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The cassava value web and its potential for Colombia's bioeconomy

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Introduction

Bioeconomy has become an increasingly important public policy issue worldwide, with more than 60 countries including it in their national strategies (GBS & IACGB 2020). Several Latin American countries, including Argentina, Brazil, Colombia, Costa Rica and Ecuador, have bioeconomy policies in place and are developing strategies for multiple purposes, including territorial or subnational economic development, reducing deforestation, and reducing high levels of inequality (Henry and Hodson 2019). These purposes are in line with the vision of a sustainable bioeconomy, where "humanity lives with respect for nature, and where the economy benefits society and protects the planet and local environments supported by technological and social innovations" (GBS & IACGB 2020, p.19).

Colombia has recognized in the bioeconomy a new road to its economic diversification. This is shown through initiatives such as the Green Growth Policy and the 2019 International Mission of Experts. The Green Growth Policy defines the bioeconomy as the "efficient and sustainable management of biodiversity and biomass to generate new products, processes and value-added services based on knowledge and innovation" (Consejo Nacional de Política Económica y Social 2018, p.26). While the 2019 International Mission of Experts adopted the definition of the Global Bioeconomy Summit where bioeconomy is the "production, utilization and conservation of biological resources, including knowledge, science, technology and innovation for the provision of information, products, processes and services across all economic sectors and towards a sustainable economy" (Global Bioeconomy Summit 2018, p.2). Through these initiatives, Colombia has set ambitious goals for 2030, including a 10% contribution of the bioeconomy to the gross domestic product and the generation of at least 100 000 jobs (International Mission of Experts 2019). The aspiration is that this growth will promote a transition to an economy based on natural capital, with high levels of productivity and economic competitiveness, ensuring sustainable and circular use of bioresources, climate compatibility and social inclusion (Consejo Nacional de Política Económica y Social 2018). Furthermore, the bioeconomy is expected to contribute to the achievement of the Sustainable Development Goals in Colombia and to reduce dependency on fossil fuels (Consejo Nacional de Política Económica y Social 2018; Misión Internacional de Sabios 2019). However, these aspirations raise several questions: which bioresources should form the basis of the future bioeconomy in Colombia? How and who should form part of this base?

Colombia is moving into a phase of bioeconomy implementation through the Bioeconomy Mission led by the Ministry of Science, Technology and Innovation, in collaboration with the National Planning Department. One of the objectives of this mission is to harmonize national aspirations with local realities, identifying specific opportunities at the territorial level (Gobierno de Colombia 2020).

Cassava, a crop domesticated in the Amazon, could be one of the base resources of the bioeconomy in Colombia since it is produced in the 32 departments of the country with potential for job generation both in primary production and in processing for use in various industries. This working paper evaluates the potential of this crop within the framework of a sustainable bioeconomy, identifying challenges and defining guidelines for new opportunities. For this purpose, a methodology called value web approach is used, which allows a rapid assessment of the potential of a bioresource (Virchow et al. 2016).

Sections 1 and 2 contextualize the importance of cassava in the global bioeconomy and the situation of cassava in Colombia. Section 3 presents the methodology used and Section 4 presents the application of the methodology for the cassava resource in Colombia. Section 5 discusses opportunities and challenges for the cassava value web and Section 6 presents key issues to enhance the role of cassava in the bioeconomy in Colombia. Section 7 proposes next steps for further research. Finally, Section 8 presents conclusions.

1. Cassava in the global bioeconomy

Cassava (*Manihot esculenta Crantz*) is an important bioeconomy crop due to its starch content, useful for bioethanol, biochemicals and bioplastics production, and with applications in various industries (Gao et al. 2020). The competitive advantage of cassava over other similar crops (roots) is due to its ability to grow in acid soils of low fertility with sporadic rainfall or long periods of drought (Aristizábal et al. 2007). There are more than 6000 accessions, seed or plant conservation units, among which there are sweet varieties for human consumption with low levels of cyanide, and bitter varieties for industrial processes. There are also multipurpose varieties suitable for industrial production and direct human consumption (CIAT 2019).

Worldwide, the largest cassava production takes place in Africa which produces 62% of the global volume with more than 277 million metric tons in 2018. The other 29% is produced in Asia and 9% in Latin America (FAO 2020). In Africa the largest producer is Nigeria, with an average productivity of 9 tonne/ha (Ikuemonisan et al. 2020). The second largest producer in the region is the Democratic Republic of the Congo, with an average productivity of 8.1 ton/ha. Ghana is the third largest producer, with a productivity of 14 tonne/ha and a growing industry led by small enterprises (Poku et al. 2018). In Asia, Thailand is one of the leaders in industrial cassava production and has put forward cassava as one of the priority crops for the development of its bioeconomy. Its proposal is to implement biorefineries to develop value-added products such as lactic acid, starches and bioplastics from cassava and sugarcane with the objective of maintaining its competitive advantage as a leading global cassava exporter (Saardchom 2017; Lane 2017). Thailand is the global market leader, exporting 26% of fresh, frozen or dried cassava and 72% of cassava starch (FAO 2020). In Latin America, the main producer is Brazil, followed by Paraguay (FAO 2020). Brazil has had one of the most modern industrial parks since the 2000s and cassava serves the starch industry in the centre-south and the flour industry in the northeast, mainly for domestic consumption (Felipe 2020). Primary production for flour is mostly developed by small farmers, while production for starch is large scale (Felipe 2019). The main buyers of these inputs are pasta, biscuits and bakery, tapioca and meat products companies (Felipe 2019). In Paraguay, 70% of production is for the producers' own consumption (human and animal feed), while 30% is marketed (Infonegocios 2019). The main production areas are in the eastern region where 69% are small producers that cultivate from 1 to 10 ha (Enciso Rodríguez et al. 2014). Paraguay is the leading exporter of cassava starch in Latin America, with Compañía de Desarrollo y de Industrialización de Productos Primarios S.A (CODIPSA) leading 60% of total exports (Diaz 2019).

Cassava starch is a product used in various industries. In the food industry, it is noted for its higher expandability compared to wheat starch, providing a crunchy but flexible texture (Oladunmoye et al. 2014; Ingredion 2019). Furthermore, the flavour profile is more neutral compared to corn starch, reducing the amount of ingredients needed to compensate for undesirable flavours (Breuninger et al. 2009; Ingredion 2019). In baking, cassava starch provides a more transparent and slightly glossy appearance, and requires less cooking and processing time (Ingredion 2019). In the paper, corrugated and textile industries, this starch is preferred to potato, corn and rice starches for its adhesive or sticking ability (Ellis et al. 1998; Integrated Cassava Project 2005). In the plastics industry, it is often used as it has better consistency than wheat starch (Lopattananon et al. 2012), and is also used for obtaining thermoplastic biopolymers and films (Bernal Bustos et al. 2017). In the pharmaceutical industry, cassava starch is used as an excipient, encapsulant, and to increase the shelf life of products (Alcázar-Alay and Meireles 2015). In the energy industry, it has also been used for bioethanol production (Aristizábal et al. 2007).

