

Research article: Agriculture

Community capitals, agricultural productivity, and household well-being in smallholder sugarcane systems

Capitales comunitarios, productividad agrícola y bienestar de los hogares de pequeños productores de caña de azúcar

Edgar Martínez-Moyano ¹; Brian Bermeo-Sandoval ²; Alejandro Buenaventura-Arturo ³, Yojan Gutiérrez-Rojas ⁴, Herminton Muñoz-Ramírez ⁵, Ivan Camilo Sánchez-Rojas ⁶, Oscar Raúl Rojas-Peña ⁷

¹ Consejo Nacional de Investigaciones Científicas y Técnicas - CONICET, Buenos Aires, Argentina, nacionaledgar2012@gmail.com, <https://orcid.org/0000-0001-7608-2872> (Correspondence)

² Universidad de la Amazonia, Florencia, Colombia, brianbermeos@gmail.com, <https://orcid.org/0009-0009-9336-0681>

³ Amazonian Research Center CIMAZ-MACAGUAL, Universidad de la Amazonia, Florencia, Colombia, a.buenaventura@udla.edu.co, <https://orcid.org/0009-0002-4903-5514>

⁴ The Norwegian Human Rights Fund, Bogotá D.C., Colombia, yojangutierrez@gmail.com, <https://orcid.org/0000-0003-1067-9945>

⁵ Universidad de la Amazonia, Florencia, Colombia, hermintonr@gmail.com, <https://orcid.org/0000-0001-7817-1633>

⁶ Instituto Tecnológico del Putumayo – ITP, Mocoa, Colombia, ivan.sanchez@itp.edu.co, <https://orcid.org/0000-0001-5959-6695>

⁷ Universidad del País Vasco, Bilbao, España, oscar1913@hotmail.com, <https://orcid.org/0000-0002-9181-8339>

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ABSTRACT

The cultivation of sugarcane (*Saccharum* spp.) for panela production is a key livelihood source for rural households in Colombia, particularly in the southwestern region of the country. Understanding the subsistence strategies associated with this activity and their connection to rural well-being is essential for promoting sustainable productive development. This study examines the influence of community capitals on the well-being of 92 panela-producing households, categorized into three livelihood typologies: (i) diversified, (ii) innovative, and (iii) traditional. Correlations between these typologies and various forms of community capital, human, social, built, natural, financial, political, and cultural, were assessed to identify shared patterns in livelihoods. Diversified households (55.9%) engage in multiple economic activities, including coffee, avocado, and sugarcane cultivation, along with livestock and pig farming. Innovative households (28.3%) primarily depend on sugarcane cultivation, whereas traditional households (11.9%) exhibit low productivity and rely predominantly on coffee as their main income source. The findings revealed that differentiated access to and management of community capitals significantly affect household well-being, with integrated and diversified strategies yielding better outcomes. Furthermore, strengthening skills, knowledge, and networking capacities is crucial for enhancing the social appropriation of sugarcane-related knowledge. This, in turn, can guide more effective strategies for the development of the panela sector and contribute to the overall well-being of rural farming households.

Keywords: community management; food sovereignty; production; sustainability; territoriality; vulnerability

RESUMEN

El cultivo de caña de azúcar (*Saccharum* spp.) destinado a la producción de panela representa una de las principales fuentes de sustento para los hogares rurales en Colombia, particularmente en la región suroccidental del país. Por tanto, comprender las estrategias de subsistencia asociadas a esta actividad y su relación con el bienestar rural resulta fundamental para promover estrategias de desarrollo productivo sostenible. Este estudio analiza el impacto de los capitales comunitarios en el bienestar de 92 hogares productoras de panela, clasificadas en tres tipologías de medios de vida: i) diversificadoras, ii) vanguardistas y iii) tradicionalistas. Para ello, se evaluaron las correlaciones

entre tipologías y los diferentes capitales comunitarios (humano, social, físico, natural, financiero, político y cultural) con el fin de identificar patrones compartidos en los medios de vida. Los hogares diversificadores (55,9%) participan en múltiples actividades económicas, entre ellas el cultivo de café, aguacate y caña de azúcar, además de la cría de ganado y porcinos. Los hogares vanguardistas (28,3%) dependen principalmente del cultivo de caña de azúcar, mientras que los hogares tradicionalistas (11,9%) presentan bajos niveles de productividad y dependen predominantemente del café como su principal fuente de ingresos. Los resultados revelan que el acceso diferenciado y la gestión de los capitales comunitarios influyen de manera significativa en el bienestar de los hogares, siendo las estrategias integradas y diversificadas las que generan mejores resultados. Asimismo, el fortalecimiento de habilidades, conocimientos y capacidades de articulación y redes resulta fundamental para potenciar la apropiación social del conocimiento relacionado con la caña de azúcar. Esto, a su vez, puede orientar estrategias más eficaces para el desarrollo del sector panelero y contribuir al bienestar general de los hogares rurales productores.

Palabras clave: gestión comunitaria; producción; soberanía alimentaria; sostenibilidad; territorialidad; vulnerabilidad.

INTRODUCTION

Agricultural production systems play a fundamental role in Colombia, as they directly influence the quantity and quality of food consumed by the population (Solís *et al.*, 2020). Advances in productivity have driven rural development by increasing income, generating decent employment, and providing processed products, with family farming playing a key role in this process (Kovtun, 2020). Among these productive systems, panela production stands out as one of the most important markets in the country, largely supported by small and medium-sized producers (Alarcón *et al.*, 2021).

Panela is an unrefined sugar derived from sugarcane juice (*Saccharum* spp.) (Alvarado *et al.*, 2024), typically marketed in block or powdered form, and available in both organic and conventional varieties. It is considered a key source of energy and nutrients for rural households (Flórez-Martínez *et al.*, 2021), and its production remains largely artisanal (Solís *et al.*, 2020). India leads the global market with an annual production of around eight million tons, followed by Colombia, which is the leading producer of panela in Latin America and the second largest worldwide, with an annual production of approximately one million tons. In Colombia, the panela sector contributes approximately 7% to the national Gross Domestic Product (GDP) and represents the second most socially significant agroindustry, after coffee. It involves around 350,000 households, accounting for 12% of the economically active rural population (FINAGRO, 2023).

The Department of Huila is one of Colombia's leading sugarcane-producing regions for panela, making it a strategic area for this activity nationwide. According to data from the National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadística-DANE, 2021), Huila's economy relies on livestock, agriculture, fishing, hunting, and forestry, which together contribute 20.2% to the departmental GDP, with panela production representing 3.56% of that total. Specifically, the southern part of Huila, (particularly the municipality of Isnos), is heavily dependent on panela production, underscoring the importance of this activity in the region's socioeconomic dynamics. Understanding the dynamics of rural communities in Isnos is essential for developing strategies that foster economic, social, and environmental development, improving the residents' living conditions, and strengthening the panela sector in the region.

The management of the panela production system faces key challenges, as

producers and technicians must make decisions regarding changes in production systems to improve sustainability (Suárez *et al.*, 2022). However, the lack of information on the efficiency of these systems limits the identification of the role that community capitals play in enhancing the well-being of producer households. In this context, livelihood analysis emerges as a valuable methodology for examining the assets available within communities and their role in meeting fundamental human needs-FHN (Suriyankietkaew *et al.*, 2025). It enables an understanding of how rural communities manage and utilize their resources to ensure sustainability (Prayitno *et al.*, 2025). Community capitals are considered essential resources for livelihood development, facilitating the generation of goods and the well-being of communities, which in turn contributes to achieving a dignified life (Tengapoe *et al.*, 2024).

