Crop Production

Comprehensive characterization of high Andean sugarcane production systems (*Saccharum officinarum*) for panela production in Colombia[1]

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10.1590/0034-737X2024710036

ABSTRACT

Worldwide, a comprehensive characterization has been implemented in different farming systems but not in sugarcane agroecosystems for panela production in high Andean regions. In Colombia, panela is an important staple food, being the second largest producer in the world; however, the predominant cropping systems in different regions have not yet been fully described. Using secondary information, as well as the implementation of semi-structured surveys with farmer participation, together with geographic information system analysis tools, 341 farms and management measures were identified in a large sugarcane productive region in Colombia. Sufficient soil and climatic conditions were found for production, siltstone parent material (38.84%), predominant spine relief (83.23%), rainfall (1,000 mm), relative humidity (86%) and annual temperature (23 °C). The types cropping systems were determined, characterizing their management, as well as variables of the socioeconomic structure of the region. The production systems were classified into five gropus, were the typification of farms was mainly by three cutting systems called "*parejo*", "*entresaque*" and a new cutting system was identified, called "*parejo*" without renewal. As a complement, deficiencies were found in socioeconomic, technical and technological aspects in the province of Gualivá (Cundinamarca), being a generalized panorama in this important productive system in the country.

Keywords: typologies; weather; soil; social; rural.

INTRODUCTION

Through the vision of agricultural systems as the analysis of their ecological, social and economic dimensions; an integrated approach is necessary to their optimal management, in order to contribute to the overall sustainability of agricultural processes (Wezel *et al.*, 2014; Vaarst *et al.*, 2018). This is how this approach broadly involves the analysis of food systems, which aims to link ecology, culture, economy, and society to maintain agricultural production and healthy environments (Francis *et al.*, 2003; Gliessman, 2015).

The analysis from a comprehensive perspective for the sugarcane crop (*Saccharum officinarum*) to produce "*panela*" in high-Andean territories, where it is a food with high energy value and traditional practices, has not been widely addressed in Latin America. The conversion of sugar cane into *panela* is carried out in a structure designed for this purpose, where the sugarcane juice is extracted in a mill

Submitted on July 04th, 2022 and accepted on June 19th, 2024.
[1] This study was financed by the Government of Cundinamarca, Secretary of Science, Technology and Innovation of the Government of Cundinamarca, BIO Program and the Ministry of Science and Technology (MINCIENCIAS). Project Code 66097
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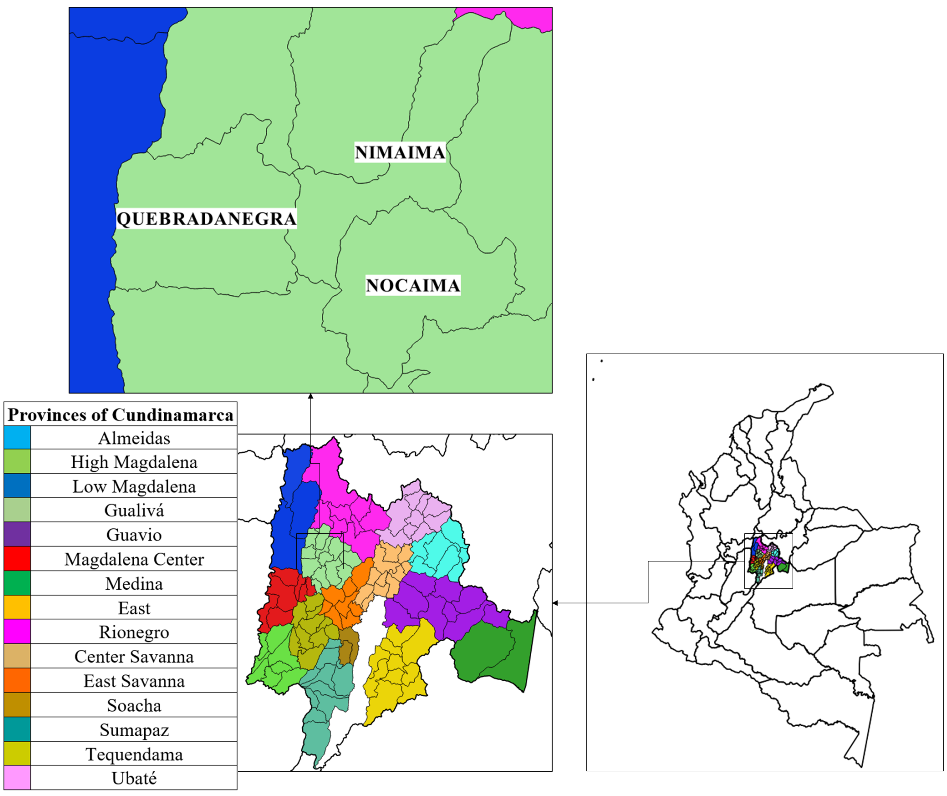
and cleaned by applying a vegetable binder, to separate residues from the sugarcane juice. The juice is subjected to heat by means of a train of evaporators, until it reaches a final evaporator, where the temperature and cooking is such that it achieves an appropriate point of sugars and reduces the water, obtaining a substance which is poured into molds, where it is left to cool, obtaining a solid block, which is called *panela*.