In addition to its usefulness in various industries, there are two market trends that could increase the demand for cassava biomass: gluten-free foods and bioplastics. The global market for gluten-free foods has been estimated at USD 5.6 billion in 2020 (MarketResearch.com 2020) with prices potentially four times higher than for gluten-containing inputs (TechNavio 2017). Cassava flour and starch, which do not contain gluten, are alternatives that could compete in this market. Another market opportunity for cassava biomass is the increase in demand for bioplastics, as it can be used to obtain thermoplastic biopolymers and films. As of 2018, 66% of countries had already adopted some type of regulation to decrease the consumption of plastics from fossil resources (PNUMA and WRI 2018). Although bioplastics production represents only 1% of the world's total plastics production, an average growth of 20% is expected by 2024 (European Bioplastics 2020).

2. Cassava in Colombia

Colombia is the third largest producer of cassava in Latin America. Cassava is the fifth most produced agricultural commodity in volume after sugarcane, plantain, potato and rice (Parra 2019). In 2019, Colombia produced 2.8 million tons in a harvested area of 259 931 ha, reporting a growth trend in area (4%) and production (11%) between 2015 and 2018 (Parra 2019). Despite this growth, the average yield in Colombia is low (11.34 ton/ha) compared to world leaders such as Thailand (22 ton/ha), and in the region, to Brazil (14 ton/ha) and Paraguay (18 ton/ha) (FAO 2020).

Cassava is grown in all 32 departments of the country. The most prominent production centres are the Atlantic Coast, Orinoco and Cauca. Preliminary figures for 2019 indicate as main producers the departments of Bolivar (17% of national production), followed by Córdoba (11%) and Sucre (8%) (Parra 2019). In the Orinoco, the production centre with the highest yields at the national level, Meta, is the largest producer (7%), followed by Arauca (5%). The Cauca production centre (5%) has one of the highest production growth rates in the country (117%) in recent years (Parra 2019).

Of the total national cassava production, 94.4% is for direct human consumption and only 5.6% is destined for industrialization (Parra 2020a). The production system is mainly small scale (85%), cultivated in areas smaller than 10 ha with traditional practices and little technification (MADR 2017). The crop is mostly (70%) grown on leased land and generates on average 53 labour days per hectare of industrial cassava and 40 labour days per hectare of fresh cassava (MADR 2017). The cultivation of fresh cassava (for human consumption) is developed in rotation or in association with corn, yams or cotton, while the industrial crop is developed in monoculture and is more technified (MADR 2017). In 2019, only about 6% of fresh cassava production was marketed through the wholesale supply centres CORABASTOS in Bogotá (47%), Barranquilla (8%) and Bucaramanga (6%) (Parra 2019). The other 94% of fresh cassava is marketed through fruit and vegetable suppliers, and exporting companies of frozen products and snacks (Parra 2020b).

There is an unsatisfied demand for cassava starch in Colombia. In 2019, Colombia imported USD 6.5 million (13 400 tonnes) of cassava starch from Paraguay (Legiscomex 2020). This represents more than double the imported value of corn starch in the same period. The two main importers are Almidones de Sucre (ADS) and Ingredion, who concentrated 81% of the total volume imported in 2019. These companies imported starch from Paraguay to counteract the shortage of industrial cassava in Colombia, common during the second half of each year (Almidones de Sucre 2020; Parra 2020b). Cassava starch was also imported for companies whose activity includes other industrial uses for 6% of the volume and for cosmetic companies (0.01% of the volume) (Legiscomex 2020).

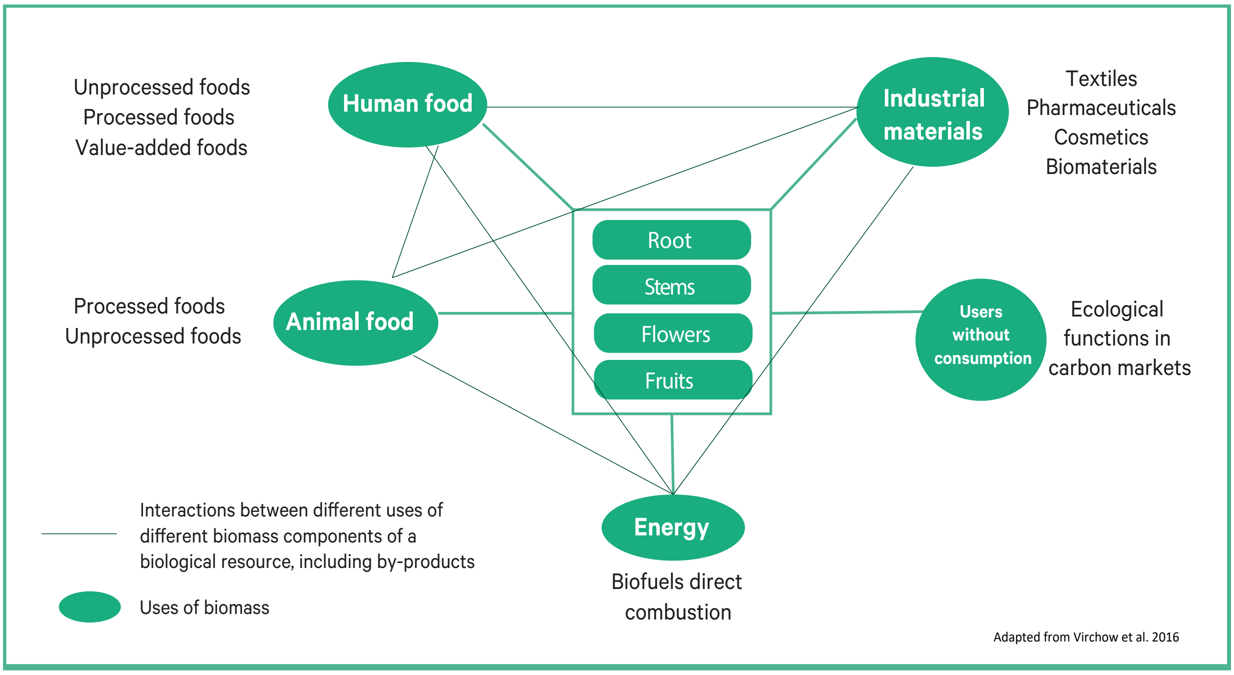
The precariousness and inefficiency of technology transfer in primary production has been one of the main weaknesses of the cassava production chain in Colombia (MADR 2014). This is despite the presence of the International Center for Tropical Agriculture (CIAT), one of the most important research organizations on cassava cultivation at the global level, its work in conjunction with the Colombian Agricultural Research Corporation (AGROSAVIA) and the fact that much of the information on technologies for this crop already exists. The vision of the cassava value chain in Colombia 2010–2024 recognizes these weaknesses and seeks to form and consolidate a competitive and economically, socially and environmentally sustainable agri-food value chain, active in domestic and international markets and with technological innovation, business development and support for food security (MADR 2014). To this end, research, development and innovation (R+D+I) requirements are focused on improving competitiveness and productivity. This includes harvest, post-harvest and transformation management, planting material and genetic improvement, socioeconomics, competitive intelligence and business development, information systems, zoning (agroecological niches), technology transfer and technical assistance, and sanitary and phytosanitary management (Corpoica, MADR, Colciencias 2016). From the bioeconomy perspective, this vision should extend beyond the agri-food sector, considering the opportunities for local value generation in other markets.

3. Methodology

This case study seeks to identify the potential of cassava in the framework of a sustainable bioeconomy in Colombia through the value web approach of Virchow et al. (2016) and the Schiffer (2007) Net-Map tool. Both approaches have been used in other value web analyses, including cassava in Ghana (Poku et al. 2018), sugarcane in Brazil (Scheiterle et al. 2018) and quinoa in Bolivia (Canales et al. 2020).

