# Challenges and strategies to promote the industrialization of cassava crop in Colombia

## Desafíos y estrategias para promover la industrialización del cultivo de yuca en Colombia

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**ABSTRACT**

Cassava (yuca) is a major crop in Colombia, with a production of more than 2.5 million t in an estimated area of more than 260,000 ha. However, the average yield in the country is 11.34 t $ha^{-1}$, a low level compared to other world-class producing countries. About 94.4% of the total production of cassava nationwide is used for direct human consumption, and only 5.6% is destined for industrialization. The aim of this research was to verify the problems faced by the industrialization of cassava crop in Colombia and to establish possible strategies to help deal with them. The strategies proposed were identified through field observations, iterative testing, stakeholder feedback, and comparative analysis. Among the most noticeable challenges in the low industrialization of cassava crop are low availability of land and high-quality planting material, low technological development, and seasonality of production. Some outstanding strategies to overcome this problem are sowing by pre-sale, access to suitable technology, change of crop varieties, and the producer's business culture. Large industrialized crops are adopting pre-sale planting as a business strategy for agribusiness; moreover, a crop with agricultural mechanization and irrigation systems on large tracts of land is economically efficient. However, the shift from subsistence agriculture to agribusiness is not enough. Government support with public policies and subsidies is needed to safeguard the cassava production chain in times of national or global crisis.

**Key words:** *Manihot esculenta,* mechanization, pre-selling, agribusiness, business culture, public policies.

**RESUMEN**

La yuca es un cultivo muy importante en Colombia, con una producción mayor a 2.5 millones t en un área estimada de más de 260 mil ha; sin embargo, el rendimiento promedio en el país es de 11,34 t $ha^{-1}$, un nivel bajo si se compara con otros países productores de talla mundial. Alrededor del 94,4% del total de la producción de yuca a nivel nacional es para consumo humano directo y sólo 5,6% se destina a la industrialización. El objetivo de esta investigación fue verificar los problemas que enfrenta la industrialización del cultivo de yuca en Colombia y establecer posibles estrategias para ayudar a superar este desafío. Las estrategias propuestas se identificaron mediante observaciones sobre el terreno, pruebas iterativas, comentarios de las partes interesadas y análisis comparativos. Entre los problemas que destacan en la poca industrialización del cultivo de yuca se encuentran la baja disponibilidad de tierras, de material de siembra de alta calidad, escasa tecnificación y estacionalidad de la producción. Algunas de las estrategias planteadas para superar esta problemática son la siembra por venta anticipada, acceso a tecnología adecuada, el cambio de las variedades del cultivo y la cultura empresarial de los productores. Los grandes cultivos industrializados están adoptando la siembra por venta anticipada como una estrategia de negocio para la agroindustria; además, un cultivo con mecanización agrícola y sistemas de riego en grandes extensiones de tierra es económicamente eficiente. Sin embargo, el cambio de agricultura de subsistencia a agronegocios no es suficiente; se necesita el apoyo del gobierno con políticas públicas y subsidios para salvaguardar la cadena productiva de la yuca en épocas de crisis nacional o mundial.

**Palabras clave:** *Manihot esculenta*, mecanización, venta anticipada, agronegocio, cultura empresarial, políticas públicas.

## Introduction

Cassava or yuca (*Manihot esculenta*) is a tropical crop native to South America. It was domesticated for food about 5,000 years ago by hunter-gatherer groups from the Caribbean and Amazon regions (Aguilera Díaz, 2012; Otálora *et al.*, 2024). Cassava is grown in more than 102 countries for its edible starchy tubers and is consumed as an energy source in the diet of thousands of people (Jisha *et al.*, 2008). It is rich in carbohydrates, calcium, vitamins B and C, and essential minerals, but the nutrient composition differs according to the variety, age of the harvested crop, the soil conditions, the climate, and other environmental factors during cultivation. Cassava is the basis of several

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products, including flour, animal feed, alcohol, starches for the food industry, paper and textiles, sweeteners, prepared foods, and biodegradable products (Aguilera Díaz, 2012; Chavarriaga-Aguirre *et al.*, 2016).