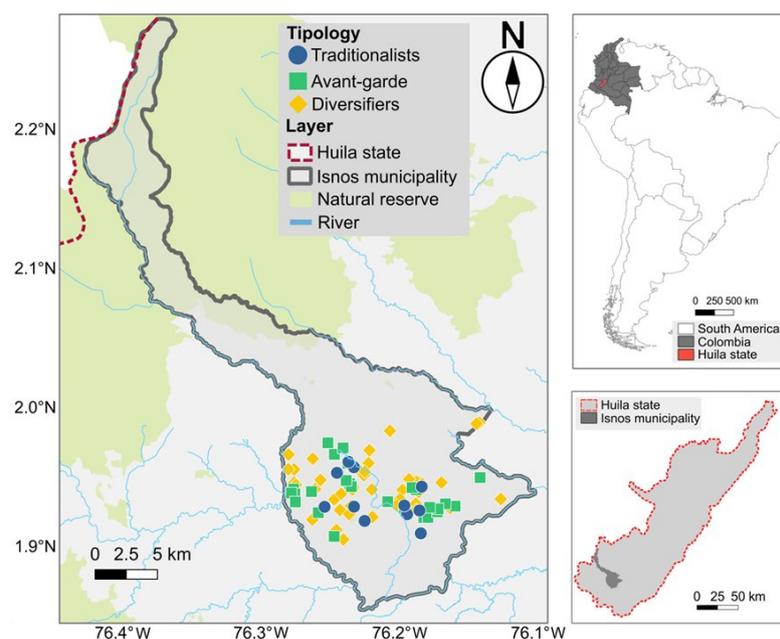
Characterizing the contribution of community capitals to the well-being of panela-producing households not only provides a better understanding of their living conditions and productive dynamics but also facilitates the design of joint actions for rural and territorial development in Colombia from social, political, economic, and environmental perspectives. In this regard, the objective of this research is to determine the impact of seven community capitals on the well-being of panela-producing households in Southwestern Huila, Colombia.

MATERIAL AND METHODS

Study area and Data collection

This study was conducted with 92 panela-producing households in the municipality of Isnos, located in the southwestern part of the Huila Department, Colombia, where a significant number of households are engaged in this activity. To ensure the representativeness of the sample, a random sampling method was employed, so that the selected households reflected the socio-economic and productive characteristics of the overall population. Isnos has a total area of 362 km², representing 1.81% of the Huila Department's territory. The average temperature is 18°C, and the altitude is 1,700 meters above sea level (Cano Sapuy *et al.*, 2023) (Figure 1).

Figure 1. Location and typological distribution of panela-producing households in Isnos, southwestern Huila, Colombia



The informed consent to participate was obtained from all the households after communicating the research objectives. Participants' personal information was anonymized during data collection and analysis. To identify key factors influencing household and community livelihoods, direct observations and semi-structured interviews were conducted with each family. The interviews included 36 questions related to capital endowments and 14 addressing Fundamental Human Needs, following the methodological framework proposed by Flora *et al.* (2018). Data collection was carried out using Android devices equipped with ODK Collect software between November 2023 and June 2024.

Typologies of Panela-Producing households

To establish the typologies of panela-producing households in Isnos municipality, 36 variables related to capital endowments were used (Table 1).

Table 1. Variables related to the livelihoods of panela-producing households in the southwestern Huila Department grouped by Capital Endowment

Capital endowment	Type of variable	Variable name	Abbreviation
Human	Quantitative	Family members	-
	Quantitative	Number of men	-
	Quantitative	Number of women	-
	Quantitative	Time of residence	-
	Quantitative	Average age of Women	-
	Quantitative	Average age of men	-
	Quantitative	Age of chief home	-
	Quantitative	Average age of children	-
	Qualitative	Educational level of women	EdeWom
Qualitative	Educational level of men	EdeMen	
Cultural	Quantitative	Number of participations in different cultural activities	-
	Quantitative	Years as farmer	-
	Qualitative	Type of soil fertilization	Fert
	Quantitative	Number of soil fertilization per year	-
	Qualitative	Type of weed control	Weed
	Quantitative	Number of weed control per year	-
Financial	Qualitative	Type of pest and disease control	Pest&DeasContr
	Quantitative	Monthly production of panela per hectare (sack)	-
	Quantitative	Monthly yield of panela (kg)	-
Built	Qualitative	Access to bank credit	BankCred
	Quantitative	Number of basic services	-
	Quantitative	Access to community resources	-
	Quantitative	Total area (ha)	-
	Qualitative	Land ownership	Land
	Qualitative	Transport of sugarcane from the crop to the mills	SugTransp

Capital endowment	Type of variable	Variable name	Abbreviation
Political	Quantitative	Years of Membership in Community Action Board	-
	Qualitative	Member of Community Action Board	MemCAB
	Qualitative	Participation in municipal or departmental activities	PartMunDep
Natural	Quantitative	Sugarcane crop area (ha)	-
	Quantitative	Coffee crop and livestock area (ha)	-
	Qualitative	Conservation of natural areas	ConsArea
	Quantitative	Forest land use (ha)	-
	Qualitative	Conservation of water sources	ConsWaterSource
Social	Quantitative	Number of participations in community activities	-
	Quantitative	Number of memberships in different organizations	-
	Qualitative	Member of the sugarcane producers' association	MemSugAsoc

A Factor Analysis of Mixed Data (FAMD) was conducted to integrate both quantitative and qualitative variables with the aim of grouping households and characterizing them according to the specific attributes associated with each typology derived from the analysis. Subsequently, a Hierarchical Clustering of Principal Components (HCPC) analysis was applied to FAMD results using Ward's method to generate three distinct typologies, using the 'FactoMineR' package (Husson *et al.*, 2025).

Capital endowment estimation

Once the typologies of panela-producing households were identified, the capital endowment of the community was assessed. This assessment was conducted by linking asset-based variables to the seven types of capital, which provide a comprehensive perspective on the resources and capabilities that support livelihoods: (i) Human, (ii) Financial, (iii) Cultural, (iv) Built, (v) Political, (vi) Natural, and (vii) Social Capital (Flora *et al.*, 2018).

To calculate the community capital's endowment, all variables were initially linearly transformed into intervals of [0-1]. Subsequently, the variables for each capital (quantitative or qualitative; Table 1) were summed and transformed into intervals of [0-1] to obtain the final index for the endowment of each community capital (Suárez *et al.*, 2022).

Fundamental Human Needs estimation

Fundamental Human Needs (FHN) were evaluated for each of the 92 panela-producing households through 14 variables grouped into four types: (i) Basics (food, health, reproduction, and safety), (ii) Personal (affection, knowledge, identity, and self-esteem), (iii) Environmental (healthy environment, and freedom), and (iv) Action (creative work, recreation, participation, and communication). Each variable was evaluated using a fixed response categorized as "bad", "regular," and "good" (Imbach, 2016; Rojas-Peña *et al.*, 2024).

