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Dialectic between family farming and coffee growing in Boyacá, Colombia: productive, socioeconomic, and environmental aspects

Dialéctica entre agricultura familiar y caficultura en Boyacá (Colombia): aspectos productivos, socioeconómicos y ambientales

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Dialectic between family farming and coffee growing in Boyacá, Colombia: productive, socioeconomic, and environmental aspects

Dialéctica entre agricultura familiar y caficultura en Boyacá (Colombia): aspectos productivos, socioeconómicos y ambientales

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Abstract

Polyculture is a more sustainable production practice and offers several environmental, economic and social benefits to society, such as promoting biodiversity and ecosystem services, increasing productivity and profitability, or improving livelihoods, among others. However, there is a worldwide trend of change from polyculture-based production systems to monoculture systems. In this scenario, the Department of Boyacá (Colombia) has faced changes in food production, as coffee production has been promoted in the region. This study aims to investigate the productive, economic, environmental, and social aspects of peasants who perform family farming with various food crops and those involved in the agricultural transition from polyculture into coffee production in two municipalities of Boyacá. The data were obtained through questionnaires and semi-structured interviews and were analyzed based on the MESMIS methodology. Regionally, the social and environmental dimensions were partially sustainable, whereas the economic dimension was unsustainable. The municipality of Guayatá invests more in coffee production. Factors referring to three dimensions are presented and can strengthen sustainable practices and reduce practices with great negative impact.

Keywords: Latin America, polyculture, sustainability indicators, agroecological systems.

Resumen

El policultivo es una práctica de producción más sostenible y ofrece varios beneficios ambientales, económicos y sociales a la sociedad, como promover la biodiversidad y los servicios ecosistémicos, aumentar la productividad y la rentabilidad o mejorar los medios de vida, entre otros. Sin embargo, existe una tendencia mundial de cambio en los sistemas de producción basados en policultivos hacia sistemas de monocultivos. En este escenario, el departamento de Boyacá (Colombia) se ha enfrentado a diversos cambios en la fabricación de alimentos, a medida que se impulsa la producción de café en la región. Con este estudio, se tiene como objetivo investigar los aspectos productivos, económicos, ambientales y sociales de los campesinos que desarrollan una agricultura familiar a partir de diversos cultivos alimentarios y de aquellos involucrados en la transición agrícola del policultivo a la caficultura en dos municipios de Boyacá. Los datos se obtuvieron a través de cuestionarios y entrevistas semiestructuradas y fueron analizados con base en la metodología Mesmis. A nivel regional, las dimensiones social y ambiental eran parcialmente sostenibles, mientras que la dimensión económica era insostenible. El municipio de Guayatá invierte más en la producción de café. Se presentan factores referentes a tres dimensiones que pueden fortalecer prácticas sustentables y reducir prácticas con gran impacto negativo.

Palabras clave: Latinoamérica, policultura, indicadores de sostenibilidad, sistemas agroecológicos.

Introduction

Family farming is responsible for about 80 % of food production worldwide, represented by more than 550 million smallholder farmers and occupying approximately 78 % of agricultural lands (Lowder *et al.* 2021). As the predominant form of food and agricultural production, smallholding plays an essential social, economic, environmental, and cultural role.

Smallholders' decisions regarding land use are influenced by various socioeconomic and environmental factors (Valbuena *et al.* 2021). A worldwide trend has been observed involving the change from production systems based on traditional subsistence polycultures to more intensified monoculture systems (Jezeer *et al.* 2019). Encouragement for this change comes mainly from the global demand for export crops and the possibility of improving income and quality of life in the short term (Shaver *et al.* 2015).

Coffee crop has received incentives for expanding farmable areas and intensifying monoculture practices (Jezeer *et al.* 2019). Coffee is a highly valued commodity that plays a significant social, economic, cultural, and environmental role, especially in tropical regions (critical production regions), where thousands of people depend on this production chain (Jezeer 2018, Guido *et al.* 2020, Harvey *et al.* 2021). In 2018, world coffee production represented 9.5 million tons of coffee and generated a total market value of US\$30.9 billion, with smallholders contributing approximately 70 % of the entire global production (Jezeer 2018).

