrating the cultivation of oil-producing plants favor the regeneration of vegetation cover and contribute to the fight against desertification and global warming. With this in mind, interest in this new domesticated species is growing in Africa.

The 33rd Permanent Interstate Committee for Drought Control in the Sahel (CILSS) meeting, held on October 4, 2018, in Ivory Coast, highlighted the importance of non-timber forest products (NTFPs) for strengthening food and nutrition security and the livelihoods of vulnerable households in the Sahel and West Africa.

Ivory Coast has an abundance of NTFPs, but its agriculture and agroforestry are poorly organized. Data on supply, volumes produced, traded and consumed are unreliable and sometimes lacking. NTFPs are not, therefore, integrated into the value chain of economic products. We consider here *R. heudelotii* (Baill.) Pierre ex Heckel, an oil-protein plant with a lipid and protein content and composition, cultural importance, value as a food and potential profitability rendering it a textbook example for agroforestry. There are several hurdles to be overcome in the cultivation of *R. heudelotii* linked to the harvesting, production and crushing of the seeds, the limited availability of the species, its traditional uses and the size of current and future markets. These difficulties provide good indicators to guide the improvement of *R. heudelotii* development as a cash crop through its domestication and the creation and structuring of an autonomous industry in Ivory Coast.

Ricinodendron heudelotii grows over almost the entire territory of Ivory Coast, being found throughout the entire southern zone and part of the northern zone of the country (Nikiema *et al.*, 2019; Kouadio *et al.*, 2020). Unfortunately, *R. heudelotii*, a source of non-timber forest products, has not escaped the devastation caused by deforestation. A study in Benin (Boko-Haya *et al.*, 2017) reported a significant decline in the number of plants of this species in recent years (Boko-Haya *et al.*, 2021). Several countries, including Cameroon (Shidiki *et al.*, 2021), Ivory Coast (Yapo *et al.*, 2020), Benin (Hounsou-Dindin et al., 2023 Agre *et al.*, 2023; Hounsou-Dindin et al., Hounsode *et al.*, 2023; Hounsou-Dindin *et al.*, 2022; Hounsou-Dindin *et al.*, 2021), and Nigeria (Ogbuagu *et al.*, 2019), have advocated the integration of *R. heudelotii* into agroforestry systems, as a means of mitigating this problem. The edaphic (well-drained soil rich in trace elements) and climatic (favorable temperature and rainfall levels) conditions in the intertropical zone of Africa are favorable for the cultivation of this plant. However, there are currently no large-scale plantations of *R. heudelotii*.

Ricinodendron heudelotii is a fast-growing tree that generally grows to a height of 20-30 m, but can reach heights of up to 50 m, with a diameter of up to 150 cm (Shiembo, 1994; Akoègninou *et al.*, 2006). The fruits are initially yellow-green, becoming black at maturity (Plenderleith, 2000). The fruits are drupes containing a maximum of four seeds (Nikiema *et al.*, 2019). The flowering and fruiting periods vary between countries, and sometimes between different regions of the same country. Globally, fructification occurs at some time between May and January, depending on the country and the region (Akoègninou *et al.*, 2006; Plenderleith, 2000). Léonard (1961) described two subspecies, but only one, *R. heudelotii* subspecies *heudelotii*, is present in Ivory Coast. *R. heudelotii* grows over almost the entire territory of Ivory Coast, being found throughout the entire southern zone and part of the northern zone of the country (Nikiema *et al.*, 2019; Kouadio *et al.*, 2020).