Statistical analysis

The quantitative variables and capital endowment indices were analysed using a simple linear model. The assumptions of normality were verified using the Shapiro-Wilk test ($p\text{-value} > 0.05$), applied to the residuals of the model, along with a Q-Q plot. Homogeneity of variance was assessed using Bartlett's test ($p\text{-value} > 0.05$) and the residuals vs. fitted plot. When variables showed non-normal distribution and heterogeneity, unequal variance was accounted for in the model. After fitting the model, a Fisher LSD test ($p\text{-value} < 0.05$) was applied to contrast the means of the typologies in each variable and capital index.

For the multivariate analysis, a Principal Component Analysis (PCA) was performed to correlate capital endowment with the typologies of panela-producing households, using the "FactoMineR" package (Husson *et al.*, 2025) and the "factoextra" (Kassambara & Mundt, 2020). Additionally, a Monte Carlo test with 999 permutations was employed to evaluate the effect of the typologies on the capitals, with the purpose of identifying the arrangement of panela-producing household typologies that best fits the established mathematical model., utilizing the "Ade4" package (Dray & Dufour, 2007). Finally, a Pearson correlation test ($p\text{-value} < 0.05$) was conducted to observe synergies between capitals. All analyses were performed using the statistical software R version 4.2.0 (R Core Team, 2024) and the RStudio development environment version 1.3.1 (Allaire, 2024).

RESULTS

Typologies of Panela-Producing households

Panela-producing household typologies were initially integrated into a Factor Analysis of Mixed Data-FAMD, which explained 22.7% of the total variance in its first two dimensions. Subsequently, a Hierarchical Clustering of Principal Components-HCPC was applied to the FAMD results, classifying panela-producing households into three typologies: i) Diversifiers (55 households), ii) Avant-garde (26 households), and iii) Traditionalists (11 households) (Figure 2) this classification was adapted from Jiménez-Carvajal *et al.* (2024).

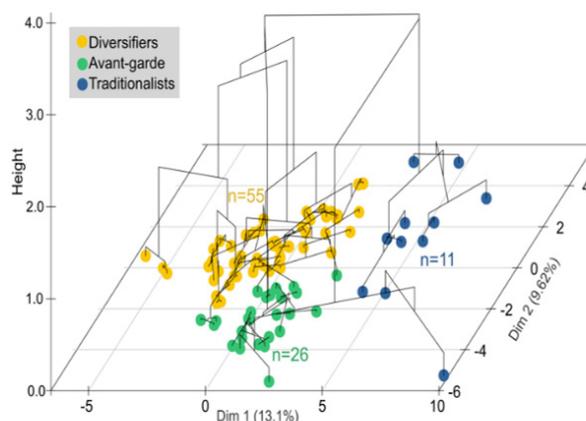


Figure 2. Hierarchical Clustering on Principal Components (HCPC) of Typologies of panela-producing households in the municipality of the Isnos, located in the Southwestern Huila, Colombia.

These typologies are analyzed as follows:

I) Diversifiers. This typology includes the largest number of households (60%) (Figure 2). It is characterized by income diversification to meet basic human needs, combining coffee production, sugarcane farming, livestock, and avocado cultivation. Households in this category have the least experience in sugarcane production and own the smallest farms in both total area and cultivable land. They also have low panela production and apply fewer fertilization cycles per year. Regarding education, men in this group have the highest educational levels compared to those in other typologies. Additionally, this is the second group with the greatest access to credit (Tables 2 and 3).

II) Avant-Garde. Households classified as avant-garde represent 28% of the total sample (Figure 2). Their economy relies mainly on panela production, although their productivity per hectare is low. This group has limited access to credit and exhibits the lowest educational levels and the highest average age among its members (Tables 2 and 3).

III) Traditionalists. Tradicionalists comprise 12% of panela-producing households (Figure 2). Coffee and sugarcane production, which are characteristic of this region, form the basis of their economic activity. This group stands out for having the highest income from these activities, the longest experience as producers, and the largest farms, with the most extensive sugarcane cultivation areas. Moreover, women belonging to this typology exhibit the highest educational attainment among all groups. These households achieve the highest panela production per hectare, apply more frequent fertilization and weed control practices throughout the year, and have the greatest access to credit (Tables 2 and 3).

Capital Endowment in Panela-producing Households Typologies

This approach enabled a comprehensive and comparative evaluation of the different typologies of panela-producing households in Southwestern Huila, Colombia.

Table 2. *Quantitative variables studied for each capital endowment in different typologies of panela-producing households*

Capital endowment	Variable name	Typology		
		Traditionalists	Avant-garde	Diversifiers
Human	Family members	4.18 (0.5) a	2.92 (0.21) b	4.00 (0.18) a
	Number of men	2.27 (0.30) a	1.27 (0.10) b	2.13 (0.12) a
	Number of women	1.91 (0.31)	1.65 (0.17)	1.87 (0.13) ns
	Time of residence	48.27 (2.92) a	50.65 (1.77) a	38.15 (1.16) b
	Average age of Women	41.45 (4.27) b	55.81 (2.45) a	31.55 (1.12) c
	Average age of men	41.55 (4.03) a	45.00 (3.07) a	28.44 (2.12) b
	Age of the chief home	52.55 (3.65) b	60.96 (1.72) a	45.85 (1.45) b
	Average age of children	4.45 (1.43) a	0.62 (0.62) b	6.45 (0.75) a

Capital endowment	Variable name	Typology		
		Traditionalists	Avant-garde	Diversifiers
Cultural	Number of participations in different cultural activities	2.45 (0.56)	2.15 (0.29)	2.78 (0.21) ns
	Years as a farmer	25.91 (2.00) a	24.62 (1.44) a	16.07 (0.84) b
	Number of soil fertilizations per year	2.36 (0.20) a	1.73 (0.13) b	1.69 (0.11) b
	Number of weed control per year	3.09 (0.37)	2.85 (0.17)	3.07 (0.11) ns
Financial	Monthly production of panela per hectare (sacks)	110.18 (15.19) a	29.81 (3.82) b	26.69 (2.68) b
	Monthly yield of panela (kg/ha)	6.64 (0.91) a	1.81 (0.23) b	1.62 (0.16) b
Built	Number of basic services	2.36 (0.28) ab	2.27 (0.16) b	2.96 (0.19) a
	Access to community resources	2.09 (0.09) b	2.62 (0.14) a	2.67 (0.16) a
	Total area (ha)	24.82 (3.02) a	5.67 (0.82) b	3.49 (0.33) c
Political	Years of Membership in Community Action Board	10.09 (3.73) a	7.69 (1.78) a	3.07 (0.50) b
Natural	Sugarcane crop area (ha)	12.55 (1.53) a	3.29 (0.43) b	2.98 (0.29) b
	Coffee crop and livestock area (ha)	10.18 (3.28) a	2.19 (0.59) b	0.51 (0.12) c
	Forest land use (ha)	2.09 (0.85) a	0.19 (0.16) b	0.00 (0.00) b
Social	Number of participations in community activities	0.18 (0.18)	0.00 (0.00)	0.13 (0.05) ns
	Number of memberships in different organizations	0.18 (0.12)	0.00 (0.00)	0.22 (0.07) ns

*Means and standard errors (in parentheses) followed by different letters indicate significant differences among typologies according to Fisher's LSD test ($p < 0.05$). ns: no significant differences.