World cassava production in 2023 was 334 million t (FAO, 2024). Africa has the highest cassava production in the world (62% of the global volume), with more than 207 million t in 2023; the remaining 29% is produced in Asia and 9% in Latin America (Ritchie *et al.*, 2023).

In Africa, the largest producer is Nigeria, with an average yield of 9 t $ha^{-1}$ and production of about 60 million t (Ikuemonisan *et al.*, 2020). The second largest producer in the region is the Democratic Republic of Congo, with an average yield of 8.1 t $ha^{-1}$ and production of about 40 million t. The third largest producer is Ghana, with an average yield of 14 t $ha^{-1}$ and production of about 23 million t, with a growing industry led by smallholders (Adebayo, 2023; Poku *et al.*, 2018).

In Asia, Thailand is one of the leaders in industrial cassava production. This has placed it as one of the priority crops for its bioeconomy development (Arthey *et al.*, 2018). These authors propose to implement biorefineries to develop value-added products such as lactic acid, starches, and bioplastics from cassava and sugar cane to maintain its competitive advantage as a leading exporter of cassava worldwide (Lane, 2017; Saardchom, 2017). Thailand is a leader in the global market, exporting 26% of fresh, frozen, or dried cassava and 72% of cassava starch.

The leading producer in Latin America is Brazil, followed by Paraguay (FAO, 2020). Brazil has one of the most modern industrial parks since the beginning of 2000 and serves the starch industries in the center-south and flour in the northeast, mainly for domestic consumption (Felipe, 2020). The predominant producers of flour are small-scale farmers. The production of starch occurs on a larger scale. The main buyers of these inputs are pasta, biscuit and bakery, tapioca, and meat products companies. In Paraguay, 70% of production is for consumption (human and animal food), while 30% is marketed (Canales & Trujillo, 2021). The main production areas are in the eastern region (69%), where small producers grow from 1 to 10 ha (Enciso Rodríguez *et al.*, 2015). Paraguay is the fourth largest exporter of cassava starch in the world and the first in the American continent; 60% of Paraguay's cassava starch exports are produced by Codipsa, the only processing plant with European technology in South America. In 2018, this company produced 60 thousand tons of starch and exported 22 thousand tons (Diaz, 2019). Science, technology, and innovation focused on cassava cultivation began about 30 years ago worldwide. In 1976, cassava was considered an orphan crop without the support of any country (Hershey, 1994).

Colombia is the third largest producer of cassava in Latin America (Canales & Trujillo, 2021). Cassava is an ancestral crop used for direct but not industrial consumption. It has traditionally been a relevant crop for agriculture, constituting an essential element in the diet of many people in various regions of the country. The products that generate added value to the crop are native cassava starch, sour or fermented cassava starch, and dry and fresh cassava (Parra Olarte, 2019). It is the fifth most produced agricultural good in volume in the country, after sugarcane, banana, potato, and rice. In 2022, Colombia produced 2.1 million t in a harvested area of 187,268 ha (Agronet, 2023). The average yield in Colombia is low (11.22 t $ha^{-1}$) compared to world leaders such as Thailand (22 t $ha^{-1}$) and, in the region, Brazil (14 t $ha^{-1}$) and Paraguay (18 t $ha^{-1}$) (FAO, 2020). Cassava is grown in all 32 departments of the country. The most prominent production centers are the Caribbean, Orinoquia, and Cauca regions. The leading producers, in general, are the departments of Bolívar (17% of national production), followed by Córdoba (11%), Sucre (8%), and Magdalena (7.5%) (Parra Olarte, 2019). From 2015 to 2018, the areas planted with the cassava crop increased by 7%, while harvested areas increased by 21%. In the same period, total cassava production varied by 34%, reaching 2.37 million t of tubers harvested by 2018 (MADR, 2021). However, production and area have decreased to values close to 2 million t and less than 190,000 ha from 2018 to 2022 (Agronet, 2023).

Different varieties of cassava are produced in the country. However, commercial production is divided into two large segments: sweet cassava, mainly aimed at human consumption, and industrial (bitter) cassava, aimed at industrial segments for processing into starch and other products (MADR, 2021). The main characteristics of industrial cassava are the high yield of fresh roots and its high dry matter content, resulting in a high dry yield per area. Likewise, industrial cassava doesn't need high contents of cyanogenic glycosides. The terms bitter cassava and industrial cassava are used interchangeably. The industry often processes non-bitter cassava (Taborda Andrade *et al.*, 2023).

