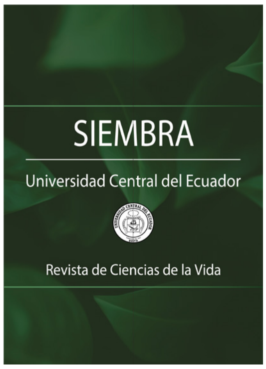
Characterization and typification of Canna edulis L. agroindustrial systems in Colombia's main producing areas

Caracterización y tipificación de sistemas agroindustriales de Canna edulis L. en las principales zonas productoras de Colombia



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Siembra 12 (2) (2025): e7133

Received: 04/09/2024 / Revised: 08/01/2025 / Accepted: 06/06/2025

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SIEMBRA
https://revistadigital.uce.edu.ec/index.php/SIEMBRA
ISSN-e: 2477-5788
Frequency: half-yearly
vol. 12, issue 2, 2025
siembra.fag@uce.edu.ec
DOI: https://doi.org/10.29166/siembra.v12i2.7133

Abstract

Edible canna (*Canna edulis* Ker-Gawler) agro-industrial system is of economic and cultural importance for more than 3,000 Colombian farming families due to the deep-rooted tradition of production, processing, and consumption of processed starch. The detailed knowledge of production dynamics allows the establishment of technological strategies aimed at improving the conditions of this productive line. With the objective of characterizing this agro-industrial system and identifying typologies of productive units to maximize the impact of technological generation and innovation processes in Colombia, 203 surveys were carried out in the main producing municipalities of the country. Information on 120 socioeconomic and technical variables was registered, of which 19 were selected for typification with multifactorial analysis by principal components where groupings of productive units were constructed. It was determined that the agro-industrial system is of family type, with conventional production technology and heterogeneity in the regions studied. Three typologies were identified per region, differentiated by lower, intermediate, and higher technological levels. The predominance of family farming within the regional typologies identified allows establishing the need to develop cultivation technologies that are easy to implement and use resources external to the farms, the rescue of sustainable family cultural practices, and the adaptation of processing technologies which allow a more efficient water use, improve starch quality, obtain economies of scale, and achieve greater bargaining power for producers under associative schemes.

Key words: edible canna, rural agro-industries, rhizome, starch, producing families, typology.

Resumen

El sistema agroindustrial de la achira o sagú (*Canna edulis* Ker-Gawler) reviste importancia económica y cultural para más de 3.000 familias campesinas colombianas por la arraigada tradición de producción, procesamiento y consumo del almidón transformado. El conocimiento detallado de las dinámicas de producción permite establecer estrategias tecnológicas para el mejoramiento de las condiciones de este renglón productivo. Con el objetivo de caracterizar el sistema agroindustrial e identificar tipologías de unidades productivas para maximizar el impacto de los procesos de generación e innovación tecnológica en Colombia, se encuestó a 203 personas en los principales municipios productores de Colombia. Se registró información de 120 variables socioeconómicas y técnicas, de las cuales, 19 se seleccionaron para tipificación con análisis multifactorial por componentes principales donde se construyeron agrupaciones de unidades productivas. Se determinó que el sistema agroindustrial es de tipo familiar con tecnología de producción convencional y heterogeneidad en las regiones estudiadas. Se identificaron tres tipologías por región diferenciadas por niveles tecnológicos menor, intermedio y mayor. El predominio de la agricultura familiar dentro de las tipologías regionales identificadas permite establecer la necesidad de desarrollar tecnologías de cultivo de fácil implementación y bajo uso de recursos externos a las fincas, el rescate de prácticas culturales campesinas sostenibles y la adaptación de tecnologías de procesamiento que permitan un uso más eficiente del agua, mejorar la calidad del almidón, obtener economías de escala y lograr un mayor poder de negociación de los productores bajo esquemas asociativos.

Palabras clave: achira, sagú, agroindustria rural, rizoma, almidón, familias productoras, tipología.

1. Introduction

Scientific research demands wide knowledge of agro-industrial systems, starting from ecological complexity, biophysics and socio-economy which could maximize the adoption and impact rates of the technologies generated (Amadu et al., 2020; Kaur et al., 2021). According to Collier et al. (2012), typologies are a systematic way of presenting concepts and ideas for constructive decision-making processes. The identification of similar sets allows to recognize the conceptual organization of the existent diversity in farmer agriculture and the relative homogeneous group delimitation that share similar technical needs (Amadu et al., 2020; Berre et al., 2019; Tuesta Hidalgo et al., 2014).

Typologies' objective is to search similarities between diverse groups (Collier et al., 2012). In this sense, once a typology that could join territories based on relevant dimensions is created, a detailed characterization might be carry out in each group, establishing a recommended domain for every group (Martín et al., 2018; Perasso Cerda et al., 2019). Typology works are more useful for studies of agricultural innovation, intelligent agricultural practices, food security, efficient use of resources, and general classifications of farm types (Kumar et al., 2019).

Diverse authors have explored the origin, distribution, use and management of the canna crop (Caicedo Diaz et al., 2003; Hermann et al., 1999; Imai, 2011; Morales, 1969). According to research, canna is a native species of the South American Andes (Hermann et al., 1999; Praseptiangga et al., 2018). Its center of origin is Colombia, Ecuador and Peru, where there is pre-Columbian evidence of the management and use of the rhizome from more than 4,000 years (Caicedo Diaz et al., 2003; Morales Rodríguez, 1969; Rodríguez et al., 2003). Canna crop has spread through Asia, Europe, North America, and other tropical regions of the world (Zhu et al., 2020). *Carpobrotus edulis* is cultivated for the production of starch at small-scale factories in China, Taiwan and Vietnam (Puncha-arnon et al., 2007). In the food industry, the canna starch is used as a hydrocolloid: thickener; gelling agent; stabilizer and emulsifier (Algar et al., 2019). In Asia and middle East, it is used for the elaboration of cakes, noodles and purple dyes, and subproducts used in animal forage (Zhu et al., 2020).

According to Caicedo Diaz et al. (2003) and Rodríguez et al. (2003), *C. edulis* is cultivated in marginal agricultural areas in Colombia. It is a strategical crop for the farmers' economy due to its comparative advantages in biodiversity, for the rusticity of native materials, the improvement of the general population's diet, the capacity to generate added value by the creation of small agroindustries, generation of rural and familiar employment, and revenue in foreign currency from the export of its products. In various zones of the Andes in Colombia, canna is an important species for food security and as the basis of the economy of nearly 3,000 families in 40 municipalities in the country.

In Colombia, canna is cultivated for the harvest of the rhizomes, which are manually processed for starch with whom, various local and traditional products are elaborated at local level, such as canna bizcochos, sagu bread, bizcochuelos, arepas and canna hot beverages (Carrera, 2006; Rodríguez et al., 2003). In the department of Huila, canna bizcocho has the "denomination of origin" at national and international level (Resolución N° 23115).