Human Capital

Among the 92 panela-producing households, 342 inhabitants were identified, with a gender distribution of 51.16% men and 48.84% women. The Diversifiers and Traditionalist typologies have households with an average of four members, maintaining a balanced gender ratio. The length of residence is highest among Avant-garde households (50.65 years) and lowest among Diversifiers households (38.15 years), a pattern also observed in the average age of men, women, and household heads (Table 2).

Regarding educational level, 18.2% of women in the Diversifiers typology and 10.9% in the Traditionalists have completed university studies. For men, these figures were 16.4% and 9.1%, respectively, indicating a relatively higher level of education in these typologies. In contrast, in the Avant-garde typology, 65.5% of men and 50% of women have only completed basic education (Table 3).

Cultural Capital

All typologies showed active participation in cultural activities within their communities. However, traditionalist producers report the longest involvement in panela production (25.91 years), followed by Avant-garde (24.62 years) and Diversifiers (16.07 years). Likewise, Traditionalists reported the highest average number of fertilizations and weed control applications per year compared to the other typologies (Table 2).

Regarding soil fertilization (Table 3), Traditionalists showed lower

dependence on synthetic fertilization alone (54.5% synthetic and 45.5% organic-synthetic mix) compared to Avant-garde (80.8% synthetic) and Diversifiers (65.5% synthetic). Despite this trend, the Diversifiers typology was the only one with producers using exclusively organic fertilization (5.5%).

In terms of weed control, Traditionalists most frequently implement a combination of mechanical and chemical practices (81.8%), compared to the other typologies. Regarding pest and disease control, all typologies exhibited high application rates of chemical products (57.6%), but Traditionalists and Diversifiers demonstrated a greater implementation of biological or mechanical control methods (Table 3).

Financial Capital

The Traditionalists typology had the highest panela production per hectare (110.18 sacks) and yield (6.64 kg/ha), surpassing the other typologies (Table 2). In terms of access to credit (Table 3), Traditionalists also had the highest access to bank financing (63.6%), followed by Diversifiers (58.2%). In contrast, only 42.3% Avant-garde households had access to bank credit.

Table 3. Relative frequencies in the categories of qualitative variables analyzed for each capital endowment across different typologies of panela-producing households.

Capital endowment	Variable name	Category	Typology			
			Traditionalists	Avant-garde	Diversifiers	Total
Human	Educational level of women	None	0.0%	3.8%	10.9%	7.6%
		Elementary	9.1%	50.0%	14.5%	23.9%
		Incomplete secondary	27.3%	34.6%	21.8%	26.1%
		Secondary	36.4%	11.5%	36.4%	29.3%
		Technical	9.1%	0.0%	5.5%	4.3%
	University	18.2%	0.0%	10.9%	8.7%	
	Educational level of men	Elementary	0.0%	61.5%	0.0%	17.4%
		Incomplete secondary	27.3%	19.2%	12.7%	16.3%
		Secondary	54.5%	19.2%	52.7%	43.5%
		Technical	9.1%	0.0%	18.2%	12.0%
University		9.1%	0.0%	16.4%	10.9%	
Cultural	Type of soil fertilization	None	0.0%	3.8%	9.1%	6.5%
		Synthetic	54.5%	80.8%	65.5%	68.5%
		Organic	0.0%	0.0%	5.5%	3.3%
		Organic and synthetic	45.5%	15.4%	20.0%	21.7%
	Type of weed control	None	0.0%	0.0%	5.5%	3.3%
		Mechanical	18.2%	50.0%	40.0%	40.2%
		Mechanical and chemical	81.8%	50.0%	54.5%	56.5%
	Type of pest and disease control	None	0.0%	11.5%	7.3%	7.6%
		Chemical	45.5%	69.2%	54.5%	57.6%
		Biological	0.0%	0.0%	5.5%	3.3%
Biological-Chemical		18.2%	3.8%	1.8%	4.3%	
Biological-Mechanical		0.0%	7.7%	18.2%	13.0%	
Biological-Chemical-Mechanical	36.4%	7.7%	12.7%	14.1%		
Financial	Access to bank credit	No	36.4%	57.7%	41.8%	45.7%
		Yes	63.6%	42.3%	58.2%	54.3%
Built	Land ownership	Owned	100.0%	100.0%	94.5%	96.7%
		Rented	0.0%	0.0%	5.5%	3.3%
	Transport of sugarcane from the crop to the mills	Animal	18.2%	84.6%	63.6%	64.1%
		Animals and car	81.8%	15.4%	36.4%	35.9%

Capital endowment	Variable name	Category	Typology			
			Traditionalists	Avant-garde	Diversifiers	Total
Political	Member of Community Action Board	No	45.5%	46.2%	50.9%	48.9%
		Yes	54.5%	53.8%	49.1%	51.1%
	Participation in municipal or departmental activities	No	90.9%	100.0%	90.9%	93.5%
		Yes	9.1%	0.0%	9.1%	6.5%
Natural	Conservation of natural areas	No	27.3%	92.3%	98.2%	88.0%
		Yes	72.7%	7.7%	1.8%	12.0%
	Conservation of water sources	No	72.7%	92.3%	96.4%	92.4%
		Yes	27.3%	7.7%	3.6%	7.6%
Social	Member of the sugarcane producers' association	No	27.3%	26.9%	38.2%	33.7%
		Yes	72.7%	73.1%	61.8%	66.3%

Built Capital

The Traditionalists typology owned the largest land area (22.77 ha), followed by Avant-garde (5.52 ha) and Diversifiers (3.66 ha). All producers had access to basic services, including electricity, aqueducts, and drinking water (Table 2).

Regarding land tenure, 100% of the Avant-garde and Traditionalist producers were landowners, while 5.5% of the Diversifiers rented their land. In terms of transportation, most Avant-garde (84.6%) Diversifiers (63.6%) producers relied solely on animals for transporting sugarcane, whereas 81.8% of Traditionalists used both motor vehicles and animals (Table 3).

Political Capital

The Traditionalists typology had the longest membership in Community Action Boards (JAC, in Spanish Junta de Acción comunal) (10.09 years), followed by the Avant-garde (7.69 years) (Table 2). More than 50% of all typologies are active members of a JAC; however, over 90% did not participate in political activities at the municipal or department level (Table 3).

Natural capital

Traditionalist households distributed their land more equitably between sugarcane and coffee production compared to the other typologies. Among Avant-garde typology, 58.02% of farmland was allocated to sugarcane, although some areas were unproductive, with the remainder allocated to other agricultural and livestock activities (Table 2).

In terms of conservation, 72.7% of Traditionalist households preserved natural areas, compared to only 7.7% of Diversifiers and 1.8 % of Avant-garde households. This pattern was also observed in water resource conservation (Table 3).

Social Capital

Panela-producing households exhibited low participation in social activities and belong to a limited number of organizations, a trend most pronounced among Diversifiers and Traditionalists (Table 2). Nevertheless, more than 60% of households were part of a sugarcane producers' association (Table 3).

Relationship between Capital Endowments and Typologies

The analysis of capital endowments showed that human, cultural, and built capital had the highest average values (0.76, 0.63, and 0.73, respectively), while political, natural, and social capital had the lowest values (0.28, 0.22, and 0.32, respectively) (Figure 3).

At the typology level, Traditionalists had significantly higher levels of human, financial, built, and natural capital, with increases of 10%, 35%, 14%, and 44%, respectively, compared to the other typologies (Figure 3).