Of the total production of cassava nationwide, 94.4% is for direct human consumption, and only 5.6% is focused on industrialization (Canales & Trujillo, 2021). The departments that have the highest industrial cassava production in the country are Sucre (40%), Córdoba (27%), and Cauca (30%); nevertheless, industrial cassava is produced in 11 out of the 32 departments of the country (Rivera *et al.*, 2021). Almost all cassava transformation is carried out by small and medium-sized companies in the communities, with intensive labor and traditional techniques (Canales & Trujillo, 2021). The agricultural production system is mainly small-scale (85%), grown in areas less than 10 ha, with traditional practices and low technology. The crop is grown primarily on leased land (70%). It generates an average of 53 working days per hectare of industrial cassava and 40 working days per hectare of fresh cassava (MADR, 2017). Fresh cassava cultivation for direct human consumption is conducted in rotation or associated with corn, yam, or cotton. In contrast, industrial cultivation is undertaken in monoculture and is more technological (MADR, 2017).

Colombia's main product of cassava cultivation is the fresh root for direct human consumption. One of the challenges of fresh cassava is its perishability since it must be consumed or transformed within the first 48 h after harvest. The roots can be waxed with paraffin or processed (peeled, chopped, used to prepare flour or dried pieces) to extend their shelf-life and sell it in frozen and pre-cooked presentations (Canales & Trujillo, 2021). Products from washed and peeled roots generate root wash effluents and solid by-products (shells and root tips). Large industries reuse washing water. The shells are often given to producers for use in compost or to farmers for consumption as animal feed without processing (Canales & Trujillo, 2021).

Cassava products can be fermented or unfermented and contribute to the growth of its industrial applications. Primary unfermented cassava products include flour and starch. Fresh cassava roots can be processed into "chips," and dried cassava chips can be transformed into flour or starch after milling (Chisenga *et al.*, 2019). On the processed product side, cassava flour is used as an additive in preparing bakery products, and starch as a stabilizing agent for soups, frozen foods, and snacks, among other uses (Aguilera Díaz, 2012). Cassava flour and starch, which do not contain gluten, are alternatives that could compete in this market. Another market opportunity for cassava is an increased demand for bioplastics, as it can be used to obtain thermoplastic biopolymers, films, and biofuels. Thus, there is potential for the development of industrial-scale multi-product biorefineries, complex systems where agricultural residues are transformed to obtain a portfolio of high-value-added products and energy sources for integration into cassava starch processing, in a scheme that promotes socio-economic growth, as these facilities provide the opportunity to create new jobs, increase the flow of profits, and improve people's purchasing power (García-Vallejo & Cardona-Alzate, 2024; Padi & Chimphango, 2021; Ravichandran *et al.*, 2024). Likewise, cassava could be an essential source of energy for animal feed and compete with the corn imports currently made in the country (Canales & Trujillo, 2021; Contexto Ganadero, 2022). Therefore, our research was to verify the problems faced by the industrialization of cassava crops in Colombia and establish strategies that can serve in the future for a clear development in strengthening this productive chain, which is very important in social and economic terms for the country.

## Current problems in the industrialization of cassava crop

The cassava chain vision in Colombia 2010-2024 acknowledges that the low transfer of innovative technologies to the cassava transformation process does not allow consolidating a competitive and economically, socially, and environmentally sustainable agri-food chain, active in national and international markets and with technological innovation, business development, and support for food security (MADR, 2014). The precariousness and inefficiency of technology transfer in primary production has been one of the main cassava production chain weaknesses in Colombia. In addition, the planting area of industrial cassava varieties should be tripled. Therefore, the country must overcome barriers like low access to or availability of land, low availability of high-quality cassava planting material (seed stalks), low profitability of current industrial cassava production systems, low commercial confidence between producers and industry, low use of technology, use of improved varieties, lack of mechanization, lack of irrigation systems, production seasonality (i.e., all producers plant and harvest at the same times, thus causing market shortages or saturation at the same time of year), cassava substitution for illicit coca cultivation, and low generational relay in the rural population to work in the crop (Taborda Andrade *et al.*, 2023). Moreover, other challenges in the cassava industry must be considered: high production costs, high consumption of resources, loss of roots and starch, increasing environmental impacts, and difficulties in adapting to climate variation derived from the effects of climate change (Pingmuanglek *et al.*, 2017; Van Giau *et al.*, 2023; Van Giau *et al.*, 2024).