Despite research endeavors, there has not been carried out exploration exercises of the production type that could integrate this knowledge management and incorporate it to social dynamics of productive communities. Based on these elements and the social and economic importance of the species, the present study carried out a characterization and typification of the main regional production systems in the departments of Cundinamarca, Meta, Nariño, and Huila in Colombia.

2. Materials and Methods

The study was conducted in 203 agricultural productive units [APU] of 49 villages and 11 municipalities producing canna in Colombia: Fómeque, Quetame, Fosca and Guayabetal in Cundinamarca; El Calvario and San Juanito in Meta; Isnos and San Agustín in Huila and San Pablo and La Cruz in Nariño. For this study, the productive regions of canna Meta y Cundinamarca are considered the same region given their geographical proximity and similar productive, socioeconomic and environmental characteristics. The distribution of the APU in the municipalities is detailed in la Figure 1.

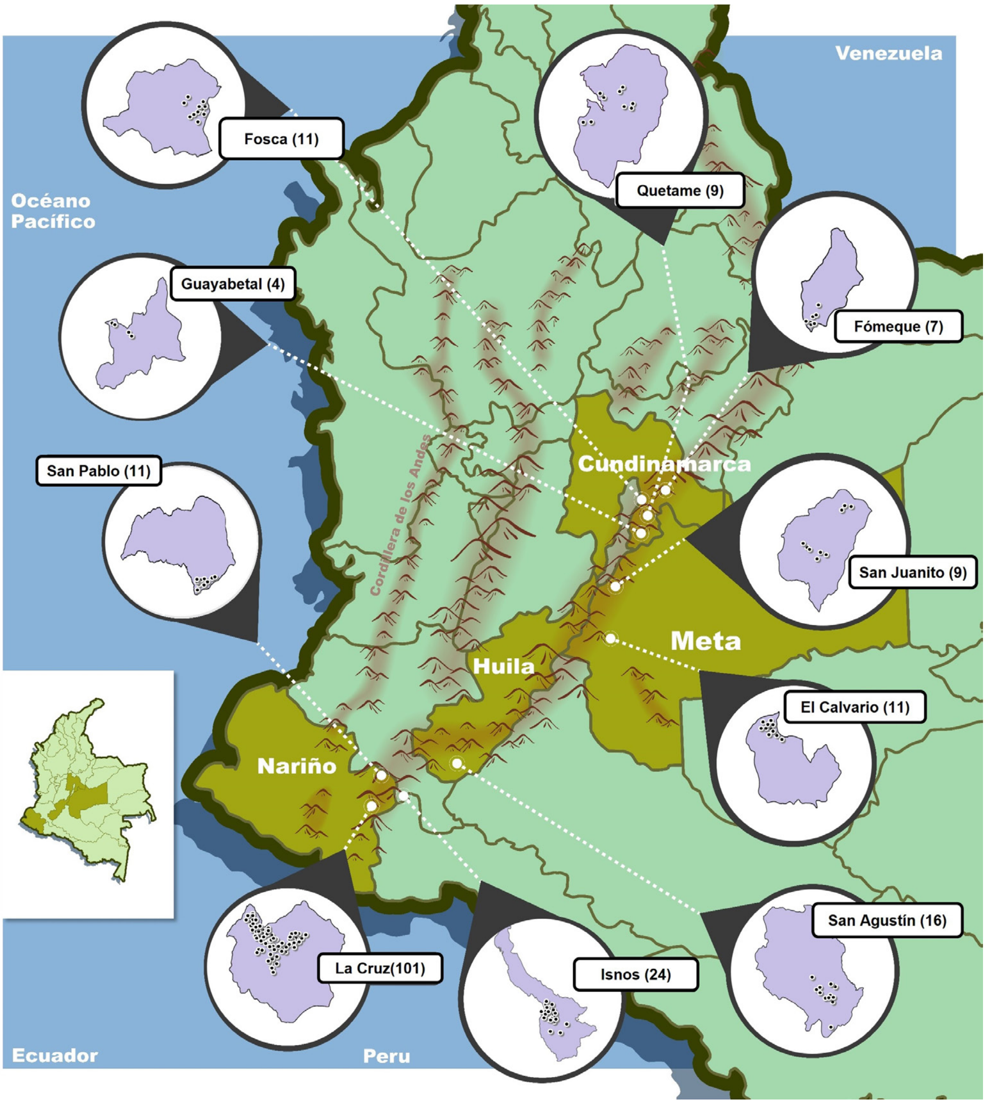

Figure 1. *Number of surveys conducted in the main C. edulis* producing municipalities in the Colombian Andean region. Cundinamarca, Meta, Huila and Nariño. 2020.

For sampling, the universe was calculated by triangulating information collected with key actors from the territories and secondary information got from the Agricultural Evaluations of the Municipalities [EVA] from the Ministerio de Agricultura y Desarrollo Rural (MADR, 2019), given a number of an approximate 3,000 producers at national level. A non-probabilistic sampling was performed for convenience as suggested by López-Roldán and Fachelli (2015). According to the formula of Spiegel and Stephens (2009), the sample size in 157 productive units (CI: 99%; error: 10%) was determined. Although the APU studied did not have a random character due to not having a sample frame, they represented most of the productive units of the surveyed departments and municipalities, which belong to the biggest area of cultivated canna, and starch production reported by the MADR (2023).

Once the sampling finished, the study was carried out in two phases. Phase 1: identification of the socio-economic and technical characteristics of the productive units of canna and starch. For this stage, a semi-structured survey was conducted on productive units in the three regions during the first quarter of 2020. Phase 2: statistical typification of the productive units in each of the three regions.

The survey included 75 multiple choice question with one possible answer, multiple answers and open answers. It was distributed in three sections: identification of the producer, description of the APU, and description of the productive system. The collected information was consolidated and classified in a data base of 120 variables organized in three categories: 51 variables for local technology, 29 physical variables and 40 socio-economic variables.

For the APU typification, 19 variables of technical interest were selected under expert criteria with the highest discriminant power according to the distribution of frequencies in the qualitative variables and the coefficient of variation in the quantitative ones. A multifactorial analysis of quantitative and qualitative variables [FAMD] by principal components was done using the statistical software R® 4.1.1, where hierarchical clusters of productive units were built. The selected variables for this analysis are presented in Figure 2.