Coffee-producing regions are widely represented in Latin America, concentrating about 60 % of the worldwide coffee supply and 80 % of the Arabica coffee produced in the world, with most coffee producers being smallholders who cultivate areas between two and five hectares (Harvey *et al.* 2021). Mexico is an excellent example to illustrate the socioeconomic and environmental impact that coffee can exert on its producing regions. Mexican peasants adopted coffee production in the 1960; however, the worldwide fall in coffee prices in the 1980s and the crisis of the Mexican Coffee Institute (INMECAFÉ) stimulated the transition from coffee monoculture into organic coffee production. Nowadays, Chiapas holds about a third of the coffee-growing areas in Mexico, where organic coffee is grown without agrochemicals and under the shade of a forest. Some aspects were essential for this change to occur, such as peasant mobilization for better conditions, strengthened cooperatives, and valuing traditional agroecological knowledge (Folch & Planas 2019).

Colombia stands out in the world coffee production scenario, ranking as the third largest coffee-producing country, with a production of 10.6 million 60-kg sacks in coffee year 2022-2023, of which 10.3 million were exported, especially for the North American market (Federación Nacional de Cafeteros de Colombia 2023). In Colombia, family farming represents 87 % of total agricultural holdings, generates 57 % of jobs and contributes to a little more than half of the country's agricultural production and around 80 % of coffee (Niño Martínez 2016, FAO 2021a).

It is estimated that there are 700,000 family farmers in Colombia, the majority of whom are subsistence farmers, represented by indigenous people, afro-colombians, and traditional populations, urban and neo-rural (Bavorová et al. 2024, FAO 2021a). However, although showing great potential, Colombian smallholding is marked by high levels of poverty and food insecurity in the rural scenario, armed conflicts, land ownership and rights disputes, expropriations, forced displacement, and absence of policies and incentives that value and ensure the rights of smallholders, among others (Collazos 2016, FAO 2021a).

Agriculture is the main economic activity in the Department of Boyacá (Central Colombia), favored by a climatic and agroecological diversity that allows the cultivation of a wide variety of crops that compose the food habits of the *boyacense* population and the neighboring municipalities (Zambrano et al. 2022). However, Boyacá and other regions of the Tenza Valley have been experiencing changes in food production since the last decade as coffee growing has been promoted through the cultivation of specialty coffees, with producers trying to improve their income and quality of life (Avella et al. 2023).

However, the intensification of coffee production involves typical practices such as reducing or removing shade trees, changing the coffee varieties, intensifying the use of fertilizers and agrochemicals, and increasing the density of coffee shrubs (Jezeer et al. 2019). This more intensive production system can impact ecosystem services and cause environmental problems. Furthermore, coffee monoculture can cause socioeconomic impacts, such as food insecurity and economic vulnerability, among smallholders, or rural conflicts, and alter subsistence strategies (Jezeer 2018, Harvey et al. 2021).

Other studies have documented that replacing a multiple-species cultivation area with a single crop can generate various socioeconomic and environmental impacts. An example can be observed in corn-growing areas in Thailand, where the intensification of monoculture increased deforestation, atmospheric pollution, and degraded natural resources, highlighting land ownership and rights conflicts and generating economic vulnerability and food insecurity among peasants, especially those who did not adopt food cultivation strategies for family consumption together with corn (Charoenratana et al. 2021). Patterns like those of Thailand were described in other countries, e.g., with pineapple cultivation in Costa Rica (Shaver et al. 2015) and palm oil production in Malaysia (Hanafiah et al. 2022).

On the other hand, shade-grown coffee agroecosystems, such as family-based agroforestry systems, represent a more sustainable alternative for coffee production, with the potential to promote economic, social and environmental benefits. These systems contribute to the conservation of soil, biodiversity, and water resources, as well as the maintenance of ecosystem services. Furthermore, they can support rural subsistence, with better working conditions, reduction of poverty and food insecurity, or access to differentiated markets, among other aspects. However, it is essential to recognize the challenges associated with these systems to maximize their benefits and ensure their viability for farmers. Therefore, when well guided,

seeking a harmonious relationship between society and nature, the coffee production can be crucial to ensuring sustainable development in Latin America (Jezeer 2018, Valbuena *et al.* 2021, Harvey *et al.* 2021, Jiménez-Soto 2020).

From this perspective, investigations that contribute to a better understanding of food production systems and the socioeconomic and environmental aspects that involve land use decisions are critical, especially for designing and implementing strategies and public policies aimed at ensuring the sustainable development of agricultural practices. Among the various methodological tools available to assess sustainability, Framework for the Evaluation of Management Systems (MESMIS) stands out for its interdisciplinarity and flexibility of adaptation. MESMIS is a tool that allows evaluating the sustainability of natural resource management systems with a focus on small producers. For this purpose, indicators are used and based on the system's strengths and weaknesses, which allows for a comprehensive assessment, that includes the tripod of sustainability (Masera *et al.* 2000). Therefore, the present study aims to investigate the productive, economic, environmental, and social aspects of smallholder peasants who grow various crops and those involved in the agricultural transition process from the polyculture of regional foods into coffee growing in two municipalities of the Department of Boyacá (Colombia), using MESMIS as an analysis methodology.