In Ivory Coast, the *Centre National de Recherche Agronomique* (CNRA) has performed domestication trials on experimental fields in the Oumé and Agboville regions (Djaha *et al.*, 2014). This domestication program is supported by the national government through the establishment of the National Project for the Improvement of Forest Governance in Ivory Coast (PNAGF-CI). This program aims to contribute, through good forest governance and adequate funding, to the restoration and sustainable management of forests in Ivory Coast. In the framework of this program, some cocoa farmers

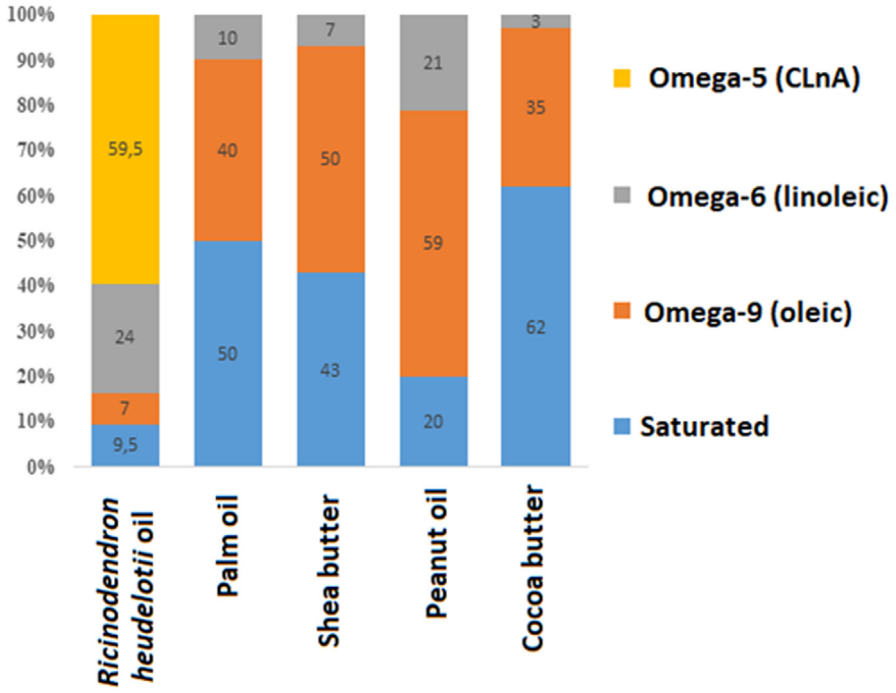


Fig. 1. Fatty-acid profiles of the main oils and butters produced and used in Africa.

are already using *R. heudelotii* as a shade tree in their fields (Vroh, 2015).

Here, we provide an inventory of *R. heudelotii* cultivation and of the products that can be derived from this species. We aim to identify the advantages of cultivating this plant and ways to develop its cultivation so that it can play an important economic role in countries like Ivory Coast. We searched the scientific literature and selected the data which relate mostly to current uses, transformation processes, chemical composition and use properties. The aim of the paper was to propose ways of developing *R. heudelotii* cultivation specific to Ivory Coast, through the possible levers for intervention, the actions and support available to achieve increase the development of the cultivation of *R. heudelotii* and to carve out an important, environmentally sustainable place for this plant and its products in the economy of the country.

1.1 Uses of *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel

In some areas of Ivory Coast, particularly in the Marahoué region (Nikiema, 2021), the bark of the trunk and the roots are used in traditional medicine for the treatment of ailments such as coughs, dysentery and stomach aches and many other diseases, as listed by Akpovo *et al.* (2022). Ash from freshly felled wood is used as a cooking salt (Tchoundjeu & Atangana, 2006). In the south-west region of Ivory Coast, the leaves are used in traditional medicine for the treatment of dysentery and female sterility (Boko-Haya *et al.*, 2017). Kernels are used directly in food and also used as a flavor enhancer, a thickening agent for soups (Tchiégang *et al.*, 1997) and to make "akpi sauce". The paste made from the kernel is also used as a remedy for toothache in Cameroon (Agbor &, Naidoo, 2015). Surveys in parts of Ivory Coast have shown that the hulls are used to produce energy by combustion in traditional domestic stoves, or as a composite construction material, to form a hard drainage layer (Nikiema *et al.*, 2019).

No study has yet reported the industrial-scale use of *R. heudelotii* anywhere in the world.