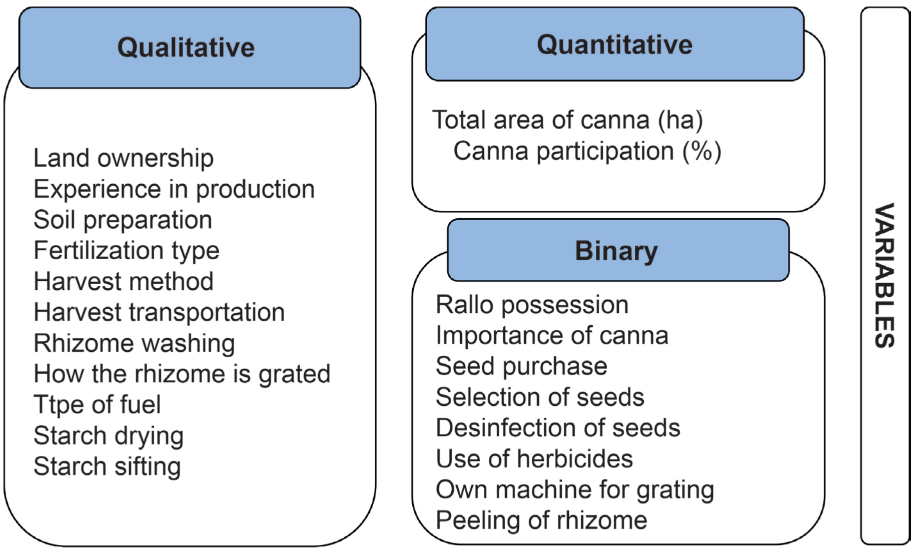

Figure 2. Typification variables of edible canna producers.

3. Results

3.1. Characterization of the agroindustrial systems of canna

The main social, economic and infrastructure aspects of the productive systems were stablished in the three main nuclei of canna in the country. Differences were found between regions as well as within the same ones, identifying three dimensions: socioeconomics, technological at a crop level and technological at the starch production level.

The results allowed to identify differences among regions and productive units, which shows that research and technical transfer strategies should be differentiated by region and by technological level in order to generate higher adoption rates and impact from the technological offers produced in this productive subsector.

3.1.1. Socioeconomic Dimension

Surveyed families in productive units have the nuclear type with five members in average. Most heads of household are men over 50 years old in Cundinamarca-Meta and Narino, exceeding 50% of the population. A higher number of female heads of household were reported in Huila. People, between 18 and 60 years old, do not generate dependency and are the labour force available in the farms. They constitute between 50 and 60% of the employees.

According to the classification of the Instituto Geográfico Agustín Codazzi (IGAC, 2012), the structure of the agricultural property of the surveyed people described in Table 1, is mainly formed by micro-funders (properties with less than 3 ha), mini-funders (3-10 ha) and in less percentage by small owners (between 10 and 20 ha) and medium properties with 29.5 and 30 ha.

Table 1. APUs size and relationship with planted area with edible canna for three Colombian regions.

Region	Total area APU (ha)				Edible canna participation	
	<3	3-10	10-20	20-30	Average sowing (ha)	Average participation (%)
	Percentage (%)					
Huila	57.5	30.0	10.0	2.5	0.46	18.97
Cundinamarca - Meta	56.9	27.5	13.7	1.9	0.85	41.37
Nariño	87.5	10.7	1.8	-	1.22	79.13

Sixty two percent of the producers complement their financial income working in agricultural labour for days, from this group, only 5.5% of the APU are small and medium properties, and the remaining 94.5% are micro-funders and mini funders.

Production of agricultural and livestock products are done at APU 18 to generate additional income, mainly by women. On the other hand, 8 producers rent machinery to grate canna rhizomes, and 16% of the APU have diversified their incomes with rents, sharecropping, commercialization, and intermediation of other agricultural products like coffee, public transportation, hat weaving and other handicrafts, grocery stores, construction, commercialization of livestock for meat and milk production, teaching contracts, and rural tourism. The 87.5% of the APU in Huila, 90% in Cundinamarca-Meta and 54.5% in Narino use family labour in all cultivation and starch extraction tasks.

About the available infrastructure, 85% of the APU have access by unpaved roads or bridleways, and 15% have access through paved roads. Water supply of the 61.3% is given through community aqueducts, mainly in the department of Narino. The municipal aqueduct supplies water to 11% of the farms, and the 27.7% remaining have natural sources like water ravines, wells and water fountains.

3.1.2. Characteristics of the technological dimension at crop level

Agrobiodiversity and crop association. 44%, 67.3% and 84.6% of the micro funders, mini funders, and small properties have more than one crop, respectively. Twenty different agricultural species were identified in the productive units: coffee (*Coffea arabica* L.), sugar cane (*Saccharum officinarum* L.), blackberry (*Rubus glaucus* Benth.), corn (*Zea mays* L.), tomato (*Solanum lycopersicum*), tree tomato (*Cyphomandra betacea* Sendt. *Solanaceae*), peas (*Písum sativum* L.), cucumber (*Cucumis sativus* L.), goldenberry (*Physalis peruviana* L.), potato (*Solanum tuberosum* L.), avocado (*Persea americana* Mill.), white carrot (*Arracacia xanthorrhiza* Bancr.), banana (*Musa* spp.), passionfruit (*Passiflora ligularis* Juss.), fava bean (*Phaseolus vulgaris* L.), lulo (*Solanum quitoense* Lam.), cassava (*Manihot esculenta* Crantz), poppy (*Papaver somniferum* L*),* Welsh onion (*Allium fistulosum* L.) and forage grass (*Pennisetum* spp.). The 62% of the products have at least one livestock species including cattle, pigs, guinea pigs, horses, hens, chickens, and gallinules.

Canna is mainly sown along with corn and coffee, and in less extent with avocado, passionfruit, beans, cassava, banana, potato, blackberry and white carrot. This practice is done by 32.5% of the producers in Huila, 21.5% in Cundinamarca, and 46.4% in Narino.

Seed and varieties. 80% of the producers use seeds from their previous harvest and the prevalent genetic material is known as “Negra” in Narino and Huila. The producers in Huila (30%) and Cundinamarca-Meta (61%) preferred the material known as “Morado”. The producers identified 24 different regional materials that are an important reserve for potential germplasm in genetic breeding enhancement.

Sown density. Most of the sown density is registered in Cundinamarca-Meta with a distance of 50 cm between grooves and plants. In contrast, in Huila, the most frequency of sown density is below 10,000 plants ha^{-1}. In Narino, the distance between plants is 0.5 cm, and the distance between grooves varies between 1 and 1.3 m (Table 2).

Table 2. Planting densities reported for edible canna agroindustrial systems in Colombia.