The value web is an approach created by Virchow et al. (2016) as a multidimensional proposal for the bioeconomy. It is a non-linear approach that allows the analysis of the different value chains originating from a single resource and the connections between them. The value web considers as its starting point the complete resource (i.e. roots, trunk, leaves, flowers and fruits, and their components) and seeks to identify its different current and potential uses. These uses include human consumption (food) and animal consumption (animal feed), fuels (energy) and industrial materials. Virchow et al. (2016) also propose to identify uses related to ecological functions or carbon markets. This more systemic view also seeks to include the concept of circular economy through the identification of uses of by-products or residues (e.g. shells, chemical components) and their reuse (see Figure 1).

Figure 1. Biomass value web



Net-Map is a participatory tool developed by Schiffer (2007) to identify which actors are involved in a network and how they relate to each other. This working paper analyses the cassava value web in Colombia, and seeks to identify which actors are involved and how they relate to each other. To this end, commercial linkages are mapped (i.e. who participates in the purchase and sale of cassava biomass), as well as innovation linkages (identifying who generates knowledge) and financing linkages (mapping who financially supports innovation).

Both approaches were used to collect information on cassava biomass in Colombia through 13 semi-structured interviews of 1.5 hours each. The interviews were conducted online in October 2020 with companies, researchers and representatives of producer associations, identifying actors through a "snowball" technique (see Annex I). The interviews were conducted in two steps with the visual aid of Miro. First, the uses, products and by-products of the value web were identified. For the second step, for the actor network, the value web was used as an input for discussion and the actors involved in commercial, financial and knowledge exchanges or linkages were identified. These linkages were selected because of the importance of identifying biomass flows, learning capacity in a value web, and existing financial support in a particular context (Lundvall 2010; Scheiterle et al. 2018).

The visualization of actors also allowed for further discussion on recommendations to develop the potential of cassava in Colombia. The interviews were processed using NVivo software according to the uses proposed by Virchow: human food, animal food, industrial materials, energy, non-consumptive uses, and to the proposed linkages. Finally, the information from the interviews was verified with a literature review.

4. Value web of cassava biomass in Colombia

From the application of the cassava value web in Colombia, it can be observed that cassava biomass, in addition to fresh cassava commercialization, is already being used, mainly in the food industry. However, there is also potential to expand its use in the feed industry and to venture into the production of bioplastics (see Figure 2).

4.1. Products and by-products of the cassava value web in Colombia

The cassava value web in Colombia includes various uses and levels of value addition. The root is the most widely used part of the plant both for human consumption and animal feed. The leaves, which are consumed in other countries as human food and whose dry base contains 26% protein, are only consumed in the Amazon. The stems are only used for vegetative propagation of the crop and therefore the plant does not develop flowers, except in research crops or in the Amazon. All parts of the crop can be used for animal feed, although for now, the root predominates in this use as well.

The main product of cassava cultivation in Colombia is the fresh root for direct human consumption. One of the challenges of fresh cassava is its perishability since it must be consumed or processed within 48 hours after harvest. To extend the life of the root, it can be waxed, or processed (peeled, chopped, or for the production of flour) for sale in frozen and precooked product versions. Cassava croquettes (fresh and frozen) and various snacks are also commercialized. Value added products made from roots also generate effluents (from root washing) and solid by-products (peels and root tips). The peels are often given to producers for use in compost, or to livestock farmers for consumption without processing as animal feed.

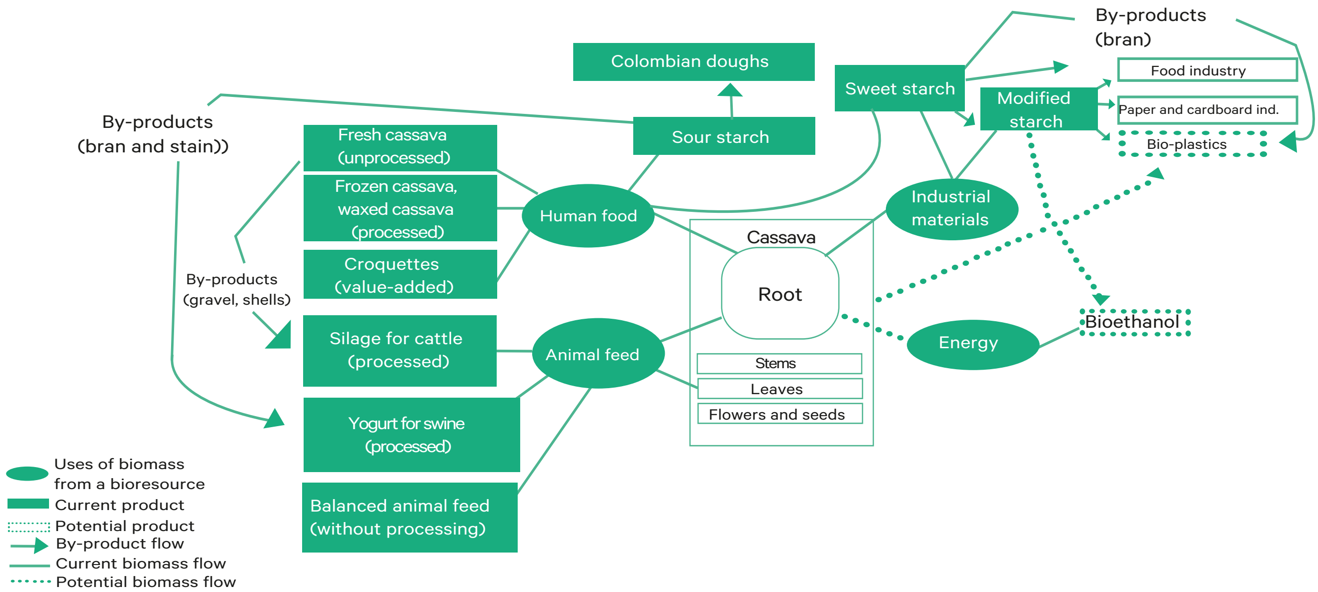
Starch is also obtained from the root. In Colombia, sour starch and sweet starch, also called native or industrial starch, are produced. Sour starch is produced on a small and medium scale in mills known as *rallanderías* and is an input for the production of Colombian doughs (e.g. *pandebono, pan de yuca*) (Taborda 2018). Sweet starch is produced by large-scale industry, and is an input in various other industries. The production of sour starch generates by-products (e.g. bran) and effluents with high cyanide contents. The solid by-products can be used as inputs in the production of concentrates for animal feed, while the effluents are mostly discharged directly into rivers or onto land, except in large starch mills (*rallanderías*) that have wastewater treatment plants (WWTP). According to our interviews, approximately 10 of the 60 operating *rallanderías* in Cauca have a WWTP. The production of sweet starch also generates solid by-products which can be commercialized, and the effluents are treated in WWTPs. In the Amazon, the effluents from artisanal starch production with high cyanide content are used to make *tucupí*, a spicy sauce that is marketed both in the Amazon and in gourmet markets.

Cassava is also used for animal feed. On the Atlantic Coast, fresh cassava is used with or without processing to feed cattle in times of drought and absence of pastures. One process is silage for cattle which includes an anaerobic fermentation process of leaves, stems and roots to conserve biomass. Additionally, there is some production of cassava yogurt for swine in which residues from fresh cassava production (e.g. tips, thin cassava, husks) are used. Dried root pieces and flour are also produced for animal feed.