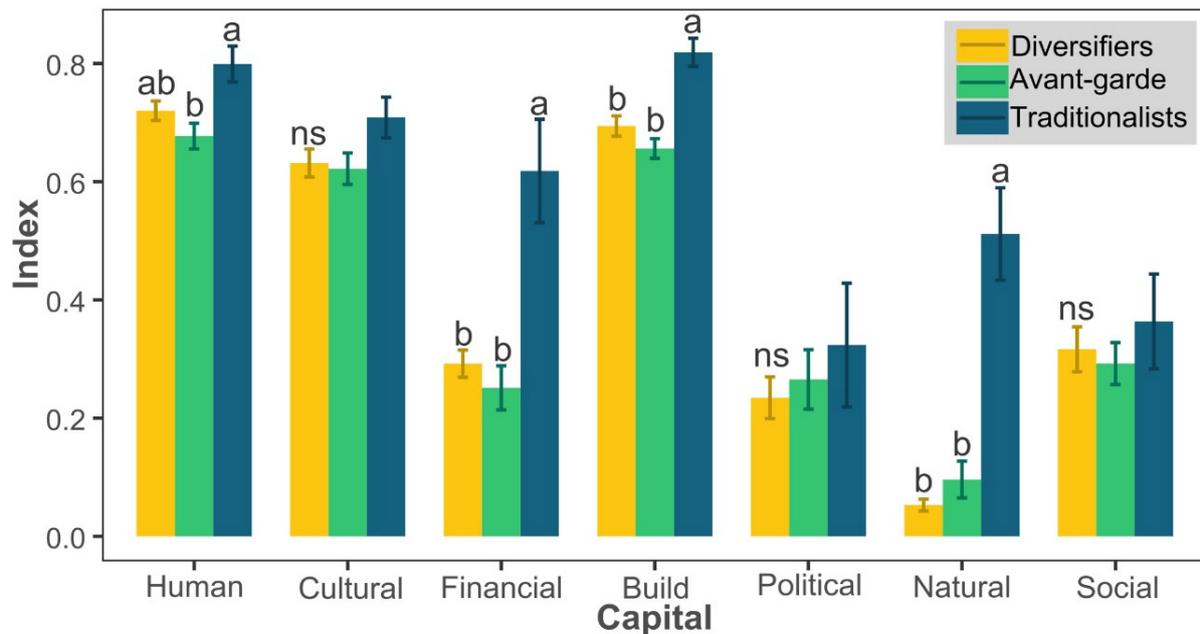


Figure 3. Community capital endowments across different typologies of panela-producing households. Different letters with each capital indicate statistically significant differences according to Fisher's LSD test (p -value < 0.05). ns: not significant.

Principal Component Analysis (PCA) revealed trends in the distribution of community capital among typologies, explaining 52.2% of the variability in the first two principal components (Figure 4a). A stronger association was observed between human, financial, built, and natural capital with Traditionalist producers, while political, cultural, and social capital did not show a clear association with any specific typology.

Finally, although no causal relationship was established between capital endowments and typologies, significant correlations were identified among various types of community capital (Figure 4b). Financial capital exhibited the highest number of correlations with other capitals (four), followed by human, cultural, built, and natural capital (three correlations each). In contrast, social and political capital exhibited the fewest correlations (two each). These negative correlations observed in political and social capital are primarily due to the fact that many of the variables analyzed showed very similar responses among all participants in this study. Consequently, the variability within the data is relatively low.

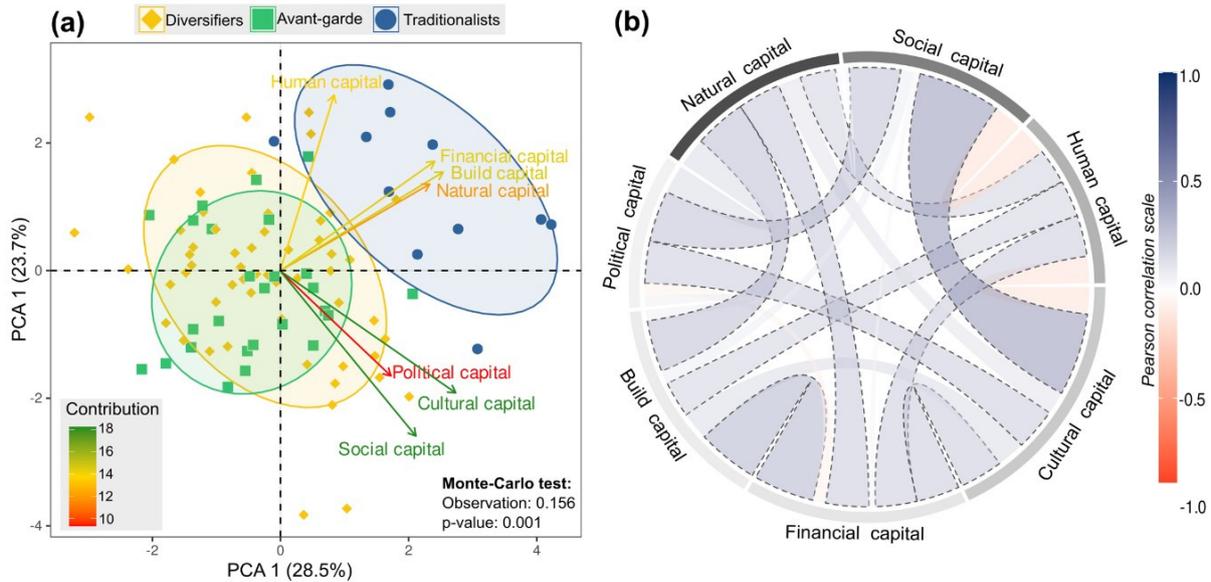


Figure 4. (a) Principal Component Analysis (PCA) of capital indices and typologies. (b) Correlation network among household capital indices, where gridlines indicate significant correlation (p -value < 0.05) based on Pearson’s correlation test.

Fundamental Human Needs (FHN)

The assessment of FHN (Figure 5) revealed notable differences among the typologies of panela-producing households, particularly in the category of Basic Needs, while Needs related to the Person, Action, and Environment were more consistently rated.