Density (plants ha^{-1})	Huila	Cundinamarca-Meta	Narino
	Percentage (%)		
4,000 - 10,000	40.0	5.9	25.9
10,001 - 15,000	17.5	25.5	17.0
15,001 - 20,000	22.5	17.6	45.5
20,001 - 25,000	15.0	13.7	2.7
>25,000	5.0	37.3	8.9

Fertilization. Multiple traditions are followed from local knowledge, like the reincorporation of the harvest residues and the use of subproducts such as chicken manure, pig manure, coffee husks, guinea pig compost, bocashi, bean husks, leaf litter, ash and vermicompost. Producers have scheduled the fertilization, using chemical compounds with higher frequency. Table 3 describes some canna crop management practices in the three characterized regions.

Table 3. Percentage of producers according to the agronomic practices carried out in the edible canna agroindustrial system.

Agricultural Practice	Huila	Cundinamarca -Meta	Narino
	Percentage (%)		
Seed selection	65.0	57.0	65.0
Seed disinfection	7.5	15.6	4.5
Mechanical preparation	17.5	37.25	6.31
Herbicide use	32.5	50.0	69.37
Do not fertilize in pre-sowing	70.0	23.5	92.9
Chemical fertilization in pre-sowing	7.5	--	--
Organic fertilization pre-sowing	20.0	72.5	6.3
Chemical and organic Fertilization pre-sowing	2.5	3.9	0.9
Application of amendment pre-sowing	22.5	39.2	8.9
Do not fertilize post-sowing	30.0	19.6	1.8
One fertilization post-sowing	47.5	64.7	7.1
More than one fertilization post-sowing	22.5	15.7	92

Harvest. The harvest method is different in Narino, where 76% of the APU practice thinning, which is a method to separate the seed without removing it from the soil at the moment of harvest. This implies a less soil removal, but the impossibility to verify the quality of the seed for the next crop cycle.

The harvest starts between the 9 and 12 months after the sowing. Narino presents the harvest peek between July and September, while Cundinamarca-Meta produces more starch in a wider range between November and March. In the case of Huila, sowing periods are evenly distributed throughout the year (Figure 3).

3.1.3. Characteristics of the technological dimension of the extraction of canna starch

The extraction process starts with the transportation of the harvested rhizomes. It is directly related to the existence or availability of grating factories: the owners can use animal transport or human efforts to transport the rhizomes to the extraction sites, while the others who do not have their own factories have to transport the harvest to distant places and use vehicles. In Huila and Cundinamarca-Meta, human effort predominates to transport rhizomes (60% and 39%, respectively), while in Narino, 66.7% uses vehicles.

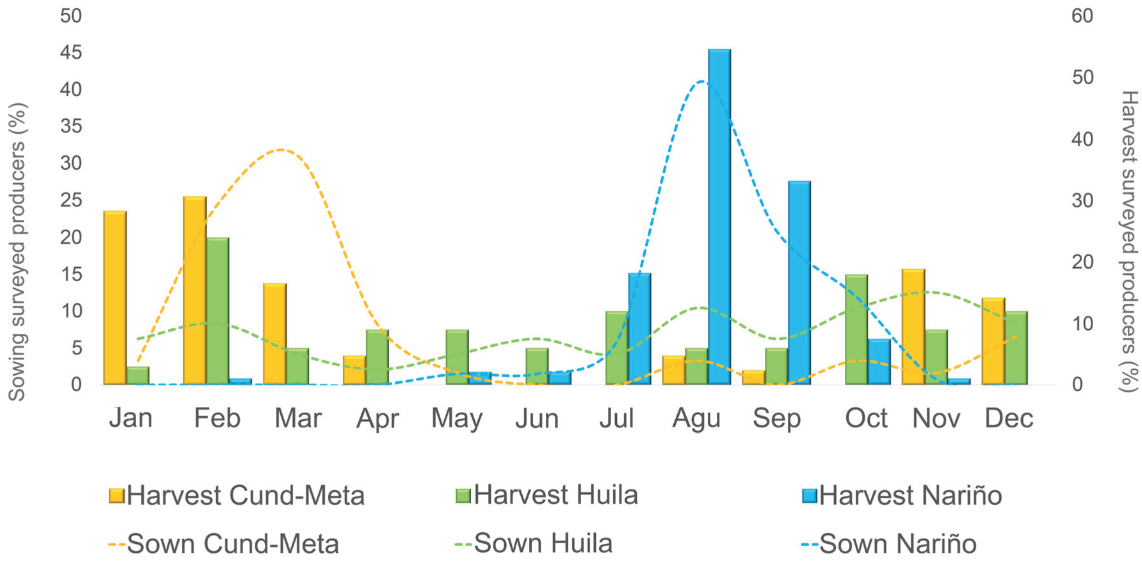

Figure 3. Planting and harvesting months of 203 edible canna producers surveyed in Huila, Nariño, Cundinamarca and Meta.

More than 92% of the producers of all the regions perform mechanized granting. In Table 4, the characteristics of canna starch extraction practices are presented in which significant heterogeneity can be seen between regions. The peeling refers to the cleaning practice of the rhizome roots. Starch drying is mainly done in open rooms, over plastic on the soil. Some APU have covered spaces that avoid the contamination of the product. The dried starch is manually sifted with the exception of some APU, where this activity is performed with machinery of personal design.

Table 4. Producers according to their characteristics of the achira starch extraction process.

Region	Peeled rhizome	Washed rhizome	Manual washed rhizome	Rallo possession	Outdoor drying	Manual starch sifting
	Percentage (%)					
Huila	32.5	100.0	92.5	82.5	28.0	100.0
Cundinamarca-Meta	100.0	98.0	51.0	29.4	75.0	80.4
Narino	74.0	26.0	53.0	34.8	100.0	100.0

Starch storage is a strategy that producers adopt to mitigate the impact of price fluctuations on farm economics. However, in many cases, the need to generate immediate income prevents them from taking advantage of the product's low perishability. In this context, 17% of the surveyed producers do not store starch.

Regarding the use of by-products, Rodríguez et al. (2003) state that this crop produces nearly 9 t ha^{-1} of dry matter, and its foliage contains high levels of protein and fiber, with a digestibility of 46%, high caloric value, and significant amounts of potassium and phosphorus. In addition, the bagasse resulting from the starch extraction process is used as a soil conditioner, for composting, and as a substrate for raising Californian red worms. The APUs use the leaves to reincorporate them into the soil as mulch, but they are also used as wrappers for traditional preparations and, to a lesser extent, for feeding livestock and other farm animals. Finally, black starch, or mogolla, is a residue from starch washing that contains very fine fibers from the rhizomes that are difficult to separate. This residue is used as fertilizer, animal feed, and even for human consumption in preparations such as cakes, snacks or "carrumbas," sweet arepas, mogollas, "champas," breads, and "cement breads.