In Colombia there have been several unsuccessful attempts to promote the use of cassava biomass for energy. For example, in 2006 a project was announced for the construction of a cassava ethanol production plant in Corozal, Sucre. However, in 2009 a starch production plant was built in its place, now ADS.

The use of cassava as an industrial material is mainly based on sweet starch. In Colombia, cassava starches are used as binders in the food industry, as glues in the paper and textile industry, as coatings in the pharmaceutical industry, and as binders in the cosmetics industry. Recently, there is evidence of a development, still at the research level, for the production of flexible and semi-rigid bioplastics that includes the use of cassava peels, leaves and starch.

Figure 2. Value web for cassava biomass in Colombia



Source: internally developed

4.2.Links between actors in the value web

From the analysis of linkages between actors, it was identified that there are relatively independent production units due to the fact that consumption is mainly fresh and the industry requires marketing within a few hours of harvest. However, dried cassava and cassava starch do move between units and there are even imports of cassava starch (see Figure 3). In the financial linkages, it is observed that current financing for primary production of small producers is essentially through microfinance institutions, without much presence of state financing lines, while in processing, the importance of royalty funds is mentioned, although these funds are still insufficient and it has not been possible to include the industry efficiently (see Figure 4). Finally, in knowledge linkages, CIAT and Agrosavia stand out as suppliers of knowledge for primary production, while the Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA) and the University of Cauca, the National University and the University of Valle are recognized as generators of knowledge at the processing level. However, the presence of spin-offs is still limited (see Figure 5).

4.2.1 Commercial linkages

Although cassava is cultivated in 32 departments in the country, Cauca, the Atlantic Coast, Orinoquía and Amazonía were identified as the productive nuclei. Actors are included throughout the supply chain: primary production, processing and marketing.

The Cauca production centre. Primary production in Cauca is mainly destined for sour starch. However, industrial cassava is also consumed as human food after several boiling processes. The crop is grown by small farmers including members of indigenous groups and is developed in plains and hillsides (Taborda 2018), and presents an intensification in the use of agrochemicals in recent years (Corpoica, MADR, Colciencias 2016). Some producers are associated (e.g. Asociación de yuqueros del Municipio de Morales Cauca (Asyumor)), but many are independent. Producers sell cassava to rallanderías through "company" systems or independently to intermediaries on the roads. In the company system, the rallanderías offer direct purchase from the producer, provision of herbicides, technical assistance, and promote fertilization with poultry manure. The production system of indigenous groups is developed through the *mingas*, the reciprocal collective work in the communities (Obando 2015). One interviewee mentioned that there is mistrust between indigenous producers and small and medium-sized rallanderías. Many rallanderías also have their own cassava crops in order to secure inputs and have better price control.

The rallanderías transform roots into sour starch. In Cauca, the number of rallanderías decreased from 210 in 1995 to 60 in 2018 (Agencia de Noticias UN 2018). This decline is explained in part by the pressures exerted by the Regional Autonomous Corporation of Cauca, the environmental authority for the control and management of wastewater discharges, and the sanitary control of the National Institute for the Surveillance of Medicines and Food (INVIMA) on the manufacture of sour starch. This is an example of how environmental regulations and their enforcement can increase the environmental quality of production processes and generate incentives for more sustainable production, protecting the ecosystem and the quality of products for human consumption.

The rallanderías produce an average of 2 tonnes of sour starch per day, and only some of them are associated (e.g. Asociación de Rallanderos del Cauca (Asoraca)). Among the most important rallanderías is Almidones 1A. The sour starch from Cauca is sold to bakeries nationwide for the production of Colombian doughs. Each rallandería has regular customers. Although the largest bakery market is in Bogotá, other important sales also occur in Valle del Cauca and the coffee-growing region. Sour starch is also sold to wholesalers for distribution to small bakeries. A recent commercial transaction is the rental of sun-drying space from non-operational rallanderías to rallanderías with growing production. From sour starch by-products, bran is marketed for the production of concentrates for animal feed. However, at the national level, this commercialization depends on the price of corn. When the price of corn is high, animal concentrate companies buy bran for the production of animal feed concentrates. If the price of corn is low, the bran is not sold and is generally abandoned and decomposed in the areas surrounding the grated cassava fields. In Cauca, bran is mostly sold on the road to intermediary families who dry it for future sale.

The Atlantic Coast nucleus. Cassava production on the Atlantic Coast is mainly for human consumption. In this area, most of the land is owned by cattle ranchers, so agriculture is carried out on seasonally leased land (only once a year), limiting investment in technical practices (e.g. fertilization, irrigation). If leases end and cassava is not harvested on time, landowners let cattle onto the land to feed on the crop. Cattle ranchers also have cassava plantations for silage to feed cattle in times of drought (Agricultura y Ganadería 2020).

In addition to fresh cassava, there is a growing production of industrial cassava in this nucleus, with varieties that are characterized by high yields (25 tonne/ha) and are not suitable for human consumption. Two of the three departments with the highest industrial cassava production are located in this nucleus: Córdoba and Sucre (the third is Cauca). This crop requires at least 10 ha to be profitable. However, in this nucleus, production is on a small scale, on farms averaging 4 ha.

The following actors are involved in industrial cassava production: the National Association of Cassava Producers and Processors (ANPPY), the Agro-industrial Cooperative of Betulia – Sucre (Cooagrobetulia), and two starch processing companies, ADS and Ingredion. ANPPY, founded in 1986, is a trade organization. Its 20 members cultivate between 600 and 1000 ha of cassava annually. ANPPY produces mainly industrial cassava for sale to ADS and Ingredion, and dried chopped cassava for the feed industry (e.g. Colanta, Solla, Italcol). Cooagrobetulia also produces dried chopped cassava for sale to Colanta.

ADS is a company created by the state that produces sweet starch and has a network of producers with whom it signs advance contracts. In 2019, ADS signed 109 advance contracts equivalent to the production of 608 ha. Furthermore, this company is also part of the national programme "Coseche y Vende a la Fija" (Harvest and Sell) and has signed 18 supply contracts in conjunction with the DAVIVIENDA bank (Almidones de Sucre 2020). The ADS plant currently operates on 15 calendar days for its production and for the other 15 days it provides the tolling service for Ingredion (Almidones de Sucre 2020). ADS's largest market is Grupo Nutresa to whom it sold approximately 59% of its production in 2019. ADS offers the by-product bran for sale and if there are no buyers, it gives it away. Interviewees mentioned that the relationship between cassava producers and ADS could improve.

Ingredion is a branch of Ingredion Corporation, a US-based multinational that produces various ingredients for the food industry, including sweet cassava starch. Ingredion is the largest ingredient supplier to the domestic food industry (MADR 2017). The main suppliers of cassava starch are companies in Brazil and Paraguay; however, Ingredion also has advance contracts with 280 smallholder farmers (between 5 and 10 ha) of industrial cassava in Sucre and Córdoba, through the project "Sowing cassava, we cultivate progress" (Ingredion Colombia 2020). ANPPY is also one of the suppliers, with advance contracts for up to 30% of the final amount (90% at germination and the other 10% at the beginning of harvest). According to the interviews conducted, cassava producers prefer Ingredion's programme to ADS's since the price is fixed and it offers technical support.