1.2 Quality and uses of *Ricinodendron heudelotii* oil

The kernels extracted from the seeds contain 21% protein and 47.4% oil (Nikiema *et al.*, 2019; Coulibaly *et al.*, 2018; Saki *et al.*, 2005). The amino-acid composition of the *R. heudelotii* proteins in the cake obtained from seeds is satisfactory for human nutritional needs (FAO, 1973). A study in Ivory Coast (Nikiema *et al.*, 2019; Nikiema *et al.*, 2022) showed that *R. heudelotii* seeds contain an oil rich in polyunsaturated fatty acids (95%), making it one of the few drying polyunsaturated vegetable oils. It contains on average 60% conjugated linolenic acid (CLnA), particularly in the form of α-eleostearic acid in the lipid fraction, which makes it one of the rare drying polyunsaturated vegetable oils and also constitutes a potential benefit for health. It is characterized by a high iodine value (180 g I2/ 100 g). It contains a mean of 60% conjugated linolenic acid (CLnA), particularly in the form of α-eleostearic acid in the lipid fraction. The minor constituents, including tocopherols (135 mg/100 g oil) and sterols (412 mg/100 g oil) are preserved during the extraction. This and the presence of high levels of dietary fibre render *R. heudelotii* seeds a very good candidate for use in food for human consumption.

The stacked histogram in Figure 1 summarizes the fatty-acid compositions of the oils most widely used in Africa, comparing them to that of native *R. heudelotii* kernel oil (Nikiema *et al.*, 2019; Lecerf, 2017; Noba *et al.*, 2014; Pages, 2009; Raynal-Ljutovac *et al.*, 2011). This comparison between oils (palm and peanut) and butters (shea, cocoa) produced in