The historical prices of different types of commercial cassava are volatile (2013-2021), and prices can vary by 100% from year to year for some cultivars. This is possibly related to periods of scarcity, low production of cassava in some parts of the country, and the oversupply of periods of cassava or other substitute products (Taborda Andrade *et al.*, 2023). Harvest times are generally between November and February, and one of the current difficulties is the availability of fresh cassava throughout the year, since there are seasonal periods where production levels are very low, and prices increase considerably.

Immersion in a globalized economy model can stimulate rural-to-urban migration and generate an absence of labor, minimal generational change, loss of local practices and knowledge, and low remuneration for selling farmer products (Ocampo, 2014). Rural areas face a peasant deactivation scenario, mainly due to a generational absence with no renewal. This can be a vicious circle since there is no work or the remuneration is very low; therefore, the worker leaves. Since there are no people to work, there is no labor to cultivate.

## Strategies for industrializing the cassava crop

Cassava is a versatile crop that can serve as an important source of income and economic development for agribusinesses by expanding raw material supply, enabling value-added products, and stabilizing supply chains. Transforming cassava root into products with added value and with greater demand in the market initially requires the crop to be industrialized. Thus, the problems mentioned above can be improved through strategies suitable to each crop's conditions and situations. The proposed strategies were identified through a mixed-methods approach that combined: 1) Field observations and iterative testing through longitudinal engagement with cassava-producing regions to document systemic bottlenecks and direct participation in pilot projects in order to assess the feasibility of mechanization, irrigation systems, and contract farming models; 2) Stakeholder feedback through interviews with smallholder farmers to identify pain points in production, pricing, and supply chain coordination where operations face difficulties or inefficiencies, and support for workshops with agricultural cooperatives and research institutions (*e.g.*, Agrosavia, CIAT) to validate technological and policy barriers; and 3) Comparative analysis through benchmarking with cassava industrialization models from Thailand, Brazil, and Paraguay, adapting lessons learned from the Colombian agricultural context. The strategies to fill this long-term gap are presented in Figure 1, highlighting sowing by pre-sale or forward contracts, access to adequate technology, switching to extensive crops, and an adequate producer business culture.

## Sowing by pre-sale or forward contract

The forward sale contract is a way of marketing a crop that enables pre-selling the harvested product that acts as a form of risk management for its future price. Under this modality, the farmer has the possibility of fixing the sale price of their product previous to the physical delivery, but the producer assumes the risk. The main difference between pre-selling and futures market is that in the latter more financial instruments enable product price management, without the physical delivery commitment required by the forward contract (Gutiérrez, 2009; Molina & Victorero, 2016). An important feature is that companies generally constantly give technical training and advice to farmers so that the harvest is obtained in the best conditions.

However, there are several risks associated with forward contracts, and one of the most incurred is trust between stakeholders. During the 2021-2022 period, competition for cassava roots in the Sucre and Córdoba departments increased. Furthermore, it is estimated that more than 60% of the cassava grown in Cauca was replaced by coca leaf crops. Therefore, the demand shifted to the Caribbean, causing increases in root prices. In 2022, one ton of fresh cassava roots of industrial varieties reached a historical maximum of $1,400,000 Colombian peso (COP) (US$ 283 at the Representative Market Rate - RMR of that year). The situation resulted in breaches of up to 70% of the forward contracts signed between industries and producers (Taborda Andrade *et al.*, 2023). This situation generated uncertainty in the industry and the economic groups that carry out these contracts, changing conventional policies and procedures in this business.