Colanta is a dairy cooperative located in the department of Antioquia. Its inclusion in the cassava value web is due to the Bitter Cassava for Sweet Milk project which uses dried and chopped industrial cassava produced in Bajo Cauca and the departments of Córdoba, Sucre and Cesar. Procurement is also carried out through advance contracts with small producers, including ANPPY members, equivalent to 1060 ha of cassava from 500 farming families. The dried chopped cassava is used to feed the cattle of Colanta's dairy farmers (Colanta 2020). This project includes technical assistance, credit and input sales for primary producers.

This nucleus also produces cassava for sour starch. This starch is produced in small and medium-sized rallanderías following the model of the Cauca nucleus. This starch is important as an input for small and medium-sized snack and traditional food enterprises (e.g. *diabolín, casabe*) led by women.

The Orinoquía nucleus. This nucleus mainly produces cassava for human consumption. It is the main supplier to Bogotá and is the nucleus with the highest yields. In this region there is a commitment to promote the fresh cassava market for sustainable value chains and processes.

One of the main actors in this nucleus is Agrícola del Llano (Agrollanos) which has one of the largest-scale productions (300 ha) in Colombia and a small supply network (approximately 5%) that includes small producers in Meta. Agrollanos' crops are technified. They practise fertilization and experiment with drip irrigation. Agrollanos processes cassava into peeled and precooked cassava (croquettes) and markets fresh frozen peeled cassava, waxed cassava (23%) and washed cassava (10%). Agrollanos supplies companies such as McCain (formerly Congelagro), a leader in frozen agricultural products in Colombia, with which it has advance contracts (Castro Rodríguez 2017). It also supplies restaurants and supermarkets (e.g. Éxito, Alkosto, Jumbo, Carulla) (Castro Rodríguez 2017).

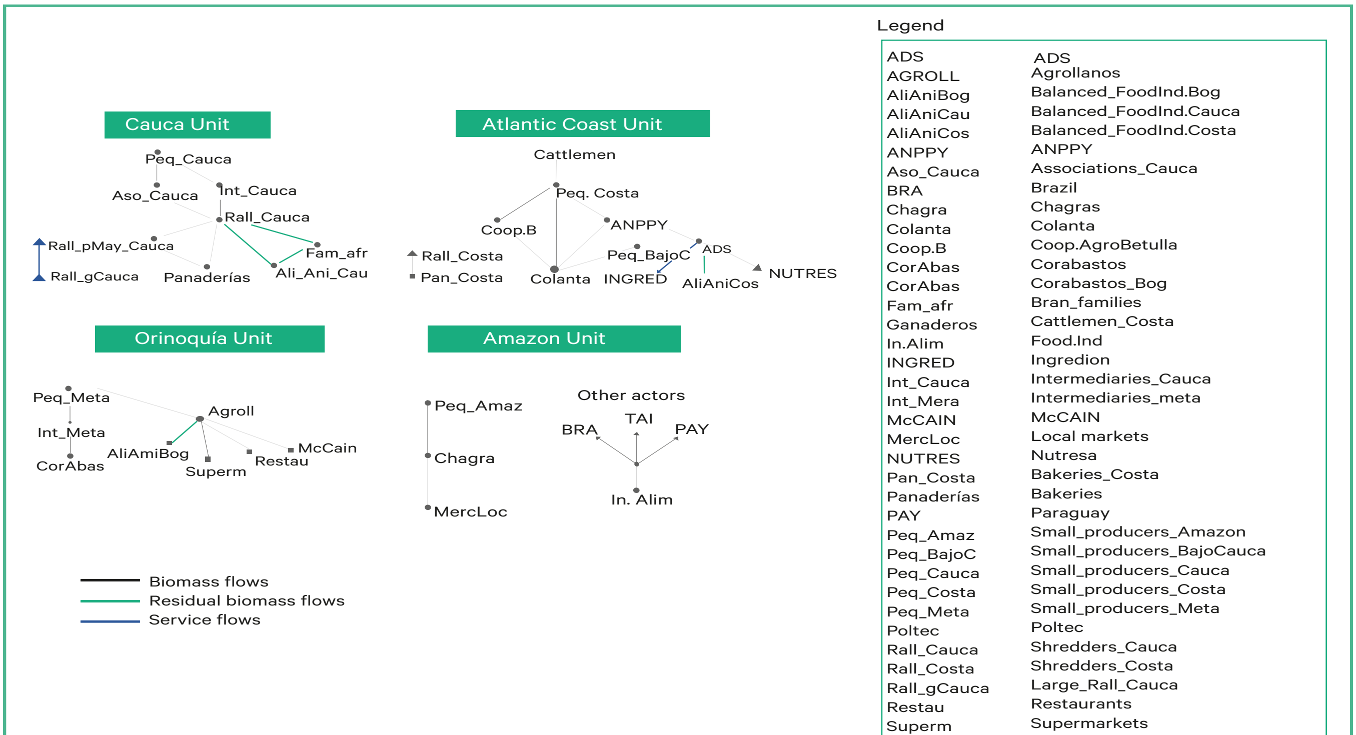
The Amazon nucleus. In the Amazon, production is carried out by families of indigenous groups in *chagras*. In this nucleus, cassava cultivation is carried out throughout the year. In the Amazon, the *chagras* have an approximate production of 30 kg cassava/day which includes up to 15 different varieties. These varieties are all considered suitable for human consumption regardless of their cyanide content. The cassava is peeled by women in the *chagra* and transported on foot to family homes for processing or consumption. The peels are left on the plot to be used as compost.

The transformation is for the artisanal production of sour starch, cassava, *fariña* (fermented flour), *masato* and *tucupí*. The residues from starch processing, which are an environmental problem in other regions, are used for self-consumption or commercialization. There is currently a pilot research project with the Sinchi Institute and the University of Cauca for the production of biodegradable packaging in the Amazon with the objective of reducing plastic waste.

Other commercial actors in the value web. Another key player is Poltec SAS (Poltec), a company dedicated to the modification of starches for different uses and applications. Poltec imports 80% of native starch from Paraguay, Nicaragua or Thailand due to insufficient domestic supply (Poltec 2019). Poltec-modified starches are marketed for the production of various products for the domestic food industry, including creams, food coatings, dressings and desserts (Rodriguez-Sandoval et al. 2017).

Finally, another important actor is the National Federation of Cassava Producers and Processors (Fedeyuca), a private initiative of actors in the value chain to promote the establishment of a guild of cassava producers and processors at the national level.

Figure 3. Commercial linkages in the cassava value web in Colombia.