Colombia is the second largest producer of *panela* in the world, and it is the largest consumer with an average of 24.7 kg year^{-1} (SIC, 2012). Therefore, characterizing the edaphoclimatic, biotic, economic, and social conditions of these territories allow obtaining a description of the study area, which could become an influential factor for obtaining yields per hectare of the production system and the provision of environmental services in the sugarcane landscape. In the province of Gualiva, Cundinamarca, the main producing municipalities are Quebradanegra with a planted area of 3,122 ha and a production of 14,913.60 t; Nimaima with a planted area of 1,661 ha and a production of 8,295 t and Nocaima, with a planted area of 1,800 ha and a production of 8,875 t (Agronet, 2019).

According to Gutiérrez-Mosquera *et al.* (2018), to enter high-value markets, it is necessary to technically characterize the sugarcane production system in different regions of the country, as well as to continue with the development and transfer of technological alternatives, with the participation of producers. On the other hand, Ordoñez-Díaz & Rueda-Quiñónez (2017), state how important it is for producers to associate to seek a common good, which would aim at positioning and projecting their product locally, nationally, and internationally, hence the importance of identifying homogeneous groups of producers with the variables of age, knowledge, generational replacement, and family composition, since the sugarcane agroindustry is a family-based industry.

Thus, the objective of this work was to analyze integral information about soils, climate, technical, social, economic, and natural resource management in high Andean panela agroecosystems of family agriculture in the municipalities of Quebradanegra, Nimaima and Nocaima, as a contribution to the strengthening of production technification processes, knowledge and use of the services provided by the ecosystems.



Source: Adapted from CAR & IGAC, 2019.

Figure 1: Study area, each color represents a province of the department of Cundinamarca, Colombia. In detail the three study municipalities: Quebradanegra, Nimaima and Nocaima.

MATERIALS AND METHODS

2.1. Study area

The department of Cundinamarca is in the central area of the national territory of Colombia, in the Andean Natural Region and on the Eastern Cordillera, it has 116 municipalities, divided into 15 political-administrative provinces (IGAC, 2019). The present study is framed in the Gualivá Province, in the municipalities of Nimaima, Nocaima and Quebradanegra, at altitudes between 680 and 1900 m.a.s.l. (Figure 1).

2.2. Characterization of the physical environment

A characterization was implemented through the review of secondary information on edaphoclimatic conditions. The edaphic variables were obtained from open data from the soil study at a scale of 1:25,000 for the ordination and management plan of the Hydrographical - POMCA basin of the Negro River (IGAC, 2019), hydrological basin to which the province of Gualivá belongs. A geomorphological analysis of the study area was carried out using the Zinck *et al.* (2016) methodology at a semi-detailed level (landform), which was used in subsequent processes.

For the weather variables, time series available at the Instituto de Meteorología Hidrología y Estudios Ambientales (IDEAM) were consulted, where precipitation data were obtained in the three municipalities, starting in 2014. A multiannual precipitation climadiagram was constructed, with a time series of 5 years (2014 - 2019). In addition, relative humidity and mean temperature were obtained from data from the station located in Quebradanegra, for a multiannual period of 12 years, from January 2006 to December 2017.

2.3. Farm typology based on geomorphological and crop management variables

For the typification of production systems based on the management and geomorphological variables of the territories, information was compiled from databases provided by the Federación Nacional de Paneleros (FEDEPANELA), the Unidades Municipales de Asistencia Técnica Agropecuaria (UMATA) of Quebradanegra y Nocaima and the Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), based on this information, an identification of planted farms with sugarcane for panela production was made.

With the participation of the farmers, detailed information was obtained regarding crop management, harvesting method, municipality and the "*vereda*" where the farm is located. In this way, the different farms in the municipalities were spatially located using the QGIS™ and Google Earth™ geographic information systems. Besides were included some variables obtained from the digital elevation model and geographic climate models. The variables used for each farm included in the database were: Total area planted in sugarcane for panela production (ha) (Quantitative – V1), Harvesting method (Categoric – V2), Geoform – type of relief and landform (Categoric – V3), Slope range (Categoric – V4), Elevation (m.a.s.l.) (Quantitative – V5), Temperature (°C) (Quantitative – V6), Normalized difference vegetation index (Quantitative – V7), Aspect (Quantitative – V8), Longitudinal curvature (Quantitative – V9), Transverse curvature (Quantitative – V10), Topographic position index (Quantitative – V11), Topographic humidity index (Quantitative – V12).