If there is no confidence in a forward contract in agricultural production, several problems and negative consequences arise: for instance, credit risk, price uncertainty, negative impact on the supply chain, and damaged reputation, among other possibilities. In the end, if there is no agreement between the parties, companies can resort to legal actions to assert their rights, seeking a solution in court. However, these actions can take too much time and economic resources, and they do not guarantee a return on the investment. Additionally, the business group can take another path, such as leasing land and contracting all the services for agricultural activity development throughout a considerable area thus benefiting from the scale economies that this enables (Gutiérrez, 2009).

## Access to adequate technology

Production includes three major activities: sowing, cultivation, and harvesting. Small producers practice traditional or manual planting in the Colombian Caribbean (Fig. 2), starting with soil preparation in the dry season from the first days of April to June, with the purpose of harvesting between May and November. The seeds (cassava stem cuttings) are buried in soil 5 to 10 cm of their average 20 cm length, and they are usually planted in an upright position, ensuring that many buds are below ground. This task requires between 6 to 8 d $ha^{-1}$ (Martínez García & Tordecilla-Acevedo, 2019).

The harvesting technique involves cutting and selecting foliage and seeds (cuttings). Only a stem (20-40 cm long) is left attached to the roots to extract them more easily from the soil by pulling them with the hands. The roots are collected and packed in sacks (*costales*) or plastic bags that are then collected and taken to the market (Fig. 3). The production of cassava roots is intended for self-consumption, artisanal chopping, industry, and fresh produce traders (Martínez García & Tordecilla-Acevedo, 2019).

At the time of starting cassava industrial production, farmers are recommended to use planting material from quality vegetative seed (genetic, sanitary, physical, and physiological) to reduce and avoid the spread of sanitary problems (Floro *et al.*, 2018; Leon *et al.*, 2021; Nassar & Ortiz, 2007). Therefore, uniformity of the crop stand, vigor in the plant establishment, and a high yield of commercial roots during the harvest can be achieved (Rodríguez Henao *et al.*, 2021). It is estimated that at least 60% of a good crop lies in the use of cuttings suitable for the different places where it is grown. In Colombia, many commercial cassava cultivars have been developed by the Alliance Bioversity International and the International Center for Tropical Agriculture (CIAT, by its Spanish acronym), partnered with the Colombian Corporation for Agricultural Research (Agrosavia, by its Spanish acronym) (Rodríguez Henao *et al.*, 2021). The most widely used industrial cassava varieties in Colombia are Corpoica Tai, Corpoica Belloti, Corpoica Sinuana, and Corpoica Ropain in the Caribbean region; Corpoica Cumbre and Corpoica La Francesa in the department of Cauca; and Agrosavia Melúa-31 in the Orinoco region (Rosero Alpala *et al.*, 2023). It is necessary to make agreements with these research centers to plant certified cassava that is pest-resistant and that can last more than 14 months without loss of dry matter (starch). Currently, 9-month harvest crops are sown, and dry matter loss has been noticed after that time.

Experience and data have shown that the mechanization of cassava cultivation is relatively difficult to execute and adopt, although there are solutions for cassava cultivation automation that are newly developed every year. Land preparation, irrigation, transport, and pest and disease management systems are readily available and adaptable to cassava cultivation. Moreover, specialized machinery, such as stem planting machines, cassava root harvesters, and cassava harvesters are being developed to improve the mechanization process (Adekunle *et al.*,