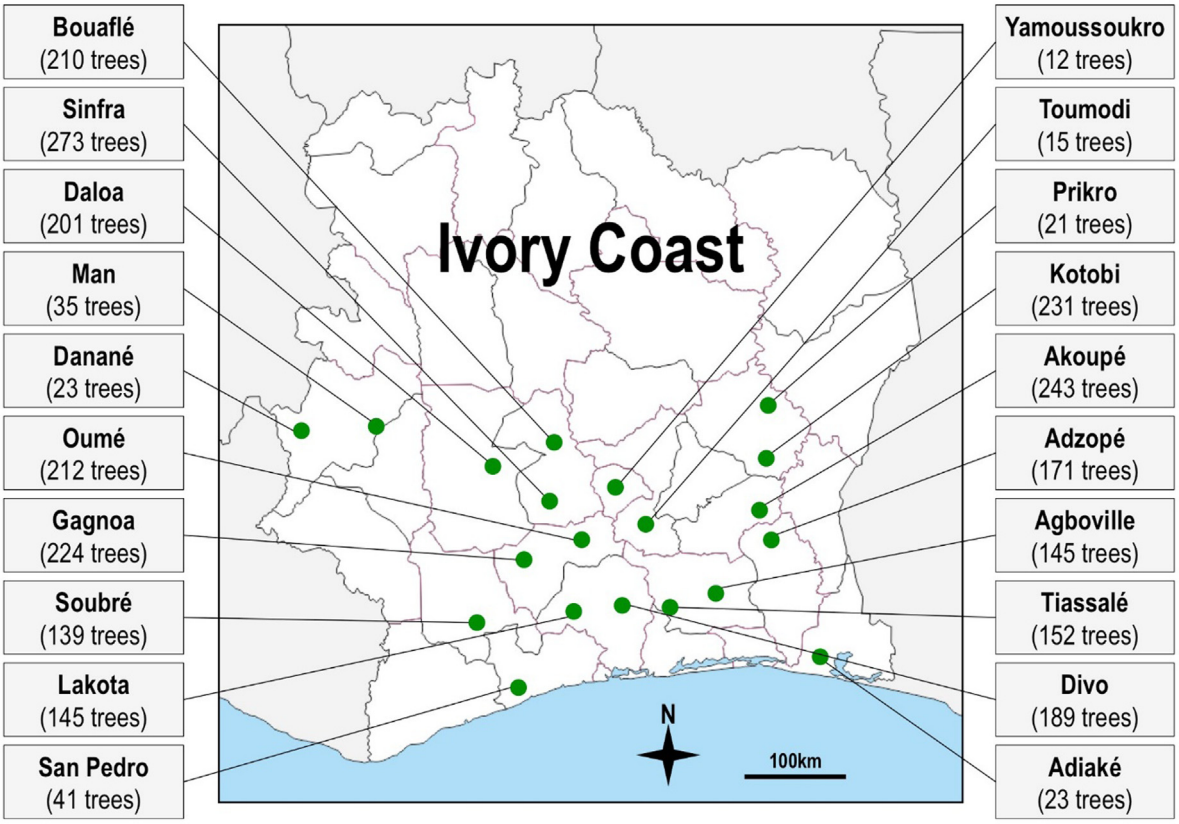


Fig. 2. Result of the census of wild *Ricinodendron heudelotii* trees in the survey areas visited in Ivory Coast.

Africa shows that *R. heudelotii* oil is the only source of CLnA among these products.

2 Focus on *Ricinodendron heudelotii* in Ivory Coast

Ricinodendron heudelotii fruit is harvested almost exclusively from trees already in cultivation (in cocoa and coffee plantations) and in accessible areas (Herzog, 1994). The fruits are harvested directly from the ground after they fall, due to the great height of the trees. This is a long and difficult process, due to the surrounding vegetation, as these trees often grow in areas left to fallow. Our survey showed that the density of *R. heudelotii* plants in the field, particularly in cocoa and coffee plantations, rarely exceeds two plants per 5 hectares. This density appears much too low to support sufficiently high levels of production for the structuring of large-scale use.

Nikiema (2021) studied the location of *R. heudelotii* trees in 23 localities of the center and south of Ivory Coast (Fig. 2), namely: Abidjan, Yamoussoukro, Sinfra, Gagnoa, Tiassalé, Toumodi, Oumé, Divo, Danané, Man, Lakota, San Pedro, Soubré, Adiaké, Adzopé, Kotobi, Bouaké, Arrah, Akoupé, Daloa, Sikensi, Agboville, Rubino. In order to obtain as much information as possible, 3 villages were chosen per locality in order to collect information on the presence and production of *R. heudelotii* almonds regions. This plant was present at all the sites surveyed during 5 harvest periods, from 2016 to 2020. The South-East and the South-West are the two major production areas. The harvesting of its seeds and kernel production are strongly linked to the dietary habits of the local population: 82.5% of the sites surveyed produced *R. heudelotii* kernels, whereas 17.5% had no harvesting and processing activities. In Ivory Coast, the annual harvest of *R. heudelotii* (akpi) seeds amounts to about 100 tonnes of almonds.

2.1 Commercial outlets for *Ricinodendron heudelotii*

Ricinodendron heudelotii sector has a poorly developed artisanal structure in Ivory Coast. Trees of this species are irregularly distributed over the country, at low density, and little is known about seed production, which is irregular. Moreover, the overall data are incomplete: kernel production levels are unknown, the quality and traceability of kernels are variable, consumption rates are not recorded, for either the kernels or kernel oil, and the market prices of kernels and oil are very variable. Efforts are being made to tailor production to demand, but kernel production remains local and artisanal. *Ricinodendron heudelotii* trees used are wild. However, efforts are regularly made to increase awareness of the nutritional and market value of *R. heudelotii* products among the populations of the areas of production, such as the Gulf of Guinea and the Congo Basin (Roques *et al*., 2019). As a result of these actions, *R. heudelotii* kernels are becoming increasingly common in markets and demand from the population seems to be growing.

There is an incipient local industry based around this tree in Ivory Coast: the fruits of *R. heudelotii* are harvested in the



Fig. 3. *Ricinodendron heudelotii* kernels on a market in Abidjan, Adjamé, "marché Gouro", packed in bags known as "Boite-Kilo".

village by women. The kernels are then separated out from the rest of the seed by hand before being sold at the various markets. In 2018, the kernels sold at markets in the production areas had an at-the-edge-of-field price of 3,000 to 4,000 CFA francs per kg (*i.e.*, 4.5 Euros per kg), whereas those transported to the major cities reached higher prices, ranging from 8,000 to 10,000 CFA francs per kg at the height of the season, and up to 15,000 CFA francs at the end of the harvest period (Nikiema, 2021). Prices vary with supply and demand, and locally according to kernel quality (dryness and shape).