For the quantitative variables, the Pearson correlation matrix was used, from which those variables with correlations above 80% were discarded, as in the case of temperature (V7), which has a 99% correlation with elevation (V6); longitudinal curvature (V9) and transverse curvature (V10), which have a correlation above 80% with the topographic position index (V11). Thus, the variables presented were included for the construction of typologies, except for temperature (V7), longitudinal curvature (V9) and transverse curvature (V10). Based on this database, a grouping procedure was carried out, according to the variables included, identifying five differentiated groups, based on a multifactorial analysis of mixed data and the construction of a hierarchical cluster by Ward method and Euclidean distance. Software R (Version 3.3.1) were used for a statistical analysis of the data (R Core Team, 2017).

2.4. Social, technical and perception characterization and management of natural resources.

Information from a semi-structured survey applied in 2015 by AGROSAVIA in 40 productive systems of panela in Nimaima, Nocaima and Quebradanegra, in three of the five groups of farms identified, representing 11% of the population, was used to identify the social, technical, economic and perception and management characteristics of natural resources in family farming "*panelero*" agroecosystems. For the analysis of the surveys a descriptive statistical analysis of the data was carried out, by means of central tendency measures. Software R (Version 3.3.1) were used for a statistical analysis of the data (R Core Team, 2017).

RESULTS AND DISCUSSION

3.1. Characterization of the physical environment

The region has predominant soil associations in the municipalities (67 in total), among which the most frequent are Typic Hapludolls, Typic Humudepts and Typic Dystrudepts as main soils (IGAC, 2019). The soils have developed from silty-clay clastic rocks such as mudstones and siltstones and carbonate chemicals such as calcareous salts (IGAC, 2019). They are deep to shallow soils due to lithic contact, with textures ranging from fine to medium, generally with good drainage (IGAC, 2019). According to Rodríguez *et al.* (2020), the predominant soils in the department of Cundinamarca in terms of their textural range are clay and silty clay, but these types of soils present aeration and internal drainage problems for sugarcane production for panela, which according to Muñoz (1981) the appropriate soils for growing sugarcane correspond to the Loamy and Clay Loam textural range.

About the relief, according to the taxonomic order of the Zinck scale, it was determined that the entire landscape of the study region corresponds to mountain, the most predominant type of relief is spine, representing 83.23% of the study area, mainly in front (48.97%) and back (33.31%), with some presence of projections (0.47%) and escarpments (0.48%) (IGAC, 2019). Other types of relief present in the area correspond to colluvial mantle (2.23%), hill (5.59%) with slope landforms, ridges (4.26%) mostly in reverse, with some presence of fronts and ledges (IGAC, 2019).

Although it is observed that annual rainfall is less than 1,000 mm, there are no periods with rainfall that could cause waterlogging of crops (Figure 2), however, a more detailed study is needed to calculate possible water deficits and the stress that plants may have, due to periods of resource scarcity in the area. The above, considering the high-water demand of sugarcane cultivation, being in other latitudes up to four times more than that of other crops, thus affecting the flow of the rivers in the basins where they are located (Lee *et al.*, 2020).

The average annual relative humidity is 75%, with November being the month with the highest humidity (86%) and September the month with the lowest relative humidity (66%). The average annual temperature is 23 °C, with August being the hottest month (25 °C) and November the coldest month (22 °C) (Figure 2). Contrasting the edaphic data with the climate data, the division of the study region according to the Caldas-Lang environmental climate, corresponds mostly to humid and very humid temperate, representing 75.54% of the area, and a second classification corresponds to humid and very humid warm climate, in which 21.94% of the study region is located.

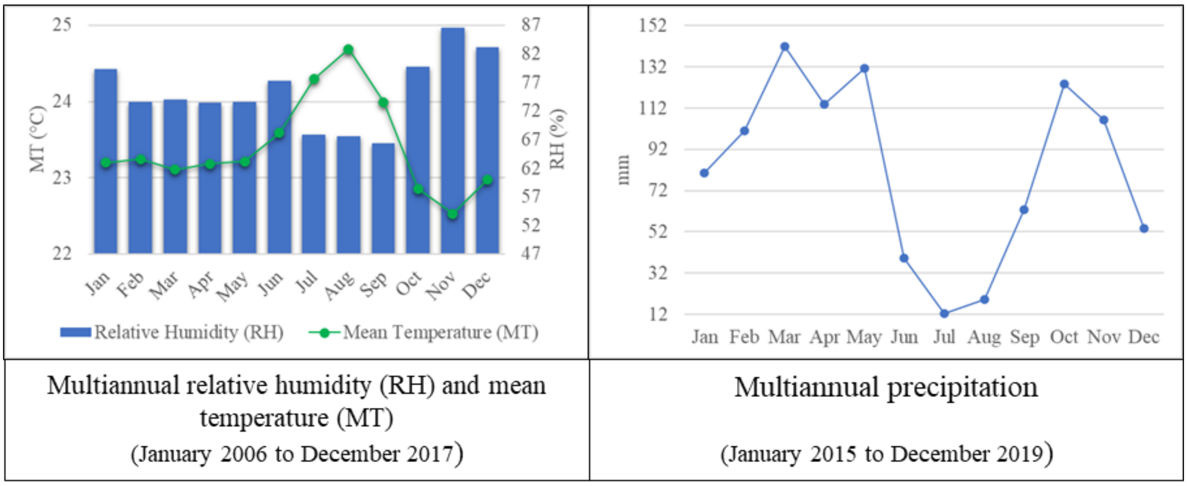
3.2. Farm typology based on geomorphological and crop management variables.