Source: internally developed

4.2.2 Financial linkages

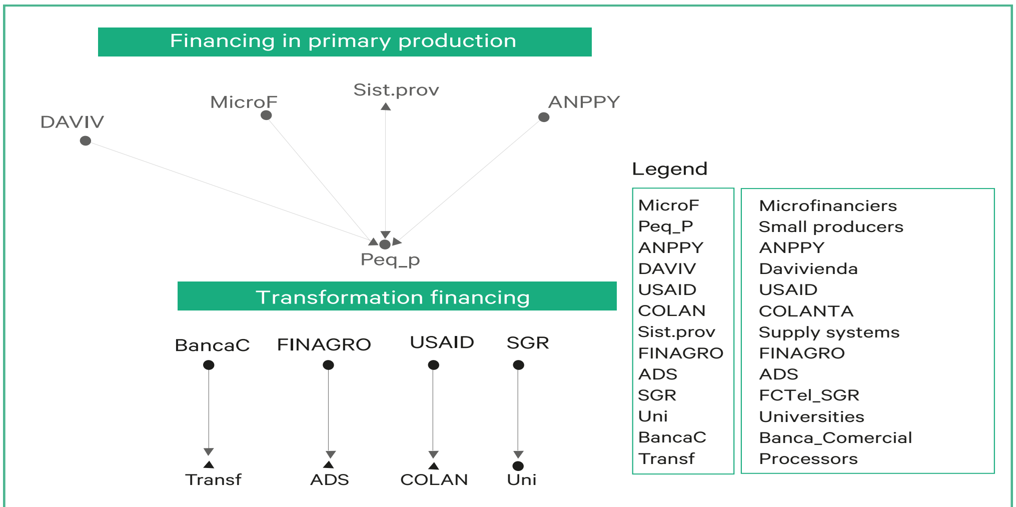
Financial linkages in primary production. Access to credit for small producers is limited. Lack of land ownership is an impediment to accessing credit, especially when not part of a supply system (e.g. advance contracts, letters of intent to purchase). In 2017, those who had access to financing obtained it through direct bank credit (50%), bank credit through associations (20%) and through supplier systems (30%) (MADR 2017). According to interviewees, the institutions that provide most credit to small producers are microfinance institutions (e.g. Crezcamos, Interactuar, Banca Mía). These are preferred over other institutions such as Banco Agrario due to their lower requirements and faster disbursements. Of the loans obtained through associations, it was identified that ANPPY grants loans for obtaining agricultural inputs to its associates.

Since 2015, supply systems have been carried out through advance contracts with producers of industrial cassava and fresh cassava (SIOC 2020). In some cases, these contracts have been used as a guarantee for access to credit. For example, the Harvest and Sell programme has used advance contracts as collateral to obtain 10 credits totalling COP 284 million with the DAVIVIENDA commercial bank (Finagro 2019). These loans for small and medium-size producers have effective annual rates of 6% and 7%, respectively, and financing equivalent to 80% of the premium for agroclimatic risk insurance (MADR 2019).

Financial linkages in the transformation link. Four types of financing were identified in the processing link, including equity investments, loans for machinery, international cooperation funds for projects, and public financing to develop new processes and products. Only one case of capital investment was identified, through Finagro's capital fund, for the establishment of ADS. Loans for machinery were granted to rallanderías. Commercial banks are the main providers of this type of credit, although some medium-sized rallanderías have been able to access Finagro loans at low interest rates. Only one case of international cooperation financing was identified: the United States Agency for International Development (USAID) for the Bitter Cassava for Sweet Milk project to which it contributed USD 5.3 million and Colanta contributed USD 38.3 million (Colanta 2020).

Public funding support for the development of new products and processes is one of the main drivers in Colombia's cassava value web, especially funds from the General Royalties System through the Science, Technology and Innovation Fund (FCTeI-SGR). These have been used to finance research and innovation projects with public universities and research institutes (e.g. University of Cauca, University of Valle, Sinchi Institute). Between 2010 and 2017, 19 R+D+I projects related to cassava were funded, including product development and generation of new varieties (García Blanco 2020). One example is the production of biodegradable cassava gloves, bags and plates developed by the University of Cauca in agreement with the Governor's Office of Cauca and with the participation of CLAYUCA (Universidad del Cauca 2018). Another example is the company-state-university alliance with Poltec for the development of methods for cassava starch applications in various industries. However, this funding continues to be considered insufficient, particularly to involve the industrial sector.

Figure 4: Financial linkages in the value web



Source: Internally developed

4.2.3. Knowledge linkages

Knowledge linkages in primary production. CIAT, part of the Consultative Group of International Agricultural Research (CGIAR) alliance in Colombia, maintains the world's largest cassava germplasm bank and manages the Cassava Genome Operations Center. CIAT's main partner in Colombia for the cassava programme is Agrosavia. CIAT develops varieties that are nutritious, resistant to pests and diseases, or have specific properties for industrial processes. Agrosavia is responsible for releasing these new varieties to the market every two to three years, facilitating access to farmers through the CIAT Secretariats, the Secretariats of Agriculture, the Umatas, and other entities. However, despite Agrosavia's efforts, the use of these improved and safe varieties by farmers is still insufficient. The Sinchi Institute has also worked with CIAT in the identification of Amazonian varieties, finding 160 cultivated genotypes, most new to CIAT germplasm (Peña-Venegas et al. 2014). Access to CIAT's knowledge and expert advice is considered limited.

Farmers can seek technical assistance through Public Agricultural Extension Service Providers (EPSEA) and through supply networks. EPSEAs are contracted by the Rural Development Agency through local governments. However, the cassava chain has received limited technical assistance services from existing providers (Corpoica, MADR, Colciencias 2016).

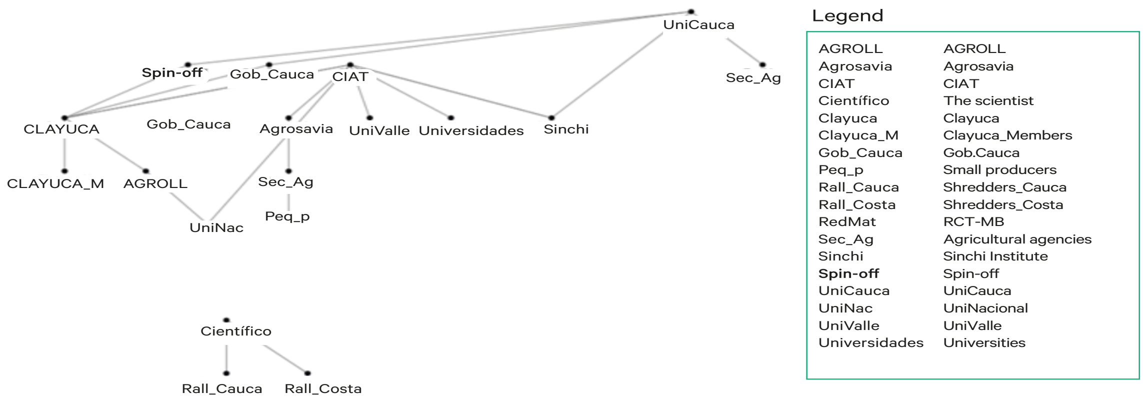
Knowledge linkages in processing. In sour starch production, knowledge for machinery and process development is limited and is developed through a system of trial and error. Industrial machinery for sweet starch production is not applicable to sour starch, as it operates at very high temperatures and would affect the fermentation process. The most important knowledge source for the rallanderías is a person from Cauca called "el científico" (the scientist), whose machinery is used both in Cauca and on the Atlantic Coast. The knowledge of "the scientist" comes from the internet and YouTube, based on industry developments in Brazil and Thailand. CIAT also works on improving technological processes for the extraction of sour starch, mainly to reduce water and energy consumption, minimizing production costs, and controlling the quality of sour starch expansion. This is developed through research projects with local universities (e.g. the National University, Palmira, and Del Valle University).