Kernel production and sale has increased the income of producers, and it also contributes to the income of traders further afield, in the large towns.

Commercially, the current mode of production, artisanal and uncoordinated, can only lead to limited development of national markets and large-volume exports. Indeed, the kernels are sold almost exclusively in small amounts (Fig. 3). The market for the kernels is almost exclusively local and a little national and the quantities of kernels available for export are very limited (through the diaspora). The development of more efficient harvesting methods and structures or cooperatives should make it possible to increase the amounts recovered, facilitating the development of structured and industrially viable exploitation.

There is an embryonic market for the export of *R. heudelotii* kernels to some European countries, such as France, Belgium and Germany (Tabuna, 2000), mostly for consumption by expatriots from the countries that produce these almonds, who know how to use them.

2.2 *Ricinodendron heudelotii* kernel production

The harmonious development of this new crop is subject to several constraints, mostly related to the harvesting, production and crushing of the kernels.

The technique used for seed hulling is archaic and very difficult to perform (Tchiégang *et al.*, 2005; Nikiema *et al.*, 2019), partly accounting for the scarcity and high price of *R. heudelotii* kernels both local markets and the markets of large towns. This method results in the production of only small quantities of kernels, destined almost exclusively for dietary consumption. A more efficient manual or automatic mechanical crushing system would make it easier to crush the hull and to separate it from the kernel. The artisanal technique of seed processing currently in use may also lead to a deterioration of kernel oil quality, due to contact with boiling water (Nikiema *et al.*, 2019).

2.3 Structuring of the development of the *Ricinodendron heudelotii* sector

There is already a market for *R. heudelotii* in Ivory Coast, and its structuring is of particular importance for the development of agroforestry in the country. The objective is to provide all stakeholders with the opportunity to generate added value, through a progressive vision, in the short, medium and long term.

This will involve farmers, traders and the state creating structures for the organization of a crop value chain, and the development of appropriate legislation. Furthermore, researchers will need to develop new ways of adding value to products and co-products. The dissemination of knowledge to the population, and the commitment of producers and of companies needing oils rich in polyunsaturated fatty acids and proteins, will underlie the structuring of this crop value chain. The agricultural sector in Ivory Coast is the principal source of income for two thirds of households, employing almost 46% of the active population, accounting for 22.4% of GDP (Gross Domestic Product) in 2014 and more than 60% to export earnings (*Note de stratégie pays*, 2017). The CNRA (*Centre National de Recherche Agronomique de Côte d'Ivoire*) and ANADER (*Agence Nationale d'Appui au Développement Rural*) could serve as the preferred state actors for the development of this sector. This structuring of the development of the *R. heudelotii* sector should lead to the establishment of this tree as a new cash crop, favoring development in rural populations, in which the economy is based largely on subsistence activities (cash and food crops).

Additionally, the pivotal timeframe for harvesting, processing, and selling *R. heudelotii* seeds spans from June to November. This period holds great significance for the communities of producers as the income generated aligns with the commencement of the academic year in Ivory Coast, emphasizing the interconnection between generated income and the resumption of academic activities. The processing of *R. heudelotii* seeds remains an artisanal activity performed by women. Improving this activity and others relating to *R. heudelotii* could therefore make an important contribution to the emancipation of women and the creation of women's cooperatives in rural areas. A key factor in this development will be the construction of expertise about the products and the transformation processes, with targeting and optimization of the parameters likely to influence product quality. This will be essential to increase production, storage and marketing capacities at the national and international levels.

2.4 Recommendations for the development of a *Ricinodendron heudelotii* value chain

Our work shows that the structural organization of *R. heudelotii* cultivation is still at an early stage, and that

Table 1. Recommendations for the development of the *Ricinodendron heudelotii* sector in Ivory Coast.