The analysis was carried out with 341 farms, 164 located in the municipality of Quebradanegra (48.09%), 114 in the municipality of Nocaima (33.43%) and 63 in the municipality of Nimaima (18.48%). The average elevation corresponds to 1171 m.a.s.l., with plots ranging from 688 to 1885 m.a.s.l. From the Chelsa Climate model, the average temperature is 21.8 °C with plots that vary in their average annual temperature from 18.08 °C to 24.53 °C.

The average of cultivated area in sugarcane on the farms was 3.46 ha, with areas ranging from 0.09 ha to 41.44 ha planted in sugarcane. Regarding the method of harvesting or cutting, 48.97% of the farmers said that they cut in "*entresaque*", which is the method of harvesting in which there is no homogeneous maturity in the stalks of the same lot, so only those that have already reached physiological maturity are cut and the others are left in the lot. This method is also related to small-scale agriculture, with producers who do not have sufficient labor, and do not carry out organic or chemical fertilization plans.

On the other hand, there is the "*parejo*", which is the method of harvesting, in which there is a homogeneous maturity within the same lot, so that a single cut is made at the end of the physiological cycle of the crop, and no stalk is left within the lot. This system is associated with producers with a higher level of technification, since they also renew the vine every few cuts, use varieties of sugarcane with better agronomic characteristics, and carry out fertilization plans in accordance with a permanent semi-intensive crop. This cutting system corresponds to 2.64% of the farms identified in the database.

A third cutting system identified in the study region corresponds to a method in which the harvest is carried out by *parejo* cutting, however, all the associated agronomic and technical management corresponds to *entresaque* cutting. It is associated with systems in which there is no renewal of the vine or fertilization management, this harvesting method is called *parejo* without renewal and corresponds to 37.24% of the farms identified in the database. The others are a combination of *entresaque* and *parejo* (2.05%), between *entresaque* and *parejo* without renewal (7.92%) and between *parejo* and *parejo* without renewal (1.17%).



Source: Adapted from IDEAM (2020).

Figure 2: Left: multiannual precipitation (January 2015 to December 2019), municipalities of Nimaima, Nocaima and Quebradanegra. Right: multiannual relative humidity (RH) and mean temperature (MT), Quebradanegra station (January 2006 to December 2017).

From the multifactorial analysis of mixed data and the construction of a hierarchical cluster by Ward method and Euclidean distance, five differentiated groups were obtained, whose characteristics associated with the qualitative variables are presented in Table 1. It is observed that the first three groups are located mostly in thorny relief type, with slopes in the range of 25 to 50%, with a significant presence of slopes above 50% and even higher than 75% in Group 2, however, these three groups differ mainly by the harvesting method used in the productive units, thus, it is observed that Group 1, corresponds in its great majority to production units whose harvesting method is *parejo* without renewal (66.98%), Group 2, to production units that carry out *parejo* (90%) and Group 3, to those production units that carry out *entresaque* cutting (74.75%), being this last group the one that represents the majority of identified farms (58.06%).

Groups 4 and 5, on the other hand, are in relief types other than the spine. Thus, Group 4 corresponds mostly to plots located in a colluvial mantle body geoform (88.89%), in which the different harvesting methods are represented, as well as the different slope ranges below 75%. Finally, Group 5 corresponds to plots located at the foot of hills (77.78%), being a more homogeneous group in the other characteristics, since most of them use *parejo* without renewal as a harvesting method (88.89%) and are located on slopes between 12 and 25% (88.89%) (Figure 3).

The comparison of quantitative variables between groups is shown in Figure 4. The Topographic Moisture Index (Figure 4A) is a variable that models the water dynamics of a watershed and is controlled mainly by topography; its values associated with soil moisture are important for defining flood zones that may affect crops, and soils that may be vulnerable to runoff. As the index value increases it reflects an area with higher moisture as a function of the digital elevation model (Roa-Lobo & Ulrich, 2012).