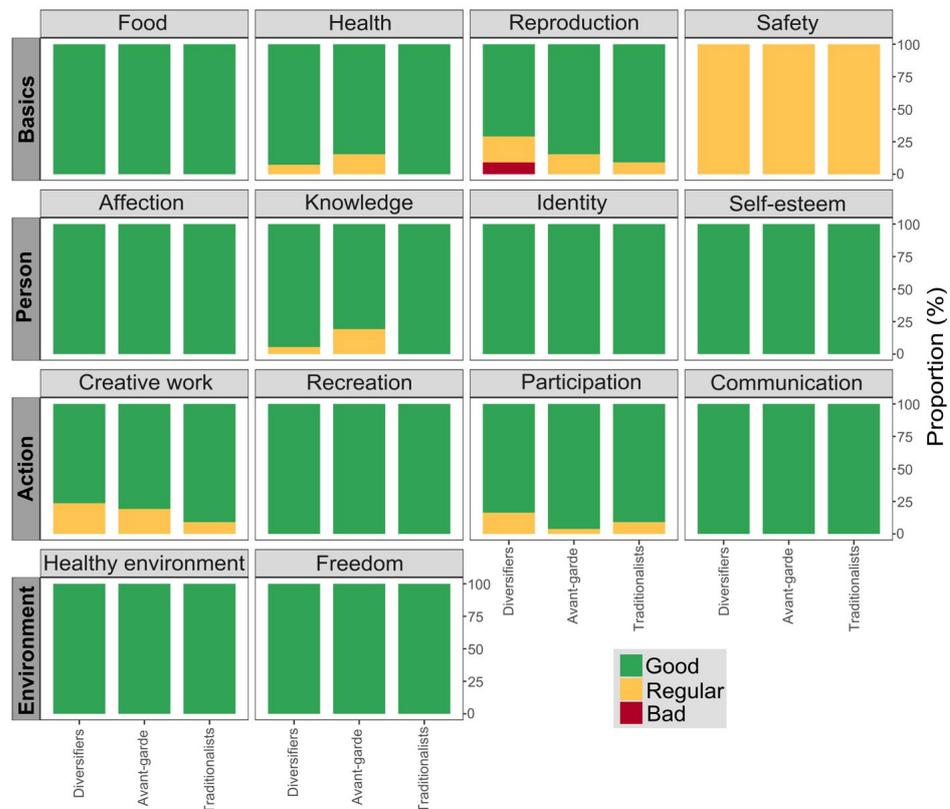


Figure 5. Relative frequencies of categories (Good, Regular, and Bad) in FHN responses, grouped by Basics, Person, Action, and Environment dimensions for each typology of panela-producing households.

Regarding Food, 100% of households across all typologies rated their access as Good. However, Safety was classified as Regular by all households, likely due to the presence of illegal armed groups or common delinquency in the territory. In terms of Health, 20% of Avant-garde households and 10% of Diversifiers rated it as Regular, whereas 100% of Traditionalist households considered it Good. In the reproduction dimension, 10% of Diversifiers perceived it as Bad, while 25% of Avant-garde and Diversifier households classified it as Regular.

In the FHN category related to the Person, all typologies reported positive levels (100%) in affection, identity, and self-esteem. However, in the Knowledge dimension, 25% of Avant-garde households indicated that their level of Knowledge in productive management was Regular (Figure 5).

In the Action category, Recreation and Communication were rated as Good (100%) by all typologies, while Creative work and Participation were considered Regular by approximately 25% of panela-producing households.

Finally, in the Healthy Environmental and Freedom dimensions, all panela-producing households classified their FHN in this respect as Good (Figure 5), reflecting a positive perception of their Environmental conditions and sense of autonomy. Furthermore, with respect to the well-being of panela-producing households, an initial diagnosis can be inferred by contrasting their livelihoods with the relationship among community capitals. This relationship becomes evident across the typologies in terms of access, use, and quality of the assets available to each household, their capacity to generate sufficient and diversified income, the stability and resilience of their productive strategies, their level of social participation and access to support networks and local governance, and finally, their overall perceived satisfaction with their living conditions.

Accordingly, the differential access to and management of community capitals significantly influence household well-being. Higher levels of well-being are achieved through strategies that are more integrated, diversified, and articulated both productively and socially. The ability to combine social skills, production-related knowledge, and effective linkages with markets for value-added products will enable the development of more effective strategies for strengthening the panela sector, ultimately contributing to the comprehensive well-being of rural farming families engaged in this productive activity.

DISCUSSION

Typologies of Panela-Producing Households

In all typologies identified in this study, significant statistical differences were observed, highlighting key variables such as the amount of land used for economic activities, farm size, and the length of time households have been engaged in panela production. These characteristics have been widely reported in studies on sugarcane producers (Jiménez-Carvajal *et al.*, 2024), small-scale livestock farmers (Martínez-Moyano *et al.*, 2024), and coffee and cocoa producers (Hernández-Nunez *et al.*, 2024; Suárez *et al.*, 2022). The three typologies identified in this study reflect the organizational patterns of panela producers in Southwestern Huila.

A similar finding was recently reported by Jiménez-Carvajal *et al.* (2024), who identified three types of sugarcane-producing households in the Caquetá

Department, Colombia. Their classification served as the basis for naming the groups in this study: Avant-garde, Traditionalists, and Diversifiers. Evaluations of 81 rural producers in Caquetá showed that despite lower sugarcane production levels compared to Southwestern Huila, these households develop similar livelihood strategies.

For diversifiers, income heterogeneity is supported by coffee and avocado cultivation, as well as livestock activities such as swine farming. This diversification strengthens household economies and enhances financial resilience (Muñoz *et al.*, 2024). Most panela-producing households operate within small-scale productive units, similar to other sugarcane producers in Colombia with comparable characteristics (Jiménez-Carvajal *et al.*, 2024). This highlights the essential role of small-scale producers in the regional economy, which is primarily driven by sugarcane production.

The results indicate that Avant-garde panela-producing households base their entire economy on sugarcane production, while Traditionalists distribute income between sugarcane and coffee cultivation. Additionally, some family members work as teachers, traders, or engage in other agricultural activities outside their farms, diversifying their income source and reducing financial vulnerability (García *et al.*, 2023).

Capital Endowment in Panela-producing Households Typologies

Statistically significant differences were found for the variable family size, which is particularly relevant for panela producers in Southwestern Huila. Family size directly influences the worker-consumer ratio in larger households, where the presence of more individuals enables greater labor availability for production, potentially leading to higher household income (Sópalo-Romero *et al.*, 2024). Similarly, Suárez *et al.* (2021) assert that family household income is positively influenced by a higher number of men in the family, as they are culturally responsible for household earnings, particularly formal employment in most rural households in Colombia.

Another critical aspect of Human Capital is the family's educational level. Education is a key asset, as it contributes to economic improvement and access to higher-paying activities (Collantes-González & Atencio-Valdespino, 2023). In this context, Traditionalists and Diversifiers households have greater opportunities to diversify their income, as a higher percentage of these households have attained higher education compared to Avant-garde households, facilitating engagement in alternative economic activities.

Cultural attachment to sugarcane production is particularly strong in rural communities, especially among Avant-garde households, which have devoted more time to this economic activity, ensuring its continuity over time. Community festivities and related activities also contribute to the dissemination and transfer of knowledge regarding sugarcane management and production (Martínez-Moyano *et al.*, 2023; Muñoz *et al.*, 2024).

Financial Capital is one of the most crucial components in the analysis of community capitals, as it directly impacts the continuity of many economic activities among panela producers. Jiménez-Carvajal *et al.* (2024) suggest that this Financial Capital is vital for rural households, as financial income is highly correlated with their quality of life and consequently influences their livelihood strategies. In this regard, higher economic returns from panela production among Traditionalists

and Avant-garde households contribute to an improved quality of life compared to Diversifiers' panela-producing households, which report lower economic income.

Greater diversification of household income largely depends on land use and the opportunities available to producers to utilize various livelihood activities, ultimately leading to economic improvements (Rodríguez-Borray *et al.*, 2022). In this case, Diversifiers households play a fundamental role, as their higher financial income from alternative economic activities also enhances their household's economy.

Built capital is critical for the proper functioning of rural households, as land availability and size significantly influence production capacity (Rojas-Peña & Martínez-Moyano, 2022). Traditionalist households generally own larger land areas dedicated to sugarcane production and, secondarily, to coffee cultivation, which enables them to generate higher economic income. According to the Jiménez-Carvajal *et al.* (2024), land availability in Huila is limited and primarily allocated for coffee production.