Intervention level	Expected results	Recommended actions	Possible support structures
Information and awareness	Information and raising of the awareness of the population and farmers about agroforestry and reforestation.	Raising awareness of the nutritional and market value of the seeds.	Agricultural cooperatives Rainforest ALLIANCE, Coffee and Cocoa Council
		Organization of information and awareness-raising sessions on the importance of reforestation for combating the effects of climate change.	
	Creation of *R. heudelotii* plantations.	Training of farmers and cocoa tree growers in good practice for the use of *R. heudelotii* in agroforestry.	CNRA Agricultural cooperatives SODEFOR
	Promotion of the cultivation of *R. heudelotii.*	Creation of *R. heudelotii* nurseries.	CNRA Agricultural cooperatives
Production	Ensuring the availability of seeds and kernels.	Collection of seeds for domestication.	Peasants Agricultural cooperatives
		Organization of women into agricultural cooperatives for the harvesting and processing of the fruit.	Agricultural cooperatives Development partners
Transformation	Modernization of seed crushing for the production of *R. heudelotii* seed kernels. Development of oil extraction methods.	Creation of a *R. heudelotii* seed-crushing unit in production areas.	Agricultural cooperatives General Council FIRCA
		Creation of a kernel-pressing unit for oil extraction.	Partners in industrial development.
Scientific research	Shortening of production processes and reduction of *R. heudelotii* tree height. Identification of opportunities for co-product valorization through the development of transformation processes: valorization of seed constituents (oil, cake, shell) as products of higher added value.	Research projects: in agronomy, on the production processes for the oil and co-products (cake, husks) of *R. heudelotii,* on the processes for transforming the oil and co-products (cake, husks) of *R. heudelotii.*	FIRCA Universities CNRA AFD
Industrial valorization	Development of added value for seed constituents: oil, cake, husks.	Formulation of agri-food, cosmetic, pharmaceutical and agromaterial products.	Industry partners FIRCA
Marketing	Increasing the incomes of producers and traders.	Definition of the modes for setting and controlling the prices of *R. heudelotii* seeds and kernels.	Traders State-owned companies

its development is currently based on the natural availability of wild trees, attempts to domesticate *R. heudelotii* and an embryonic market. Many actions are required to improve the development of this sector. Our recommendations are listed in Table 1, with possible levels of intervention, expected results, recommendations for achieving results and the support structures potentially required for the implementation of the necessary actions.

3 Conclusion

The production of kernels and oil from *R. heudelotii* in Ivory Coast has been developing in recent years, to meet the growing needs of the local population in terms of lipids and proteins, and for the development of new markets for these products locally and globally. Ivory Coast, has testing the use of *R. heudelotii* plants in agroforestry and in experimental fields, with the principal objective of increasing production. *R. heudelotii* kernel production in Ivory Coast is currently limited in terms of quantity, due to its artisanal nature, in an informal crop value chain operated at a local level by women. This production appears to contribute to household income and provides significant potential business opportunities highlighting the extent to which the potential of this tree as a cash crop is far from well exploited. This lack of optimization is linked to the difficulties involved in organizing the *R. heudelotii* value chain, from cultivation to kernel production, the traditional system of production and an uncontrolled market. However, the cultivation of *R. heudelotii* in agroforestry is likely to be the key to developing economic growth and restructuring plant cover. The development of outlets for the kernels, oil and proteins of *R. heudelotii*, the improvement and control of product quality, and the modernization of seed crushing and oil extraction methods are essential conditions for increasing production and for the structuring and expansion of the market, which will be a key element in the economic development of Ivory Coast.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to this article.

Author contribution statement

Conceptualization: Z.M., RV.; Supervision: Z.M. K.O.K., A.A., C.R.; Validation: M.C., O.M. J.F.F., E.L.; Writing—original draft preparation: D.N., R.V., Writing – Review & Editing: R.V.; Resources: S.B. All authors have read and agreed to the published version of the manuscript.

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