As can be seen in Figure 4A, group 5, which presents large areas and is in flat or slightly undulating reliefs and at low altitudes presents a mean of 6.95, representing the highest soil moisture values. Looking at group 1 and group 2, it is understood that these values with means of 5.44 and 5.72 reflect soils with lower moisture and possible runoff, while groups 3 and 4 present neutral values. The area is also considered one of the most important quantitative variables to generate the groupings, particularly group 5 is characterized by presenting large extensions, such that can reach 40 ha (Figure 4B); however, the other groupings are in the normal range of extensions occupied by small farmers, values around 3 ha which represents peasant family farming as described by Monroy-Martínez *et al.*, 2017.

In contrast, studies in the department of Caquetá in the Colombian Amazon, shows three different types of panela producers: (1) Avant-garde, there is the main crop cultivated in hills; (2) Traditionalists, predominantly located in the mountains; and (3) Diversifiers, located in hillsides, their main activity is livestock (Jiménez-Carvajal *et al.*, 2024). Other types of panela producers, located at Colombian south (Huila), were cataloged as: (1) Productive diversification and technological transition; (2) Traditional y technified, with basic crop management, mainly family agribusiness, lack of crop techinification; and (3) Highly specialized group, which implement thecnical recomendations (Rodríguez-Borray *et al.*, 2022). While, as explained, in the present study typing is mainly defined by the harvesting system *parejo*, *entresaque* and *parejo* without renewal.

3.3. Social, technical and perception characterization and management of natural resources

According to the methodology of the information used in the AGROSAVIA survey, 2015, groups 1, 3 and 5 were characterized, the first two representing most of the sugarcane systems (106 and 198, respectively, Table 1), and the last one, where the largest areas planted with sugarcane are located. In Group 1, 14 surveys were conducted, representing 13% of the total number of farms identified in this group; in Group 3, there are 25 surveys, corresponding to 12% of the farms belonging to this group; finally, in Group 5, one survey was conducted, corresponding to 11% of the total number of farms in the group.

Among the social aspects, it was determined that at least 60% of those surveyed in the three groups have access to drinking water, most of the water in groups 3 and 5 comes from the local aqueduct (40% and 100% respectively), while group 1 has access to water from natural springs (64.3%). More than 92% of the respondents in the three groups have sanitary services, most of which correspond to septic tanks (more than 64% in the three groups). In Group 3 and Group 1 more than 20% of the respondents correspond to families with only one person. In Group 3, only 50% of those surveyed corresponds to families with at least 3 people, while Groups 1 and 5 have at least 60% of the families with at least 3 people. In Group 1, 57.5% of the family members are men and 42.5% are women; this proportion is similar in Group 3, where 58.7% are men and 41.3% are women, while the productive unit surveyed in Group 5 is made up of a family of 6 people, where 16.7% are men and 83.3% are women.

Table 1: Levels of grouping through the contribution of each of the qualitative variables for the farms typifications in the study area

Variable	Class	Group 1 (n=106)	Group 2 (n=10)	Group 3 (n=198)	Group 4 (n=18)	Group 5 (n=9)
				%		
V2	*entresaque*	13.21	0.00	74.75	22.22	11.11
	parejo	0.00	90.00	0.00	0.00	0.00
	parejo without renewal	66.98	10.00	19.70	44.44	88.89
	entresaque and *parejo*	19.81	0.00	5.56	11.11	0.00
	parejo and *parejo* without renewal	0.00	0.00	0.00	22.22	0.00
V3	Spine-scarp	1.89	0.00	0.00	0.00	0.00
	Front-crest	17.92	10.00	0.51	0.00	0.00
	Front-spine	36.79	10.00	30.81	11.11	0.00
	Slope-slope	1.89	0.00	5.05	0.00	0.00
	Backhand-crest	19.81	20.00	12.63	0.00	0.00
	Backhand-spine	20.75	50.00	35.86	0.00	0.00
	Body-manto-coluvial	0.00	0.00	0.00	88.89	0.00
	Escarpment-crest	0.94	0.00	2.53	0.00	0.00
	Body-glacis-accumulation	0.00	0.00	0.00	0.00	22.22
	Foot-slope-hill	0.00	0.00	0.00	0.00	77.78
	Top-slope-slope-hill	0.00	10.00	12.63	0.00	0.00
V4	12 a 25 (%)	4.72	10.00	14.65	44.44	88.89
	12 a 50 (%)	2.83	0.00	7.07	11.11	11.11
	25 a 50 (%)	80.19	50.00	60.61	27.78	0.00
	25 a 75 (%)	1.89	0.00	5.56	5.56	0.00
	50 a 75 (%)	10.38	20.00	12.12	11.11	0.00
	>75 (%)	0.00	20.00	0.00	0.00	0.00