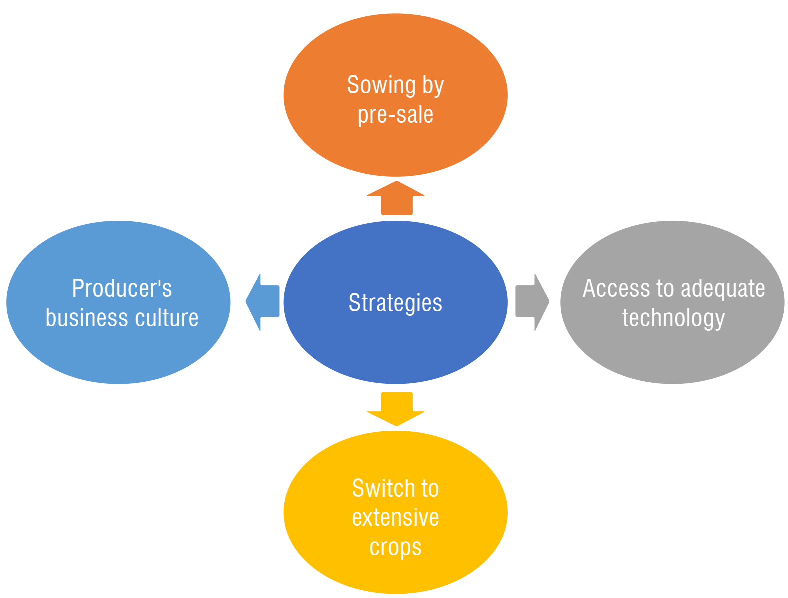


**FIGURE 1.** Strategies for industrializing cassava crop in Colombia.

2016). Unfortunately, technological advances often do not translate into real applications in the field, mainly due to the cost of these technologies. However, in most cases, the social aspect is linked to economic limitations with regard to the users of these technologies.

Cassava cultivation mechanization is one of the main agriculture needs in Colombia considering the projection of that crop in national and international markets and its application in the industry. Agricultural development not only depends on the opening of new land or more intensive use of already used land but also on the mechanization of crops and the use of different technologies for agro-industrial processing, *e.g.*, mechatronics, the internet of things, the use of drones and sensors, precision agriculture, autonomous vehicles, and rural and renewable energies. Smart production can greatly contribute to the productive efficiency of these processes and the reduction of their environmental impact (Alonso-Gomez *et al.*, 2024; ONU & CEPAL, 2018; Tran *et al.*, 2015). However, mechanization for crop extraction from the field is conditioned on the dimensions reached by the variety sown, its developmental level, and the soil type (García-Pereira *et al.*, 2017).

Mechanization in Colombian cassava production is currently limited to land clearing (preparation for planting), seedbed preparation, and transportation-practices adopted primarily by large-scale agro-industrial farms. Small-scale producers (85% of farmers) remain dependent on manual labor due to land fragmentation, financial constraints, and limited access to machinery (Rodríguez Henao *et al.*, 2021). Since implementing mechanization in agriculture drastically reduces the total person-hours needed to perform a specific task, a typical effect of technological improvements in agriculture is a temporary increase in the number of unemployed people in society (Adekunle *et al.*, 2016). While it seems logical to assume that such an increase in unemployment would be restricted to the sector directly affected by innovation, the overall impact on unemployment in the country could be large, as the adoption of technologies is known to reduce labor needs by up to 84%. This problem can only be avoided if the government is receptive enough to create proactive programs that stimulate the economy, including initiatives such as programs for acquiring skills that target workers who will be affected by structural unemployment (Adekunle *et al.*, 2016).

Cassava is considered a relatively drought-tolerant crop, since it reduces water use by reducing leaf area and stomatal closure (Polthanee, 2018). However, water stress causes a reduction in yield, especially during early growth stages. All supplemental irrigation water regimens increase the leaf area index and yield of cassava roots in contrast to a lack of irrigation during the dry season. With supplementary crop irrigation during the dry season, a higher tuber yield and higher starch content can be achieved, translating into greater productivity (Polthanee, 2018). Dry matter and starch content are commonly considered quality factors and can vary widely among cassava varieties. The factors described are closely related to the potassium content of the soil, the age of the crop, the climate, especially rainfall and soil moisture content (Santos *et al.*, 2019). In general, cassava is considered to be more resistant than other crops to harsher climatic conditions (Guerrero Hernandez & Ramos de Arruda, 2021). However, the effect of climate chang on this crop would be less if an adequate irrigation system is implemented.

As mentioned above, the average yield in Colombia is 11.22 t $ha^{-1}$, which is low when compared to cassava root production in Thailand with an average yield of 22 t $ha^{-1}$. This can vary greatly depending on the area and agricultural


**FIGURE 2.** Traditional sowing of cassava in the Colombian Caribbean: A) Soil preparation, B) cuttings for sowing, C) manual planting of cassava cuttings (Photos with permission of Poltec SAS).