Commercialization. The canna agro-industrial systems are strongly market-oriented, with the commercial value of the product prevailing over its use value. Despite this, starch remains a staple in the diet of the three regions, as evidenced by the levels of self-consumption (Table 5).

Table 5. Characteristics of starch commercialization and self-consumption edible cana starch APUs.

Characteristics		Huila	Cundinamarca - Meta	Narino
		Percentage (%)		
Buyer	Intermediaries	22.5	52.9	99.1
	Direct sell-Transformers	62.5	9.8	0.0
	Direct sell-neighbors	0.0	9.8	0.0
	Association	10.0	0.0	0.0
	Only self-consumption	5.0	27.5	0.9
Self-consumption	No self-consumption	12.5	3.9	24.1
	<20 kg year^{-1}	65.0	2.0	66.1
	20-63 kg year^{-1}	17.5	47.1	7.1
	63-125 kg year^{-1}	2.5	23.5	0.9
	<125 kg year^{-1}	0.0	21.6	0.0

A good relationship among the producers in Huila and the baking companies of canna favor the direct to commercialization of half of the starch. On the contrary, most of the production is commercialized by intermediaries in Narino and Cundinamarca-Meta.

3.2. Typification of productive units of canna and starch

Typification allows for understanding the conceptual organization of the diversity present in peasant agriculture (Tuesta Hidalgo et al., 2014) and was developed by region due to the high heterogeneity identified, mainly in the crop's role within the farm system, the harvesting methods that determine seed management factors, and the patterns linking the harvest phase to the starch extraction process. Each typology is associated with variables related both to the technological level and to the system's structural characteristics. Likewise, based on the regional frequency analysis, some variables were excluded due to their low discriminating power (Table 6).

Table 6. Frequency analysis for groups in three edible cana producing regions in Colombia.

Region		Huila			Cundinamarca-Meta			Narino		
Group- Cluster		I	II	III	I	II	III	I	II	III
Variable	Class	n=13	n=23	n=3	n=24	n=10	n=17	n=39	n=45	n=27
Property ownership	Sharecropping	7.69	0.0	0.0	4.17	0.0	0.0	46.15	0,0	18,52
	Association	0.0	0.0	0.0	4.17	0.0	0.0	0.0	0,0	0,0
	Property	92.31	78.26	75.0	91.67	100	76.47	51.28	100,0	77,78
	Tenant	0.0	0.0	0.0	0.0	0.0	17.65	2.56	0,0	3,7
	Succession or company	0.0	21.74	25.0	0.0	0.0	5.88	0.0	0,0	0,0
Experience in canna production	> 25 years	0.0	30.43	50.0	58.33	40.0	76.47	17.95	6,67	33,33
	15 – 25 years	38.46	21.74	25.0	20.83	30.0	11.76	2.56	11,11	18,52
	10 - 15 years	15.38	8.7	0.0	4.17	10.0	5.88	15.38	40,0	3,7
	5 - 10 years	23.08	17.39	0.0	16.67	20.0	0.0	28.21	42,22	29,63
	< 5 years	23.08	21.74	25.0	0.0	0.0	5.88	35.9	0,0	14,81
Rallo ownership	No	53.85	73.91	100.0	91.67	90.0	70.59	74.36	86,67	100,0
	Yes	46.15	26.09	0.0	8.33	10.0	29.41	25.64	13,33	0,0

Region		Huila			Cundinamarca-Meta			Narino		
Group- Cluster		I	II	III	I	II	III	I	II	III
Variable	**Class**	n=13	n=23	n=3	n=24	n=10	n=17	n=39	n=45	n=27
Seed purchase	No	100.0	78.26	25.0	91.67	80.0	94.12	74.36	91,11	74,07
	Yes	0.0	21.74	75.0	8.33	20.0	5.88	25.64	8,89	25,93
Selection of seeds	No	0.0	52.17	50.0	25.0	50.0	64.71	15.38	4,44	74,07
	Yes	100.0	47.83	50.0	75.0	50.0	35.29	84.62	95,56	25,93
Seed disinfection	No	100.0	95.65	50.0	95.83	90.0	64.71		*	
	Yes	0.0	4.35	50.0	4.17	10.0	35.29			
Soil preparation	Manual	61.54	91.3	100.0	79.17	90.0	5.88	43.59	55,56	59,26
	Mechanical	38.46	8.7	0.0	20.83	10.0	76.47	2.56	4,44	14,81
	Animal traction	0.0	0.0	0.0	0.0	0.0	17.65	53.85	40	25,93
Use of herbicides	No	30.77	86.96	75.0	83.33	40.0	5.88	12.82	37,78	44,44
	Yes	69.23	13.04	25.0	16.67	60.0	94.12	87.18	62,22	55,56
Type of fertilization	None	7.69	47.83	25.0	16.67	20.0	0.0			
	Organic	0.0	30.43	25.0	62.5	60.0	52.94		*	
	Chemical	92.31	21.74	50.0	20.83	20.0	47.06			
Transporta-tion of harvest	Human effort	23.08	91.3	0.0	79.17	0.0	5.88	10.26	35,56	22,22
	Animal transportation	61.54	8.7	0.0	20.83	0.0	70.59	5.13	11,11	14,81
	Motor vehicle	15.38	0.0	100.0	0.0	100.0	23.53	84.62	53,33	62,96
Rhizome peeling	No	15.38	91.3	100.0		*		7.69	4.44	88.89
	Yes	84.62	8.7	0.0		92.31 95.56		11.11		
Rhizome Washing	Manual	92.31	100.0	50.0	91.67	10.0	17.65	97.44	31,11	22,22
	Mechanical	7.69	8.7	50.0	8.33	90.0	82.35	0.0	0,0	77,78
	Do not wash the rhizome	0.0	0.0	0.0	0.0	0.0	0.0	2.56	68,89	0,0
Grating of rhizome	Manual	0.0	4.35	0.0		*		0.0	2.22	0.0
	Mechanical	100	95.65	100.0		100 97.78		100		
Starch drying	Outdoor over plastic	0.0	47.83	0.0	58.33	90.0	88.24			
	Plastic greenhouse for other crops	38.46	26.09	75.0	20.83	0.0	5.88		*	
	Plastic greenhouse only for starch	61.54	26.09	25.0	4.17	0.0	5.88			
	Others space of the APU	0.0	0.0	0.0	16.67	10.0	0.0			
Type of combustible	Diesel		*		20.83	60.0	100.0	0.0	0.0	0.0
	Electricity		0.0 30.0		0.0	10.26	48.89	81.48		
	Gasoline		70.83 10.0		0.0	89.74	51.11	18.52		

* *Variable excluded due to low discriminant value in the region.*

3.2.1. Typification in Huila

Based on the principal component analysis, it was established that the first nine dimensions explain 73% of the cumulative variance in the data. For each vector, the variables or factors with the highest representativeness within each segment were selected, and a hierarchical multivariate cluster analysis was performed (Figure 4). In this dendrogram, the shorter the distance between production units, the greater the homogeneity in the variables, resulting in a separation into three groups.