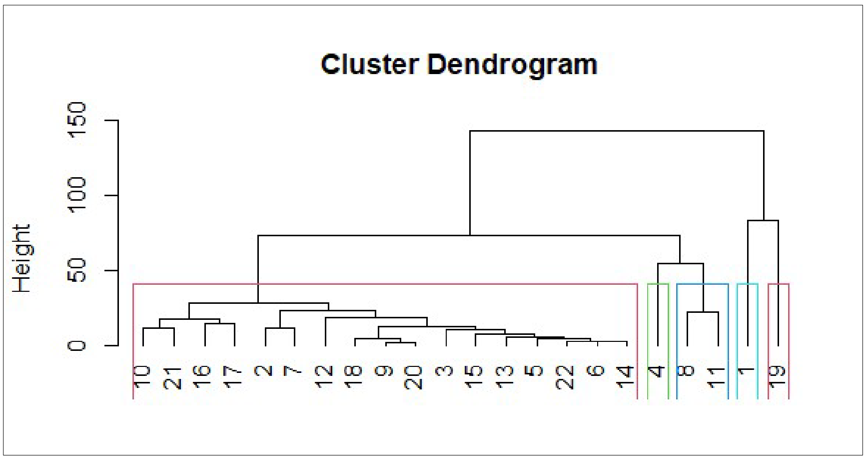


Figure 3: Cluster dendogram, groups of panela typified farms from the study area: Quebradanegra, Nimaima and Nocaima, Cundinamarca.

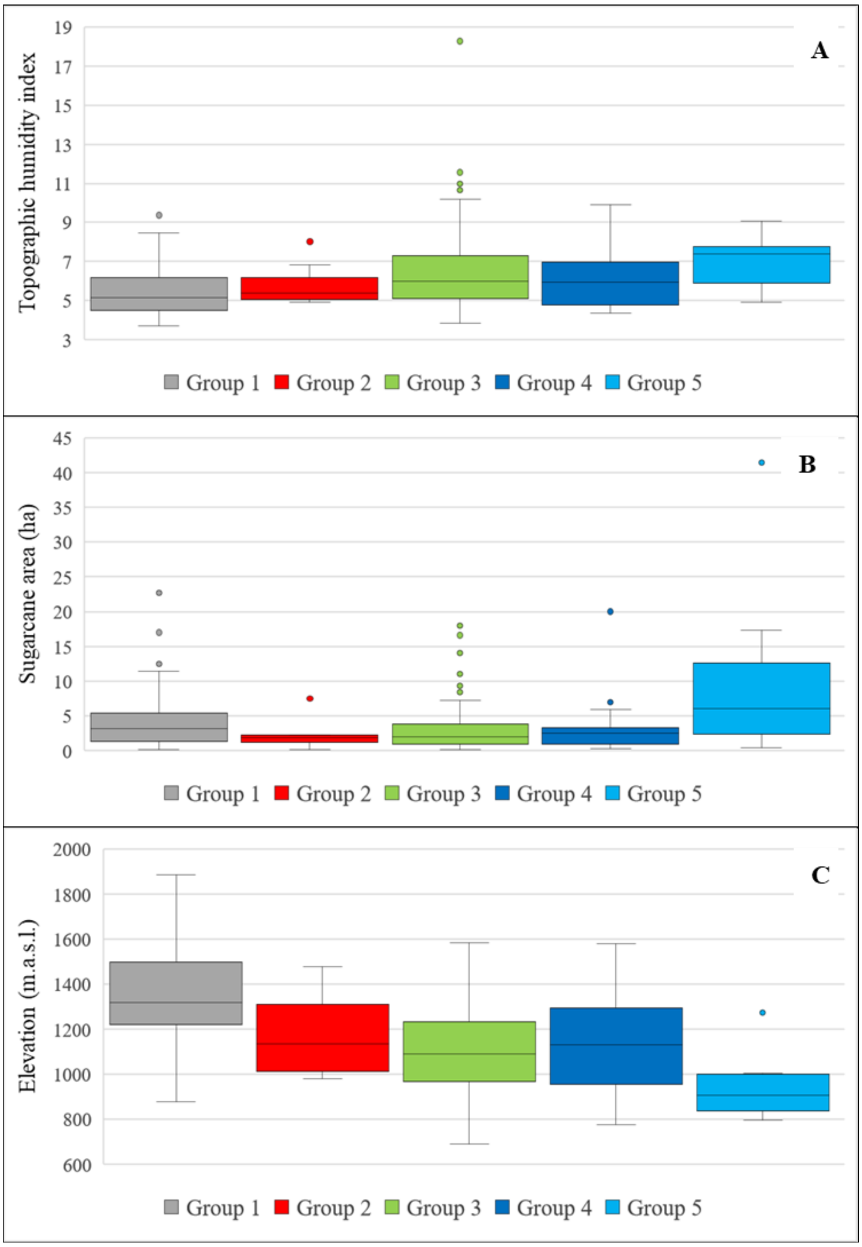
Group 1 is made up of 15% of children under 18 years of age, of which 33.3% are under 5 years of age, and 66.7% are of school age, and in fact all of them are currently in school. About the adults, 39.4% have incomplete primary schooling, 24.2% have completed primary school, 9.1% have incomplete secondary education, 24.2% have completed secondary education, and 3.1% are university graduates. Group 3 is made up of 17.5% of children under 18 years of age, 36.4% are children under 5 years of age and 63.6% are school-age children, all of whom are in school. Of Group 3, 52.4% are adults between 18 and 60 years of age, and 30.1% are over 60 years of age. Among those over 18 years of age, 11.8% have no schooling, 41.2% have incomplete primary schooling, 21.6% have completed primary school, 9.8% have incomplete secondary education, 11.8% have completed secondary school and 3.9% are university professionals.