Various community characteristics, as described by capital endowments, have demonstrated significant synergies. Economic, social, and cultural activities, along with the availability of tangible resources such as human and physical capital, play a crucial role in livelihood strategies (Collantes-González & Atencio-Valdespino, 2023). However, it is important to note that while correlations between community capital and household typologies provide descriptive insights, they do not imply causality. The relationships observed may be influenced by multiple external factors that shape production strategies and household well-being. The interaction among different community capitals fosters resilience, supports the fulfillment of Fundamental Human Needs (FHN), and enhances rural livelihood strategies. These social associations and relationships improve knowledge distribution and facilitate experience-sharing among producers (Sópalo-Romero *et al.*, 2024).

Fundamental Human Needs

FHN play a crucial role in rural communities, as their fulfillment directly impacts community well-being and sustainability. Many rural households face unmet fundamental needs, and the availability of resources enables significant improvements that significantly enhance overall life satisfaction (Atkinson *et al.*, 2023). In this study, diversified households demonstrated a better categorization recharging Basic Needs. However, all typologies consistently rated security as "Regular", a trend likely influenced by the persistent internal armed conflict across various regions of Colombia (Arias, 2020; Rojas-Granada & Cuesta-Borja, 2021).

The fulfillment of personal and action-related needs plays a pivotal role in shaping rural communities, reinforcing the sense of coexistence and belonging between households and their natural environment (Rodríguez-Borray *et al.*, 2022). Likewise, the satisfaction of environmental needs suggests that households perceive their communities as favorable places to live (Atkinson *et al.*, 2023). All three household typologies rated environmental needs positively, particularly in terms of Freedom and a Healthy environment. Similarly, recreation and communication are key aspects of action-related needs, which were also highly valued.

Finally, the integration of community capitals within the livelihoods framework of rural households is essential for understanding the social dynamics of rural communities. The subsistence strategies observed across the different typologies (diversifier, avant-garde, and traditionalist) reflect the interaction between the

productive capacities of the territory and the capitals available to each household. In this context, territorial conditions favor diversification and expand income-generating opportunities, resulting in greater economic resilience. In contrast, traditionalist households are generally located in areas with limited access to infrastructure or more restrictive agroecological conditions, which constrain their productive options and force them to rely on lower-margin activities.

Furthermore, FHN and community capitals are closely interrelated, as both depend on the household's capacity to secure adequate satisfiers in dimensions such as housing, food, education, health, and community participation. In this study, well-being was analyzed from a multidimensional perspective, considering capitals as resources that enable households to meet their needs and improve their overall quality of life.

CONCLUSIONS

Panela-producing households in Southwestern Colombia maintain a long-standing economic tradition centered on artisanal panela production. This study identifies three household typologies based on productive strategies: Traditionalist and Avant-garde households rely primarily on sugarcane cultivation, while Diversifiers incorporate additional crops such as coffee and avocado, thereby expanding their livelihood base.

The analysis of community capitals highlights the central role of financial capital, particularly for Traditionalist and Avant-garde households, given its direct influence on household income and production sustainability. Financial capital also interacts with other forms of capital, strengthening local economic dynamics. Despite persistent security challenges related to the internal conflict in Colombia, households generally perceive their environment as conducive to well-being.

This study contributes to the understanding of rural livelihoods by demonstrating how diversified productive strategies enhance resilience and sustainability. Future research should extend this analysis to other panela-producing regions and incorporate technological innovation, improved market access, and climate adaptation strategies to further strengthen the long-term well-being of rural households.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

- Alarcón, A. L.; Palacios, L. M.; Osorio, C.; César Narváez, P.; Heredia, F. J.; Orjuela, A.; Hernanz, D. (2021). Chemical characteristics and colorimetric properties of non-centrifugal cane sugar (“panela”) obtained via different processing technologies. *Food Chemistry*. 340: 128183. <https://doi.org/10.1016/j.foodchem.2020.128183>
- Allaire, J. (2024). RStudio: Integrated development environment for R. <https://www.r-project.org/conferences/useR-2011/abstracts/180111-allairejj.pdf>
- Alvarado, J. P.; Palma, H.; Ramos, C.; Moreno, A.; Osio, E.; Horta, R.; Caraveo, G.; Moreno, S. (2024). Evaporation automation at the Central de Mieles de Útica, Colombia, for non-centrifugal sugar cane production: Sustainable optimization strategies. *Bioresource Technology Reports*. 26: 101850. <https://doi.org/10.1016/j.biteb.2024.101850>
- Arias, D. P. (2020). La implementación del acuerdo de paz y la transformación del conflicto armado en Colombia. *Revista Científica General José María Córdova*. 18(31): 565-584. <https://doi.org/10.21830/19006586.621>
- Atkinson, R.; Berru, S.; Delgado, L.; Yovera, F.; Berru, J.; Robledo, Y.; Cruz, G. (2023). Identifying the origin of acrylamide in Peruvian panela production to inform strategies for its reduction. *Food Additives & Contaminants: Part A*. 40(4): 508-517. <https://doi.org/10.1080/19440049.2023.2187646>
- Cano Sapuy, A. L.; Carvajal Calderón, N.; Lasso Bolaños, O. (2023). Estrategias didácticas, blog educativo y desarrollo de habilidades lectoras en estudiantes del grado cuarto, municipio de Isnos Huila. <https://repositorio.unicartagena.edu.co/server/api/core/bitstreams/f2832c25-bb25-4cb8-84aa-d2a5a6ec69b2/content>
- Collantes-González, R. D.; Atencio-Valdespino, R. (2023). Producción artesanal de panela en Tinajas, Dolega—Ciriquí: Estudio de caso. *Revista Investigación Agraria*. 5(3): 6-13. <https://doi.org/10.47840/ReInA.5.3.1937>
- Departamento Administrativo Nacional de Estadística-DANE. (2021). Cuentas nacionales departamentales. <https://www.dane.gov.co/index.php/estadisticas-por-tema/cultura/economia-cultural-y-creativa/reportes>
- Dray, S.; Dufour, A. B. (2007). The ade4 Package: Implementing the Duality diagram for ecologists. *Journal of Statistical Software*. 22: 1-20. <https://doi.org/10.18637/jss.v022.i04>
- FINAGRO. (2023). Informe de gestión sostenible 2023. https://www.finagro.com.co/sites/default/files/basic-page/2024-03/Finagro-IGS-2023_o.pdf
- Flora, C. B.; Flora, J. L.; Gasteyer, S. P. (2018). *Rural Communities: Legacy + Change*. 5th ed. New York: Routledge. pp. 506. <https://doi.org/10.4324/9780429494697>
- Flórez-Martínez, D. H.; Contreras-Pedraza, C.; Rodríguez, J. (2021). A systematic analysis of non-centrifugal sugar cane processing: Research and new trends. *Trends in Food Science & Technology*. 107: 415-428. <https://doi.org/10.1016/j.tifs.2020.11.011>
- García, R.; Rosas, G.; Sanchez, V. (2023). Socio-financial functioning of sugarcane (*Saccharum officinarum* L.) processing for the production of panela: the case of the Bellavista village. *FACE: Revista De La Facultad De Ciencias Económicas Y Empresariales*. 23(1): 211-225. <https://doi.org/10.24054/face.v23i1.2476>
- Hernández-Nunez, H.; Suárez, J.; Andrade, H.; Acosta, J.; Núñez, R.; Gutiérrez, D.; Gutiérrez, G.; Gutiérrez, I.; Casanoves, F. (2024). Interactions between climate, shade canopy characteristics and cocoa production in Colombia. *Frontiers in Sustainable Food Systems*. 8: 1295992. <https://doi.org/10.3389/fsufs.2024.1295992>
- Husson, F.; Josse, J.; Lee, S.; Mazet, J. (2025). FactoMineR: Multivariate exploratory data analysis and data mining. <https://cran.r-project.org/web/packages/FactoMineR/index.html>
- Imbach, C. A. (2016). Estrategia de vida: Analizando las Conexiones Entre la Satisfacción de las Necesidades Fundamentales y los Recursos de las Comunidades Rurales. 1st edition. Turrialba, Costa Rica: Geolatina Ediciones.
- Jiménez-Carvajal, D. A.; Sánchez-Avilés, A. M.; Hernández-Núñez, H. E.; Gutiérrez-García, G. A.; Rojas-Vargas, S.; Hembuz-Falla, G. D.; Salamanca-Falla, C. S.; Ortiz-Morea, F. A. (2024). Role of sugarcane cultivation for panela production in the livelihood strategies of peasant families in the Colombian Amazon. *Human Ecology*. 52: 409-423. <https://doi.org/10.1007/s10745-024-00494-5>
- Kassambara, A.; Mundt, F. (2020). Package ‘factoextra’. Extract and Visualize the Results of Multivariate