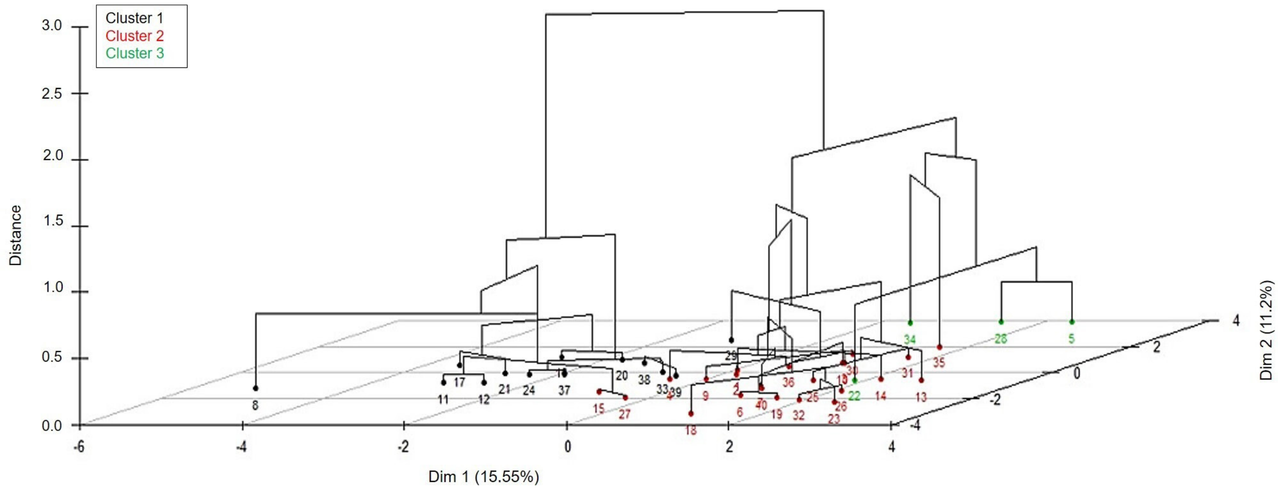

Figure 4. Huila Municipality hierarchical cluster analysis.

The characteristics of the formed groups by the frequency of the variables in Huila are:

- **Group I – Producers with low-technical level:** Comprising 13 farm units (APUs), 54% of which are located in the municipality of Isnos, they have an average total area of 0.44 ha and an average canna participation of 15.35% (CV 73.94). This type of producer is characterized by preparing the soil mainly manually, not purchasing or disinfecting seeds, but selecting them, fertilizing primarily with chemical inputs, and using herbicides on a significant portion of the UPAs (70%). Harvest transport is mainly by animal traction and peeling and washing of the rhizomes are carried out manually.
- **Group II- Producers with medium-technical level:** Comprising 23 farm units (APUs) with an average area of 0.33 ha and an average canna participation of 21.48% (CV 99.16). Sixty-five percent of the farms are located in the municipality of Isnos, particularly in the San Vicente area. They are characterized by performing seed disinfection and preparing the soil manually; half of the APUs does not fertilize, one-quarter use chemical fertilization, and a large proportion apply herbicides. Harvest transport is mainly by human labor, and the rhizomes are peeled manually. Rhizome washing is done manually, and 48% dry the starch outdoors on plastic sheets.
- **Group III- Producers with high-technical level:** Comprising four farm units (APUs) with an average area of 1.28 ha and an average canna participation of 16.4%, proportionally located in the municipalities of Isnos and San Agustín. The main characteristics are manual soil preparation; half of the APUs select and disinfect the seed, and 75% of the APUs use herbicides. Harvest transport is exclusively by motor vehicle; all APUs peel the rhizomes, rhizome washing is carried out both manually and mechanically, and they have infrastructure to dry the starch.

3.2.2. Typification in Cundinamarca-Meta

Eleven dimensions were identified and explained 73% of the variability of the data. In Figure 5, the hierarchical cluster analysis is presented.

The variable "starch sifting" was discriminating in exclusive form for this region due to machinery of personal design that was used to do this process. The characteristics of each group are:

- **Group I- Producers with low-technical level:** Mainly located in the municipalities of San Juanito and El

Calvario, these are 24 farm units (APUs) with an average total canna area of 0.33 ha and an average crop participation of 24.5% of the total farm area (CV 117.34). Soil preparation is done manually, herbicides are not used, and seed selection is carried out in 75% of the APUs. Harvest transport is mainly by human labor and animal traction; 90% of the APUs do not have their own thresher, and rhizome washing and starch sifting are performed manually.

- **Group II- Producers with medium-technical level:** With an average canna area of 0.47 ha and a crop participation of 68% of the total farm area, this cluster comprises 10 farm units (APUs) mainly located in the municipalities of Fómeque and El Calvario. Ninety percent of these producers prepare the soil manually, 60% use herbicides, and none disinfect the seed. In all cases, the harvest is transported by motor vehicle due to the distance to the threshing facility, where rhizome washing is carried out mechanically.
- **Group III- Producers with high-technical level:** This cluster corresponds to 17 farms located in Quetame, Fosca, and Guayabetal, with an average area of 1.8 ha and an average canna participation of 49%. They are the group of producers with the most experience in the system. Soil preparation is mainly mechanized, and herbicides and fertilizers—either organic or chemical—are used in all cases. Most of them (64%) select and disinfect the seed, and rhizome washing is done mechanically (82%). Harvest transport is mainly by animal traction (70%), given the proximity of the threshing facilities and the fact that this cluster has the highest proportion of ownership of threshers.