Finally, Group 5, represented by a single productive unit, whose 50% of the members are under 18 years of age, who are of school age and are all studying. The 33.3% are in the group of adults between 18 and 60 years of age, and 16.7% are adults over 60 years of age. Regarding the schooling of the older adults, 33.3% have incomplete primary schooling, 33.3% have incomplete secondary education and 33.3% have completed secondary education. Considering the population structure found, it is advisable that entities provide tools that encourage young people and children to recognize the environmental and economic importance of sugarcane cultivation in the country and to focus their professional studies on rural development with environmental emphasis, for the conservation of this traditional family production system (López, 2013).

From the construction of typologies, it was determined that both Group 1 and Group 5 correspond mostly to farms that harvest by *parejo*, without renewing vines (50% and 100% respectively), while Group 3 corresponded to farms that harvest by *entresaque* (84%). In the case of the survey, these classifications were highlighted, in addition to observing differences between the type of fertilization and weed control. The Group 5 is represented by only one individual, who performs *parejo* without renewal, does not fertilize, and performs weed control manually.

Like Group 5, Group 3 does not apply any type of fertilization (64%), although 21% of those surveyed apply chemical fertilizers, while Group 1 applies some type of fertilization (58%), mainly organic (22%) or a combination of chemical products, such as compost and chemical fertilizers (36%). Regarding weed control, in all three groups, this practice is predominantly carried out manually (at least 60% in the three groups); however, in Group 3, there are most cases of farmers using herbicides for weed control (40%), compared to the other two groups (21% in Group 1, 0% in Group 5).

As for the area planted in sugarcane, in the case of Group 1, the average was 3.12 ha, while in Group 3, the average was 2.88 ha, while Group 5 has the largest planted area among the 5 groups identified, with an average of 10.08 ha. In terms of the surveys carried out, the production unit belonging to Group 5 has a planted area of 31.4 ha, being also a representative of the large extensions, characteristic of this group. According to the survey most of the areas in groups 1 and 3 range between 2 and 7 ha (72% and 84% respectively), with a higher average in Group 1 (8.93 ha) compared to Group 3 (5.61 ha).



A: Topographic humidity index; B: Sugarcane area (ha); C: Elevation (m.a.s.l.).

Figure 4: Quantitative variables with the highest contribution for the typification of farms from the study area: Quebradanegra, Nimaima and Nocaima, Cundinamarca.

The structures of the processing plants in most of the surveys have been built in wood, representing 50% of Group 1 and 48% of Group 3. Zinc roofing represents the totality of group 1 and 84% of group 3, only the remaining 16% have fiber cement shingles. The heat supply to the evaporators is done through a chamber that includes the dry bagasse from the sugarcane, which is stored inside the same processing plant. Traditionally, these chambers have a flat inlet where the combustion is fed by means of the dry bagasse. This type of chamber, called flat chamber, is the most used in the region, representing the totality of Group 5, 52% of Group 3 and 50% of Group 1. In some cases, there are two flat combustion chambers, which have some modifications to have a more efficient process; this type of chamber is traditionally known as flat chamber with two inlets, which are found in 44% of the processing plants of Group 3 and 42.8% of those of Group 1.

It was observed that 7.2% of Group 1 corresponds to a chamber system called Ward, in which there is a modification at the entrance of the chamber, increasing the volume inside the chamber and allowing the entrance of wet bagasse. Finally, 4% of Group 3 corresponds to a boiler, a system in which the evaporators are not heated by means of a chamber, which is in direct contact with the evaporators, but the bagasse is burned separately, and the hot air is transported by means of pipes, functioning as an open evaporation system.

Other important parameters in the characterization of the processing and obtaining of panela correspond to the capacity of the kiln, which is understood as the amount of panela in kg that a processing plant can produce in one hour, and the annual production, understood as the amount of panela in t that is produced in one year in a production unit. In the case of the Group 5 production unit, the capacity corresponds to 93.75 kg h^{-1}, and in one year it produces approximately 36 t. The Group 1 have an average production capacity of 88.8 kg h^{-1} and an average annual production of 69.3 t, and the Group 3 have an average production capacity of 73.56 kg h^{-1} and an average annual production of 28.25 t.