**FIGURE 3.** Cassava harvest in the Colombian Caribbean: A) Manual harvest, B) transport of harvested cassava (Photos with permission of Poltec SAS).

management practices. However, it is estimated that using a certified and suitable seed for each type of soil, applying mechanization technology and irrigation systems with good agricultural management practices (*e.g.*, the application of manure or compost, mulching, fertilizer optimization, cassava rotation with grain legumes to fix atmospheric nitrogen, and conservation tillage) could increase yield up to 50 t $ha^{-1}$ (Pingmuanglek *et al.*, 2017; Rubiano-Rodriguez & Cordero-Cordero, 2019).

## Switch to extensive crops

In line with global trends, the large land tracts in Colombia destined for a specific crop seem to be related to agro-industrial transformation, especially biofuels from sugarcane, oil palm, and soy, which are highly encouraged by the State. These species are interesting because they serve multiple agro-industrial purposes (Pardo & Ocampo-Peñuela, 2019; Torres-Mora, 2020). A relevant example is the use of large land tracts in the Valle del Cauca department by the sugar cane agro-industry. This industry does not necessarily acquire the land where they grow the cane but they lease the land and buy the harvested product through forward contracts, as mentioned above. In this new model used today, more than 70% of the land is owned by suppliers while only 25% is owned by sugar mills (Torres-Mora, 2020).

Considering the case of Almidones de Sucre – a company that transforms cassava into native starch and generates 60 direct jobs in the plant and 600 indirect jobs in the field in the Sucre, Córdoba, and Bolívar departments – processing requires maintaining 3,000 ha of cassava for plant operation at a maximum of 80 km around the company, so that the freight does not increase the price of the product, which must be brought to the factory no later than 48 h after harvest (Martínez García & Tordecilla-Acevedo, 2019). However, producers are scattered throughout the department and are not always part of associations, thus they sell their product to the highest bidder. Incentives are lacking that generate loyalty to the customer companies, so, there is little clarity about their product's importance in the links of the production chain, and the derivatives and diverse uses of the product (Martínez García & Tordecilla-Acevedo, 2019; Pabon-Pereira *et al.*, 2019). Traditionally, cassava has been grown by smallholders with less than 5 ha of cassava per farm that were mostly intercropped with maize and yams. More recently, larger plantations of more than 10 ha of cassava per farm have arisen in response to a sharp increase in demand from cassava processors (Pabon-Pereire *et al.*, 2019).

For the market, around 11,000 t of *fécula de mandioca* (cassava starch) (the batch code name registered in international trade and revised in Legiscomex for 2022) were imported. In addition, the current scenario in the post-pandemic context (global container crisis, increase in the USD to COP exchange rate, conflicts in Ukraine and Israel, among others) has dynamized national demand for native, fermented, and modified starches (Taborda Andrade *et al.*, 2023). Thus, an industrialized cassava crop to meet this demand, (*i.e.*, large extensions of crops using modern technology) need a continuous supply for agro-industrial transformation.

One of the alternatives that could be implemented to industrialize the crop and link it with the agro-industry is to convert large land tracts dedicated to low-density livestock into cassava crops with technological applications and locate them near the processing centers. This is the case in some areas of Sucre and Córdoba. Nevertheless, associations or cooperatives of small producers could be created to generate scale economies that respond to the industry demands with forward contracts respecting the agreed contractual clauses. However, this strategy requires farmers, who produce cassava roots, to change these practices.

## Producer business culture

Smallholder farmers have low financial and human capital, as well as limited physical and social capital. Low financial and human capital reflects poor access to financial resources such as savings, credit, or assets, and lower educational attainment, skills, or health status to perform well in agricultural activities. This, in turn, makes it difficult for them to face and adapt to the numerous crises and challenges they face (Hendrawan *et al.*, 2024). This means that the majority of cassava farmers have educational attainment below fifth grade, do not maintain accounting of their production, live in extreme poverty conditions, are geographically dispersed, have no knowledge of the value chain, have access to little market information, and have poor assimilation of the value concepts and intermediation margins throughout the chain. Furthermore, the vast majority of farmers are an older population with little actual generational relay (Ariza García *et al.*, 2021; Martínez García & Tordecilla-Acevedo, 2019).