In animal feed, Agrollanos and CLAYUCA were the key knowledge players. Agrollanos is developing a yogurt for swine feed with fresh cassava roots and by-products (ripios). This product is still in its pilot phase and has received advice from the Tropical Food Research Institute (INIVIT) of Cuba, the National University and CLAYUCA. CLAYUCA also stands out for its role in innovation and development of new production lines, particularly for cassava flour and cassava yogurt for animal consumption, and exchanges between Colombian and Caribbean companies.

In terms of industrial applications beyond the food industry, interviewees highlighted the role of the University of Cauca in the development of bioplastics. This university has developed biodegradable plastics based on flour, starch and cassava bran. In addition, in conjunction with the Governor's Office of Cauca and CLAYUCA, the University has established the technology-based company, or spin-off, named Bioempaques (Universidad del Cauca 2020). The University of Cauca is also working with the Sinchi Institute to transfer knowledge and technology to the industrial sector to use cassava roots and bagasse in the production of semi-rigid packaging, and in research on Amazonian cassava varieties. This university also leads the Technological Cooperation Network for the Development of Biodegradable Materials (RCT-MB).

Several universities also participate in the development of knowledge for transformation in the value web, especially those that receive funding from the FCTeI-SGR. The University of Sucre stands out for its efforts to develop products for human consumption (e.g. diabolines, breads, food supplements) and for carrying out technology transfer to small and medium-sized producers. The University of Antioquia stands out for its role in the development of cassava bioethanol and also cassava leaf animal feed. Other universities mentioned by interviewees include the University of Quindío (human food products) and La Salle University (transformation processes).

Figure 5. Value web for cassava biomass in Colombia



Source: Internally developed

5. Sustainability opportunities and challenges for the bioeconomy in the cassava value web

Opportunities and challenges in the cassava value web in Colombia are identified in order to ensure consistency with the concept of a sustainable bioeconomy.

5.1. Opportunities and challenges in trade or market linkages

One of the commercial opportunities is the unsatisfied demand for cassava starch evidenced by imports for the food industry. Starches are niche markets, which could guarantee better prices for producers (MADR 2017). To meet this demand, it is necessary to improve the productivity of industrial cassava cultivation and compete with imported starch from Thailand and Paraguay. However, the increase in domestic starch production will need to be planned at the territorial level considering the potential impact on the water bodies surrounding the production centres due to the high water demand of this industry.

Another opportunity to increase the national demand for cassava biomass is through government purchases. Currently, the School Feeding Programs (PAE) work mainly with imported wheat flour. However, these programmes could, for example, replace up to 15% of imported wheat flour with domestically produced cassava flour, encouraging short marketing circuits and benefiting domestic producers. Furthermore, flour production does not require as much water as starch. CLAYUCA has developed a technological process for the production of cassava flour for human consumption that could be used in rural plants, managed by producer communities and coordinated with school feeding programmes. However, this opportunity is also currently limited by the high cost of domestic cassava.

There is also market potential in the Colombian animal feed industry. The animal feed industry mainly uses imported corn, soybeans and sorghum. In 2020 this industry imported 8.1 million tonnes, including corn (68%) and soybean cake (19%) (ANDI 2020). The importance of imports of these inputs is reflected in the temporary suspension of tariffs on imports of these products in 2020 in order to reduce costs for the agricultural sector (Reuters 2020). These imports could be replaced by local cassava biomass inputs. This industry uses chopped dried cassava root, a low-tech product developed by smallholder farmers, but could also use crop residues (e.g. leaves and stems) and by-products from the starch industry (i.e. bran) and from fresh cassava-based value-added products (i.e. root tips, peels).

The bioplastics industry could also be a new market, if current growth projections are met. The University of Cauca already has several patents for the production of bioplastics with cassava inputs. However, there is still a need to develop products at the commercial level with local companies. For now, the price of domestic cassava (root) is not competitive with other sources of domestic biomass or with imported inputs (cassava starch), so it will also be important to include by-products or focus on production that is currently being lost. The global trend to restrict the fossil-based plastic market is an opportunity to encourage the bioplastics industry in Colombia. Legislative initiatives to support this trend could include promoting the use of domestic biomass and products generated by small-scale producers such as cassava.

Several of the described opportunities are aimed at industrial cassava production which requires more human capital than fresh cassava production in terms of the number of workers both in primary production and in processing. However, in order to contribute to an inclusive bioeconomy, it is important to identify who would be able to participate in these industrial supply chains, especially given the existing inequalities related to access to roads to transport biomass from the production plots to the industries.

5.2. Opportunities and challenges in financial linkages

One of the challenges is the limited access to loans for small cassava producers, which limits investments to increase productivity. This situation is partly due to the high levels of land leasing, especially on the Atlantic Coast. Access to loans, even when working on leased land, could be solved in part through the development of supply chains, whose contracts function as collateral. Current developments for the establishment of a guild, such as FEDEYUCA and the formalization of the production chain by Ministerio de Agricultura y Desarrollo Rural (MADR), are expected to provide institutional support to producers to expand access to credit.

Limited access to loans or financing in processing was also identified, especially for small and medium-sized enterprises. Most of these companies work with commercial banks, with few references to programmes or incentives developed by the state. These types of incentives or programmes could increase their access to financing, essential to include more efficient and environmentally sustainable production processes, such as investments in water-efficient production plants (10 and 20 m^3 per ton of starch) or in WWTPs.

5.3. Opportunities and challenges in knowledge linkages

One of the most important challenges for the development of a cassava value web for the bioeconomy in Colombia is the low technification of the crop, low productivity and high transaction costs due to the presence of intermediaries. Therefore, it is necessary to increase technical assistance or agricultural extension, including the increased use of improved seeds, encourage mechanization and fertilization practices, and promote the sustainable use of herbicides.

It is also necessary to ensure that the increased demand for cassava will not harm biodiversity. Several of the most important industrial cassava production centres are located near important ecosystems such as the tropical dry forest on the Atlantic Coast and the Andean Forest in Cauca. If cassava is to be promoted as a crop that respects biodiversity, the regional environmental authorities and the agricultural sector must work together to ensure that the soil use, the type of ecosystem in which it is grown, and climate change projections are considered.

A transition from plants for the production of specific products to biorefinery-type plants, in which the use of biomass is maximized, is proposed in the bioeconomy. Biorefineries are characterized by coupled energy generation, a combination of mechanical and thermochemical processes, and the use of different materials including residues (Hingsamer and Jungmeier 2019). This could be an option for cassava in Colombia, particularly if they are designed to maximize the use of residues. However, existing cassava biorefineries have been proposed taking into account central productions of starch and ethanol. The production of bioethanol from cassava has not been successful in Colombia and the six bioethanol plants that currently exist in Colombia are all from sugarcane. Research on the feasibility of biorefineries for cassava in the Colombian context will be key to develop a bioeconomy around this crop..

6. Key issues to increase the role of cassava in Colombia's emerging bioeconomy

The application of the value web and stakeholder mapping shows that the potential of cassava in Colombia's bioeconomy could be high, and it has some emerging markets where this potential could be developed. However, the average productivity of the crop in Colombia is below the leading countries in production and exports, such as Brazil, Paraguay and Thailand. This low production is partially explained by the situation of land ownership, the limited technification of the crop, and the lack of commercial coordination. From the industrial point of view, there is currently a production deficit in the national starch industry that is covered by imports. In order to develop the potential, key issues are presented that could represent the beginning of a roadmap to increase cassava's role in Colombia's emerging bioeconomy:

- Explore the various market opportunities for biomass beyond cassava root. There is a need to focus on being able to consume or process cassava root within 48 hours post-harvest to reduce the risk of perishability. For bitter cassava, one of the main unsatisfied market demands was identified in the starch market. However, competition from imported cassava starch represents a major challenge in terms of price. Another opportunity is in the market for biomaterials such as bioplastics. However, this industry is still developing in Colombia and faces competition from other starches. In human food, government purchases of products such as cassava flour for school feeding programmes could contribute to increasing domestic demand. In the feed and biomaterials industries, there is potential for using cassava biomass that is not currently utilized, such as harvest residues and agro-industrial wastes.