The cultivation of sugarcane and its processing to produce panela generates some plant residues, which are traditionally used in other activities within the same production system. The upper part of the plant, commonly known as the bud, is one of these residues that is not used to produce panela, but is left on the lot as plant cover, as is the case of the production unit of Group 5, 48% of the production units of Group 3 and 21.4% of Group 1. In some cases, it is collected and fed to animals of the same production unit, 78.5% of Group 1 uses it as animal feed, and in the case of Group 3, this percentage corresponds to 52%.

Regarding the production unit's own waste, 42.8% of the respondents in Group 1 use animal manure and different vegetable waste to prepare compost, while in Group 3 this practice is carried out by only 16% of the respondents, and in the case of the representative production unit of Group 5, this activity is not carried out. Three vegetable residues are obtained during processing. Some farms have a pre-cleaner, which cleans the juices by decanting them, separating some residues known as "*bagacillo*". Previously it was mentioned that a binder of vegetable origin is applied to eliminate impurities from the juices, which is commonly known as "*cachaza*". Finally, when dry bagasse is used as fuel to heat the evaporator train, in addition to wood, and in some cases charcoal, the residue obtained is a mixture of ash from the different elements used in combustion.

Group 1 uses a higher percentage of the different residues obtained during processing. In the case of the *bagacillo*, there is a high percentage in both groups, which, not using a pre-cleaner, do not differentiate this residue from that known as "*cachaza*" (36% in group 1 and 28% in group 3). In Group 3, the percentage of production units that do not use this residue is quite high (44%), while in Group 1, 50% of producers use it to prepare compost or to use it as animal feed.

The *cachaza* is used by 93% of the productive units of Group 1 and by 76% of those of Group 3, the animal feed differs from the case in which the *cachaza* is given directly, from the case in which the heat of the same stove in which panela is produced is used. The heat is used to add an evaporator exclusively for the cooking of this residue, taking advantage not only of the residue as such, but also of the thermal energy of the process, and in addition, traditionally, some elements are added that contribute more calories to the diet of the animals. In the case of Group 3, 8% of the production units do not use the cachaza for their animals, but they do give it away, generally to neighboring production units that use it for animal feed.

In the case of ash, some production units use it for the preparation of compost, as in the case of bagasse (22% of the group 1 and 8% of the group 3), and another percentage applies it to the crop, traditionally it is added to the soil, as a kind of amendment, and some producers even compare it with agricultural lime (58% of the group 1 and 52% of the group 3). The productive unit representative of Group 5 does not have a pre-cleaner, uses the *cachaza* for animal feed, processing it by cooking it and including some elements of higher caloric contribution, and applies the ash directly to the crop, since it does not prepare compost. Only 14% of the respondents in Group 1 reported having received agricultural environmental training, and 24% in Group 3. Finally, 92.8% of Group 1 and 72% of Group 3 said they were willing to develop environmental strategies in their production units.

Throughout the study, it became evident the lack of technification as in the country; other works propose alternatives such as certified organic production as viable option for improving the technical, social, economic and environmental conditions of these production systems (Guevara *et al.*, 2023). These systems have also demonstrated high negative environmental impacts, not only in Colombia but also in countries such as Ecuador, measured with Life Cycle Analysis (Quezada-Moreno *et al.,* 2021; Sierra *et al.*, 2022), which invites to establish more sustainable production measures in those production systems.

CONCLUSIONS

The physical conditions found at regional and farm level for the soil, geomorphology, and climate, with textural ranges of loam soil, the predominant mountain landscape, as well as the humid temperate climate, indicate conditions suitable for growing sugarcane, this is a favorable environmental offer to maintain the crop in the future, taking account the climatic variation. In this sense, a baseline of the physical environment for this crop in the region was provided.

The typification of farms in the province of Gualivá was defined mainly by three harvesting systems, *parejo* with higher technology, *entresaque*, and *parejo* without renewal, the latter was identified as a new cutting system, where there is no renewal of stocks, the land is not prepared for a new planting and fertilization is not implemented, this denotes the traditional management of family farming.

The comprehensive characterization and typification of these production systems was complemented with social, technical and natural resource information, which showed the predominance of the peasant family economy, with deficiencies in terms of access to water and education, and with special interest in a circular economy, where the waste is used for animal feed and composting. At the same time, the general population is made up of older men and women, which constitutes a recurring challenge in Latin American family farming in terms of generational renewal and maintenance of traditions for future rural generations.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

To the Tibaitata Research Center of the Colombian Agricultural Research Corporation (AGROSAVIA), for formulating and executing the research and thus promoting the importance of the Panelera Agroindustry in the department of Cundinamarca. This study was founded by the Government of Cundinamarca, Secretary of Science, Technology and Innovation of the Government of Cundinamarca, BIO Program and the Ministry of Science and Technology (MINCIENCIAS) Project Code 66097.

Authors declare there is no conflict of interests in carrying the research and publishing this manuscript.

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