This situation can be improved if policy interventions are implemented with a comprehensive approach that should focus primarily on covering and strengthening the financial and human capacity of these smallholder farmers (Taborda *et al.*, 2018). This could be achieved through direct financing, such as the provision of direct financial aid or subsidies, and capacity-building interventions, such as extension support to agricultural management practices (Hendrawan *et al.*, 2024). Along with the above, a strengthening of producer organizations and companies must be structured; that should enable the producers to collectively negotiate conditions of financial services packages, zoning according to the sizes of areas dedicated to cultivation to establish stocks that reduce transport costs, and to coordinate the product placing on the market and the technology needed to cultivate (Ariza García *et al.*, 2021; Martínez García & Tordecilla-Acevedo, 2019).

Farmers should have information on the sector's behavior and the suitable technology in the crop that is translated for their educational attainment. The implementation of any technology can have positive or negative effects on society, depending on the pace at which it is introduced and adopted by the population. The adoption of agricultural technology by a rural population will normally depend to a large extent on the socio-cultural and economic ideologies, gender, religion, and the individual's economic position, as well as on the application of these technologies to local production systems. The economic and social structure of society, more than any benefit or improvement arising from new technologies, plays a crucial role in the way in which the population accepts innovation (Adekunle *et al.*, 2016).

Another challenge agricultural production faces is rural population aging, a phenomenon that is observed worldwide and that must be taken with great caution by government entities and society in general. Making agriculture attractive to young people requires changes in the economic, social, and political structures of the food system by adopting new agricultural approaches. Changes include civic agriculture that considers the development of activities from agriculture to food, giving life to a social movement to resist isolation and inequality (Farkas *et al.*, 2023; Salgado Sánchez, 2015).

It is important to highlight that the technology applied to cultivation can only benefit farmers willing to specialize, mechanize, and expand their agricultural operations. The research and extension programs were designed to help farmers turn their farms into agribusinesses. Large specialized agricultural operations can be economically efficient, but they are also risky and vulnerable to economic collapse, as shown during the agricultural financial crisis of the 1980s and the COVID-19 crisis that started in 2020. The agricultural policies of the 1980s were an experiment to see if large, specialized farms could survive without government assistance. They could not. Government price support, deficiency payments, subsidized crop insurance and crop income, guaranteed loans, and disaster payments are means by which governments have absorbed the risks of industrial agriculture (Ikerd, 2024). Large specialized agricultural tracts can be the product of cooperatives or associations of cassava farmers. However, there is another alternative: transform the land dedicated to low-density livestock into cassava crops using technology and taking advantage of the fact that people in the livestock sector have a credit culture and access to the financial sector.

## Conclusions

Cassava has traditionally been a relevant crop for agriculture in Colombia. The country ranks third as a producer in

Latin America. However, the average yield in the country is only 11.34 t $ha^{-1}$, a low level when compared to Paraguay (18 t $ha^{-1}$) or Thailand (22 t $ha^{-1}$). About 94.4% of total production of cassava nationwide is dedicated to direct human consumption, and only 5.6% is destined for industrialization. Among the problems that stand out from the low industrialization of cassava cultivation in Colombia are low access to or availability of land, low availability of high-quality planting material, low commercial trust between producers and industry, lack of technology, production seasonality, and aging of the rural population. Among the strategies proposed in this research to overcome these challenges are as follow: sowing by pre-selling, access to appropriate technology, switching to extensive crops, and the producer business culture. These stand out. It is estimated that at least 60% of a good crop lies in the use of suitable and certified seeds, suitable for the different soils and growing conditions in the country. In addition, cassava cultivation mechanization is one of the main agricultural needs in Colombia. The application of supplementary irrigation systems can lead to a higher tuber yield and higher starch content that translates into greater productivity. Large extensions of crops with technology are necessary, favoring a continuous supply in the agro-industrial transformation to meet the demand for industrial cassava. However, it should be noted that not only the approach of specialized farmers willing to mechanize and expand their agricultural operations is sufficient, rather, a shift from subsistence agriculture to agribusiness with government support is also essential to face different crises. Some ways of absorbing the industrial agriculture risks by the government could be the offer of subsidized crop insurance, guaranteed loans, and disaster payments.

### Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

### Author's contributions

AMV and VH formulated the overarching research goals and aims, ERS wrote the initial draft, AMV and VH obtained the financial support for the project leading to this publication. All authors approved the final version of the manuscript.

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