- Data Analyses. <https://CRAN.R-project.org/package=factoextra>
- Kovtun, O. V. (2020). Pluriatividade e agroindústrias rurais no Maranhão: Uma análise baseada no censo agropecuário de 2006. *Revista Pós Ciências Sociais*. 16(32): 189-217. <https://doi.org/10.18764/2236-9473.v16n32p189-217>
- Martínez-Moyano, E.; Agudelo Ardila, D.; Capera Montalvo, E. A.; Loaiza Molina, L. C.; Cuéllar Ramírez, M.; Rojas Peña, O. R. (2023). Medios de vida rurales de familias porcicultoras del municipio de La Montañita, Caquetá, Colombia. *CES Medicina Veterinaria Y Zootecnia*. 17(3): 10-24. <https://doi.org/10.21615/cesmvz.6952>
- Martínez-Moyano, E; Hernández-Aya, D; Hernández-Guerrero, K; Arias-Betancourth, J; Zapata-Ortiz, C; Rojas-Peña, O. (2024). Evaluación de los medios de vida sostenibles y la aplicación de los capitales de la comunidad: Estudio de caso de familias ganaderas de El Doncello, Caquetá-Colombia. *Investigación & Desarrollo*. 32(2): 20-34. <https://doi.org/10.14482/indes.32.02.986.765>
- Muñoz, J; Carranza, B; Cortés, Y; Rodríguez, L. (2024). Comprehensive characterization of high Andean sugarcane production systems (*Saccharum officinarum*) for panela production in Colombia. *Revista Ceres*. 71: e71036. <https://doi.org/10.1590/0034-737X2024710036>
- Prayitno, G; Auliah, A; Efendi, A; Hayat, A; Subagiyo, A; Salsabila, A. (2025). The role of livelihood assets in affecting community adaptive capacity in facing shocks in Karangrejo Village, Indonesia. *Economies*. 13(1): 13. <https://doi.org/10.3390/economies13010013>
- R Core Team. (2024). R: A Language and Environment for Statistical Computing. Vienna, Austria. Available: <http://www.r-project.org/>
- Rodríguez-Borray, G. A.; Cruz-Castiblanco, G. N.; Tauta-Muñoz, J; Huertas-Carranza, B.; Polo-Murcia, S. M. (2022). Rural agro-industrial enterprises diversity: Typologies of panela production in Huila, Colombia. *Agronomía Mesoamericana*. 33(2): 47969. <https://doi.org/10.15517/am.v33i2.47969>
- Rojas-Granada, C.; Cuesta-Borja, R. (2021). Los estudios sobre el conflicto armado y la construcción de paz en Colombia desde una perspectiva territorial: Abordajes y desafíos. *Revista CS*. 33: 205-235. <https://doi.org/10.18046/recs.i33.3995>
- Rojas-Peña, O; Martínez-Moyano, E. (2022). Main agricultural production projects implemented by ex-combatants from “Héctor Ramírez” rural settlement located in La Montañita, Colombia. *Revista FAGROPEC*. 14(1): 1-22. <https://doi.org/10.47847/fagropec.v14n1a4>
- Rojas-Peña, O. R.; Martínez-Moyano, E.; Pérez-Medina, M. J.; Espinosa-Calderón, L. M (2024). Construcción de un índice de calidad de vida en el marco de los capitales de la comunidad de excombatientes de las FARC: un estudio de caso. *Revista FAGROPEC*. 16(1): 15-35. <https://doi.org/10.47847/fagropec.v16n1a2>
- Solís, L; Lanari, M.; Oyarzabal, M. (2020). Tipificación integral de sistemas caprinos de la provincia de Santa Elena, Ecuador. *La Granja*. 31(1): 82-95. <https://doi.org/10.17163/lgr.n31.2020.06>
- Sópalo-Romero, J.I.; Quezada-Torres, D. C.; Valarezo-Quinaluisa, R. A.; Quezada-Torres, W.; Proaño-Molina, M.; Recalde-Luna, S.; Tapia-Zúñiga, M.; Quezada-Moreno, W. (2024). Socioeconomic evaluation in the intensification of a panela agroindustry. *Afinidad. Journal of Chemical Engineering Theoretical and Applied Chemistry*. 81(603): 1-15. <https://doi.org/10.55815/431819>
- Suárez, A. E.; Gutiérrez-Montes, I.; Ortiz-Morea, F. A.; Ordoñez, C.; Suárez, J. C.; Casanoves, F. (2021). Dimensions of social and political capital in interventions to improve household well-being: Implications for coffee-growing areas in southern Colombia. *PLOS ONE*. 16(1): e0245971. <https://doi.org/10.1371/journal.pone.0245971>
- Suárez, A. E.; Gutiérrez-Montes, I.; Ortiz-Morea, F. A.; Suárez, J.; Di Rienzo, J.; Casanoves, F. (2022). Contribution of Livelihoods to the Well-Being of Coffee-Growing Households in Southern Colombia: A Structural Equation Modeling Approach. *Sustainability*. 14(2): 743. <https://doi.org/10.3390/su14020743>
- Suriyankietkaew, S; Krittayarungroj, K; Thinthan, S; Lumlongrut, S. (2025). Community capitals framework for sustainable development: A qualitative study of creative Tourism in Ban Chiang World Heritage Site. *Sustainability*. 17(8): 3311. <https://doi.org/10.3390/su17083311>
- Tengapoe, K.; Baddianaah, I.; Yaradua, A. S. (2024). Access to social capital and smallholder agricultural practices: The case of smallholder farmers in North-Western Ghana. *Cogent Food & Agriculture*. 10(1): 2353670. <https://doi.org/10.1080/23311932.2024.2353670>