2

Material and methods

2.1. Study area

The present study was conducted in two municipalities of the Department of Boyacá: Guayatá and Guateque. The municipalities are in the Tenza Valley region (formed by the Oriente and Neira provinces) and were chosen because of its different coffee cultivation histories involving small producers, for being currently identified as specialty coffee-producing areas, and due to the increase in coffee production in the region in the last few years (Boyacá 2019).

The Department of Boyacá has an area of 23,189 square kilometers, which represents 2.03 % of the national territory; it is in east-central Colombia and is crossed by the eastern Andean Mountain Range. The Department shows different landscapes, due to its relief, and the geography provides a thermal gradient (*pisos térmicos*), with temperatures ranging from 35 °C to subzero values, although cold and very cold areas predominate throughout the Department. The rainfall regime is also varied, ranging from 500 to 3000 millimeters per year (Béland 2013).

The economy of Boyacá is mainly based on agriculture and livestock. Boyacá has 307,793 hectares of land dedicated to agriculture, and the agricultural sector contributes 13.6 % of the department's gross domestic product (Boyacá 2019, Béland 2013). Some of the most cultivated species are potatoes, corn, onion, wheat, turnip, faba bean, cassava, *cubio* (*Tropaeolum*

tuberosum), *ruba* (*Ullucus tuberosus*), *arracacha* (*Arracacia xanthorrhiza*), barley, sugarcane, and cassava, among others (Béland 2013, Zambrano *et al.* 2022). The Boyacá coffee region covers approximately 10,000 hectares and is located between two slopes of the Eastern Mountain range. Furthermore, 92 % of coffee crops are under shade or semi-shade, and 95 % of coffee growers are small producers, with less than 5 hectares (Giraldo-Jaramillo *et al.* 2021).

2.2. Participants and data sampling

No consistent data are available on the universe of farmers in Guayatá and Guateque. In Guateque, the local Association of Coffee Producers (CAFEGUATOC) reported having 22 associated peasants, whereas the city hall verbally reported 506 registered peasants, according to the 2017 census. In Guayatá, the Coffee Producers Committee reported 320 associates. In contrast, the Rural Development Secretariat of the Guayatá City Hall had no updated and reliable record about the peasants of that municipality. However, the person responsible for the sector estimated that approximately 800 farmers performed this activity on a small scale.

With this previous scenario of the people involved in the activity, the snowball technique (Bailey 2008) was used to select the leaders among coffee producers. We used three main methods: questionnaires with the exact same order and wording, semi-structured interviews using a question guide without an exact order and wording (Valles 2002), and participant observation (Dewalt & Dewalt 2002).

Interviews were conducted with the peasant families to characterize and evaluate the aspects and impacts (productive, socioeconomic, and environmental) of coffee production in the region. The heads of peasant families were selected using the following criteria: having ages equal to or higher than eighteen years and a minimum dwell time in the territory of ten years. In total, 40 interviews were conducted with the heads of families, 20 for each municipality. All interviewees were smallholders who cultivated various food crops and/or coffee producers. Overall, the questionnaires applied to the peasants aimed to evaluate the production, socioeconomic, and environmental aspects of smallholder peasants who grown various food crops and those involved in the agricultural transition process from the polyculture of regional food crops into coffee monoculture. No questionnaires were applied to the city halls of Guateque and Guayatá. However, semi-structured interviews were conducted, to know the projects developed by smallholders and coffee producers and future actions for the sector.

2.3. Data analysis

The data were analyzed by considering the assumptions of the MESMIS indicator, which aims to assist the sustainability evaluation of management systems for natural resources (Masera *et al.* 2000). Indicators (shown in the Results – Figure 1) were selected to measure the

level of sustainability of the agricultural activities considering the social (19 indicators, Figure 1A and B), economic (8 indicators, Figure 1C), and environmental dimensions (9 indicators, Figure 1D).