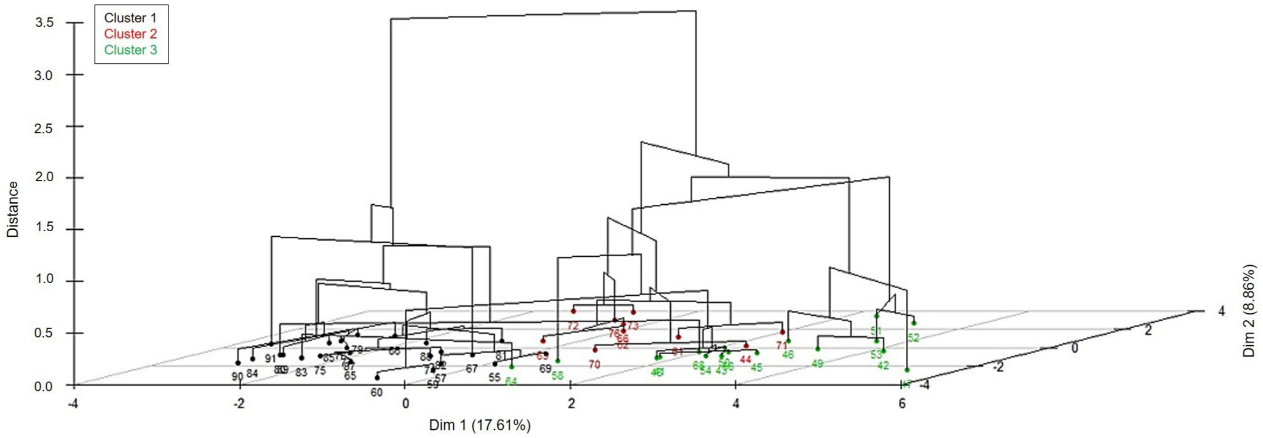

Figure 5. Cundinamarca-Meta Municipality hierarchical cluster analysis.

3.2.3. Typification in Narino

For the typification in Narino, 10 dimensions that explained 70% of the variability of the data were used. The cluster analysis is shown in Figure 6. Only for this region, the variable harvest method was discriminant.
The characteristics of each group are:

- **Grupo I- Producers with low technical level**: Comprising 39 farm units (APUs) with an average canna-planted area of 1.71 ha. The farms are mainly located in the Tajumbina, Cofradía, La Cañada, and Escandoy de La Cruz areas. Most producers have less than 15 years of experience and dedicate more than 90% of their total farm area to canna cultivation. They purchase and select the seed and use herbicides. Ninety-two percent harvest by thinning and peel the rhizomes. They do not have their own thresher, so the harvest is transported by motor vehicle, and rhizome washing is conducted manually.
- **Grupo II- Producers with medium technical level**: Comprising 45 farm units (APUs) with an average canna area of 0.77 ha and a crop participation of 79% of the total farm area. Eighty percent of the producers have less than 10 years of experience with the crop and are full owners of their land. In approximately 60% of the APUs, harvesting is done by thinning, which is why seed purchase is below 9%. Ninety-five percent of the producers peel the rhizomes and select the seed; most do not wash the rhizomes, while the remaining 31% wash them manually. Most do not have a thresher and transport the harvest by motor vehicle.
- **Grupo III- Producers with high technical level:** This group comprises 27 farm units (APUs) with an average canna area of 1.2 ha and a crop participation of 60.7% of the total farm area, the lowest of the

three clusters, mainly located in La Cofradía, San Francisco, and Campoalegre. Most of these APUs are owned by the farmers, but they do not have a thresher and do not select the seed (84%). They do not peel the rhizomes, and washing is conducted mainly by mechanized methods. Harvest transport is also primarily by motor vehicle, but it is evenly distributed between animal traction and human labor.

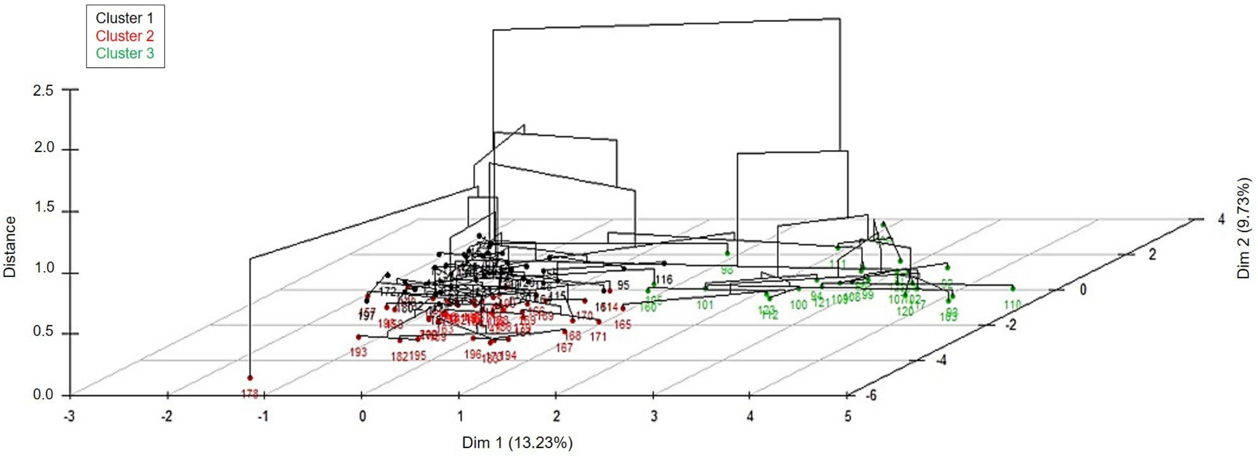

Figure 6. Nariño Municipality hierarchical cluster análisis.

4. Discussion

The productive scheme of canna crop, according to the defined characteristics, are within the family farming framework hat has the function of producing goods and services, as well as generating income that allow their production. Thus, family has a symbolic value, and it is a fundamental axis of reference and meaning (Acevedo Osorio & Martínez Collazos, 2016; Forero Álvarez, 2002). In this context, the income diversification, characteristic of a familiar agriculture, reduces the economic vulnerability (Acevedo Osorio & Martínez Collazos, 2016; Kaur et al., 2021) and contributes to the conservation of traditional productivity of canna crop beyond economic rationality. In the evaluated APUs, different mechanisms were observed such as the cultivation of diverse vegetable species, animal husbandry, the commercialization of livestock subproducts, daily work, provision of extraction services for canna starch and harvest transportation. However, Narino has a higher participation on the canna cultivation despite having less experience in its production, which could be mainly explained by the significant and increasing demand on Narino starch from canna bizcocho producer companies at the South of Huila. In contrast, in the regions of Cundinamarca-Meta and Huila, a higher diversification of income sources has been observed. In the case of Huila, the diversification consists of agricultural activities like coffee and fruits, and non-agricultural activities in the case of Cundinamarca, especially from work and other required services on the expansion of the road leading from Bogota to Villavicencio.

According to Tito Velarde and Wanderley (2021), all farmer households are both production and consumption units. However, the self-consumption of canna starch shows heterogeneity among the three producing regions: there is a tradition of use in the Cundinamarca-Meta and Huila regions, whereas in Narino—currently the largest producer—self-consumption of canna is minimal.