- Develop inclusive supply chains to counteract the low investment in the crop. The low level of technification of the crop is one of the main challenges facing cassava in Colombia. This could be countered, in part, through supply chains with small producers, including land tenants, and current restrictions on access to roads for transporting biomass should be considered. These chains could include mechanisms to increase access to loans for technification investments. These supply chains could serve as a platform to improve relations between small farmers and processors, and reduce transaction costs. Recognition of cassava as a production chain by the MADR and the FEDEYUCA guild (currently in formation) would play a significant role in establishing these chains.

- Promote cassava as part of a sustainable bioeconomy to address the environmental impacts of its production and processing. In this study, two issues were repeatedly mentioned by interviewees in terms of environmental impacts: the uncontrolled increase in the use of herbicides and soil erosion from hillside crops. These impacts must be addressed as part of a sustainable bioeconomy production. In processing, the sour starch industry, in addition to being water intensive, generates wastewater with cyanide content that without proper treatment can have a negative impact on water sources. To ensure their sustainability, the bioeconomy should include incentives to have WWTPs, including environmental regulations and the monitoring of their compliance by authorities at the territorial level. Furthermore, the circular economy, also part of the sustainable bioeconomy, can be a strategy to reduce waste generation, both from primary production and processing.

- Technify agricultural production to ensure its sustainability. One of the priorities to ensure a role for cassava in Colombia's bioeconomy is to guarantee the use of improved varieties with high genetic and phytosanitary quality. While the role of CIAT and Agrosavia is recognized by stakeholders, it has also been highlighted that efforts to bring these varieties to producers are insufficient. It is also necessary to encourage sustainable agricultural practices, expanding technical assistance services that increase productivity, while maintaining biodiversity and soil and water quality. These practices include fertilization and sustainable use of herbicides, considering climate change projections that will affect areas suitable for cultivation, as well as the incidence of pests.

- Generate more incentives for innovation and its integration at the commercial level. Research support for the development of new cassava products has been acknowledged. However, the need has also been identified for greater incentives to involve the private sector and achieve the commercialization of these products. Suggestions to encourage greater innovation include: tax exemptions for companies that produce high value-added products; use of the General Royalties System for the creation of startups or spin-offs; and expanding the supply of loans for small and medium-sized companies that want to invest in improving their machinery or developing more sustainable production processes.

7. Next research steps

In order to propose specific recommendations on key issues at the territorial level, it is suggested that the following additional research be carried out by production units or at the departmental level:

- Develop research on potential markets at the territorial level: (a) From public procurement, School Feeding Programs (PAEs) have been identified as sustainability tools for agriculture at the territorial level (Zuleta 2016). To increase the demand for cassava products within the PAEs, studies should be developed to identify why there have not been greater purchases of these products in the cereal-derived or accompanying cereal food groups. This, despite the fact that cassava is grown in all departments nationwide, and that since 2014 it is the territorial entities that select and contract supplies depending on availability at the regional level (MinEducación 2014). This research could also include evaluations on school feeding programmes in Brazil, Nigeria and Paraguay, which include cassava in these programmes as one of the policy incentives. These evaluations should include, not only market elements, but also issues related to bioeconomy objectives, such as impacts on employment and income for small farmers, and on the reduction of maize and wheat flour imports. (b) Investigate the potential of cassava in the feed industry at the territorial level, particularly for the integral use of the resource (roots, leaves and stems). This would include the experiences of silage and yogurt, as well as the potential impact on the gradual reduction of imports of inputs and their replacement by products derived from national cassava. It is recommended that this potential be developed at the territorial level through a more detailed mapping of actors at the nucleus level to maximize the use of short marketing circuits. (c) Within a territorial context, evaluate the potential of cassava and its derivatives for the production of biofuels and its derivatives for the production of bioplastics, within the framework of the new bill that bans single-use plastics and regulates their gradual replacement by biodegradable alternatives. In particular, how to address the higher price of biodegradable products in the Colombian context that can be up to two to three times higher than fossil plastic products, and taking into account the existing local recycling and plastics industries (Hernández Parada 2019).

- Investigate the impact of existing supply chains in terms of inclusion of small producers and investment in technification at the territorial level.
- Develop prioritization criteria to identify resources to be developed within the bioeconomies at the territorial level. This prioritization should include environmental aspects that guarantee sustainable production and transformation, including the potential for circular economies, as well as water and land use.
- Develop a critical evaluation of the Departmental Agricultural Extension Plans (PDEA). This evaluation should include criteria for productivity, sustainability and capacity building of producers in the PDEAs, in force since 2020, which include cassava as a priority crop. This evaluation would incorporate the analysis of proposed solutions to existing problems, including increased use of improved seeds, proper phytosanitary management of the crop and the incorporation of sustainable and climate-smart agriculture approaches.
- Identify whether there are specific incentives associated with innovation to generate products derived from cassava or other products of Colombian agro-diversity, particularly those products or processes with high added value.

8. Conclusions

Cassava has potential for development in various industries in Colombia's bioeconomy with the potential to benefit a large sector of small producers. However, these opportunities cannot be pursued if the current levels of low productivity in primary production that limit the crop's competitiveness persist. The increase in productivity must be generated without expanding the agricultural frontier, with sustainable practices, without neglecting the impact on water and prioritizing technical assistance to small producers. The guild and the production chain can play a fundamental role in the transfer of knowledge among the actors in the value web. One of the keys to cassava development within the bioeconomy framework is the development of products based on cassava residues (agricultural and agro-industrial). To this end, possibilities for the development of biorefineries based on this type of product should be explored.

It is likely that cassava, which has potential but also significant challenges, is similar to other bioresources that could contribute to the development of the bioeconomy in Colombia. The application of the value web and stakeholder mapping approaches in this network offers a model of how Colombia could organize rapid assessments of the potential of components of its biological wealth. This would allow progress towards a national-level bioeconomy vision that prioritizes an economy based more on renewable resources than on the extraction of non-renewable resources.

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Annex 1

Interviewees	Entity	Role
Javier Sánchez	Almidones 1A	Industry
Lili Sofia Mendoza	FEDEYUCA	Industry
Victor Hugo Hernández	Poltec SAS Company	Industry
Elías Rico	Agrollanos	Industry
Guy Henry	CIRAD LA	Research
Elvia Rosero and Olga Perez	Agrosavia	Research
Clara Peña	Sinchi Institute	Research
Héctor Villada and Juan Manuel Duque	University of Cauca	Research
Thierry Tran	CIAT- CIRAD	Research
Jairo Salcedo	Universidad del Sucre	Research
Tatiana Díaz	ANPPY	Primary producers
Bernardo Ospina	CLAYUCA Corporation	Technology transfer
Jenny Parra	Ministerio de Agricultura y Desarrollo Rural	Governing institution

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