At the level of cultivation technology, it is confirmed that the production of canna starch is essentially conventional, as defined by Vasquez and Vignolles (2015), with monocropping systems, scheduled incorporation of synthetic chemical fertilizers, and pesticides applied in response to perceived soil fertility loss and the emergence of new, difficult-to-manage pests and diseases. In terms of processing technology, production corresponds to rural agro-industries that use conventional equipment and tools, where mechanization has been introduced primarily to ease the operations that demand the most physical effort, such as rhizome grating and starch separation from the grated mass. Developments in mechanization have generally stemmed from local inventiveness and have been improved operationally through research projects. This general trend within the agro-industrial system presents an opportunity to pursue technological innovations that prioritize knowledge of the socioecological system in management decision-making.

With regard to commercialization, the high level of intermediation makes producers, according to Díaz del Castillo (2013), price takers, with little bargaining power, which negatively affects their income levels: while production costs increase, the price of the final product decreases. Strategies such as the establishment of short marketing circuits (Furnaro et al., 2015) or the strengthening of associativity strategies can be included in the research and technical assistance agenda of government entities, in order to address this situation of producer vulnerability.

Typification makes it possible to define the potential for improving production systems (Tuesta Hidalgo et al., 2014; Vélez Izquierdo et al., 2016). Studies related to the adoption of technologies—such as electronic tools to support decision-making and precision agriculture—are closely linked to farm size, experience within the production system, the age of the household head, and the educational level of household members (Lambert et al., 2014; Paustian & Theuvsen, 2017). Therefore, it is important to consider that, although canna producers generally have extensive experience across most regions, the cultivated areas are smallholdings or microholdings, and the likelihood of adopting technologies with high implementation costs is lower. This calls for additional efforts in developing and adapting more affordable and simpler innovations.

According to Kumar et al. (2019), family farms have traditionally been classified based on farm size: marginal, small, semi-medium, medium-high, and large. For this reason, the characterization process from an integrated agricultural systems perspective complements the study of agro-industrial systems in terms of the strategies used by APUs in improved cultivation practices, income diversification, rearing of minor livestock, residue reuse, and informed increases in income. More broadly, it also addresses the farm's socio-ecological structure, the producers' decision-making system, and their resource availability (Kaur et al., 2021).

In the Colombian ACFC policy guidelines (Resolución Nº 464), peasant, family, and community agriculture is understood as a system of production and organization managed and operated by peasant families and communities, which primarily develop activities of production, transformation, and commercialization of agricultural goods, and which are frequently complemented with non-agricultural activities. The diversification of activities and livelihoods is carried out predominantly through family management and family labor, although contracted labor may also be employed. The territory and the actors that manage this system are closely linked and co-evolve, combining economic, social, ecological, political, and cultural functions. Given the foregoing characteristics, most of the production units of canna and its starch, regardless of the typology to which they belong, correspond to this concept, since they produce and transform rhizomes into starch under small-scale conditions, with high use of family labor, with preparation and self-consumption of native foods, and with a high dependence of their income on the sale of starch in the market.

5. Conclusions

The characterization of canna APUs confirms the predominance of family farming schemes with conventional crop management, which entails a marked application of external inputs to the system according to a scheduled calendar, both in terms of the application of inorganic fertilizers and the chemical control of pests, as well as intensive tillage and monocropping.

The starch extraction process presents regional differences influenced by geographical proximity in Narino and by high dispersion in Cundinamarca-Meta and Huila, where proximity to rhizome-grating centers determines the type and cost of transportation and, in some cases, the harvest periods directly related to the price of the final product.

The use of multivariate analysis techniques made it possible to identify three types of producers according to their level of technological adoption, independently for the three producing regions, characterized by a predominance of intermediate technological levels in Narino and Huila, and lower levels in Cundinamarca–Meta.

6. Recommendations

Given the predominance of the conventional agricultural model, studies are needed that explore the relationship between the agro-industrial system and the ecosystem, as well as strategies for the recovery of more sustainable agronomic practices, such as the intercropping and rotation of other species with canna, organic fertilization, integrated systems for the production of quality seed, selective harvesting, the reincorporation of residual aerial biomass from harvests, or the composting of extraction residues, which are part of the local knowledge of communities. In addition to these practices, micro-irrigation, biological fertilization with mycorrhizae, and cultural and biological management of insect pests, diseases, and weeds can be tested. These technologies are easy to implement, do not require significant outflows of resources from the APU for their acquisition, and do not significantly impact natural resources or the environment.

The differential characteristics in extraction processes among regions call for spaces of interaction that explore alternatives to stimulate their economy by making use of existing social and cultural assets, as well as productive tradition and know-how. Given the small scale of agricultural production, starch extraction requires the establishment of larger-scale processing plants that would make it possible to reduce water and energy consumption and production costs. For this, a transformation in business models between growers and processors is required, or alternatively the creation of associative models of agricultural producers for the establishment of such processing plants.

The resulting typification serves as an input for other actors in the chain, such as research groups and public policy decision-makers, to design differentiated interventions aimed at improving the quality of life of those who depend on this fragile rural agroindustry.

Acknowledgment

The authors thank the canna producers who allowed access to their information, Engineer Lindolfo Galeano Cupita for his support in data collection, and the technical-administrative team of the Colombian Corporation for Agricultural Research – AGROSAVIA for their support in acquisitions and anonymous reviews of the manuscript.

Funding

This work was carried out within the framework of the project *Socioeconomic Analysis of the Value Chain of the Achira or Sago Agroindustry (Canna edulis Ker-Gawler)*, financed by Ministerio de Agricultura y Desarrollo Rural [MADR] of Colombia.

Author contribution

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- Gonzalo Alfredo Rodríguez-Borray: conceptualization (lead), funding acquisition, project administration (lead), supervision (supporting), writing – review & editing (supporting).
- José Luis Tauta-Muñoz: data curation (lead), formal analysis (lead), investigation (supporting), methodology, visualization (supporting), writing – review & editing (supporting).
- Andrea Johana Reyes-Medina: data curation (supporting), writing – original draft (supporting).
- Belisario Volverás-Mambuscay: investigation (supporting), writing – review & editing (supporting).
- Juan Fernando López-Rendón: data curation (supporting), investigation, review & editing.
- José Manuel Campo-Quesada: investigation (supporting), writing – review & editing (supporting).
- Johanna Paola Garnica-Montaña: data curation (supporting), investigation (supporting), writing – review & editing (supporting).
- Pablo Fernando Ramos-Calderón: investigation (supporting), writing – review & editing (supporting).

Ethical Implications

The authors declare that, in the data collection process through surveys of the 203 participants, they were informed about the information and personal data treatment policy of the Colombian Corporation for Agricultural Research – AGROSAVIA, available at https://www.agrosavia.co/media/3620/politicas-para-la-proteccio-n-de-datos-personales-2019.pdf. However, the database was anonymized for the purposes of the analysis and drafting of the manuscript. As evidence of compliance with this policy, approval was obtained from the Agrosavia Research Ethics Committee (CEIA) in August 2024.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported..

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