To integrate the data, each indicator received weights from 1 to 3 (descriptions of the indicator are presented in supplementary material S1), which were used to calculate the index of each indicator and, subsequently, the dimensions (Equation 1) (Ferreira *et al.* 2012). The indicators and dimensions were calculated separately for each municipality (since the municipalities showed different production characteristics) and together (to obtain a regional analysis parameter). The valuation and analysis criteria for the indices were classified into ranges, with indices ranging from 0.00 to 0.30 being considered unsustainable, from 0.31 to 0.69 being partially sustainable, and from 0.70 to 1.00 being sustainable (Ferreira *et al.* 2012):

$$I = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (\text{Equation 1})$$

Where: I = index, X = mean of the indicator, X_{min} = minimum grade attributed, and X_{max} = maximum grade attributed.

Finally, a percentage method was used to calculate the index of each dimension and the general index (IG) (Lacerda *et al.* 2019), where: if less than 30 % of the indicators are sustainable, the dimension will tend to be unsustainable; if 31 % to 69 % of the indicators analyzed are sustainable, the dimension will tend to be partially sustainable, and if more than 70 % of the indicators analyzed are sustainable, the dimension will tend to be sustainable.

3

Results

3.1. Sociodemographic profile of family farmers and aspects of the farms

Most peasants interviewed were males (57 %), with a mean age of fifty-six years and low level of education (42 % of which had a primary school level) (Table 1). Although there is greater male participation, about 75 % of the adult women work in the field, dedicating from two to eight hours a day and performing the same tasks as the men (63 %). However, these female peasants conciliate the workday in the field with other tasks that are virtually under their full responsibility, *e.g.*, childcare (83 %), food preparation (93 %), and domestic chores (75 %), among others. In addition, most women showing low education levels (63.3 % with primary school) and not participating in agricultural association/cooperatives or organizations meant for the female public. The peasants informed that there are few children and young people in the cities (only 10 % reported having children younger than five years) (Table 1).

Characteristics	Guatequ		Guayat		Total	
	e		á			
	No	%	No	%	No	%
Gender						
Female	11	55	6	30	17	42.5
Male	9	45	14	70	23	57.5
Education level						
Preschool	1	5	-	-	1	2.5
Primary School	11	55	6	30	17	42.5
High School		25	7	35	12	30
	5					
Technical Education	1	5	2	15	3	10
Undergraduate Degree	2	10	3	10	5	10
Graduate Degree	-	-	2	10	2	5
No. of people living in the house						
Up to 2 people	13	65	8	40	21	52.5
Between 3 and 4 people	6	30	12	60	18	45
Between 5 and 6 people	1	5	-	-	1	2.5
No. of children						
None	3	15	1	5	4	10
1 child	-	-	2	10	2	5
2 children	8	40	3	15	11	27.5
3 children	4	20	9	45	13	32.5
4 children	3	15	3	15	6	15
5 children	1	5	1	5	2	5
6 to 8 children	-	-	1	5	1	2.5
9 to 11 children	1	5	-	-	1	2.5

No. of people from 6 to 18 years of age per house						
None	16	80	12	60	28	70
1 person	1	5	6	30	7	17.5
2 persons	2	10	2	10	4	10
3 persons	1	5	-	-	1	2.5
No. of people younger than 5 years per house						
None	17	85	19	95	36	90
1 person	3	15	1	5	4	10

Table 1

Socioeconomic data of the peasants ($N = 40$) of Guateque and Guayatá (Boyacá, Colombia)

In Guayatá, 15 families (75 %) interviewed grow coffee, 7 of which have performed this activity for more than ten years and increased the number of coffee plants in their properties yearly. On the other hand, in Guateque, 19 families did not grow coffee before 2009, 12 of which still do not perform this activity. Only 1 family has grown coffee for more than ten years. Seven families of coffee farmers (35 %) stated that the number of plants in their properties increased in the last few years.

Coffee can be cultivated under different management systems. However, in all properties of the peasants interviewed, coffee plantations are managed under shade. In the Tenza Valley region, coffee is grown in association with fruit trees, which is an important and positive point regarding environmental aspects.

3.2. Sustainability indicators: «social dimension»

Guateque had 42.11 % of its indicators characterized as sustainable, 36.84 % characterized as partially sustainable, and 21.05 % characterized as unsustainable (Figures 1A and B). Guayatá had 47.37 % of its indicators characterized as sustainable, 42.10 % characterized as partially sustainable, and 10.53 % characterized as unsustainable (Figures 1A and B). Therefore, the social dimension of both municipalities can be classified as partially sustainable. Our data and index calculation can be access in the supplementary material (S2).

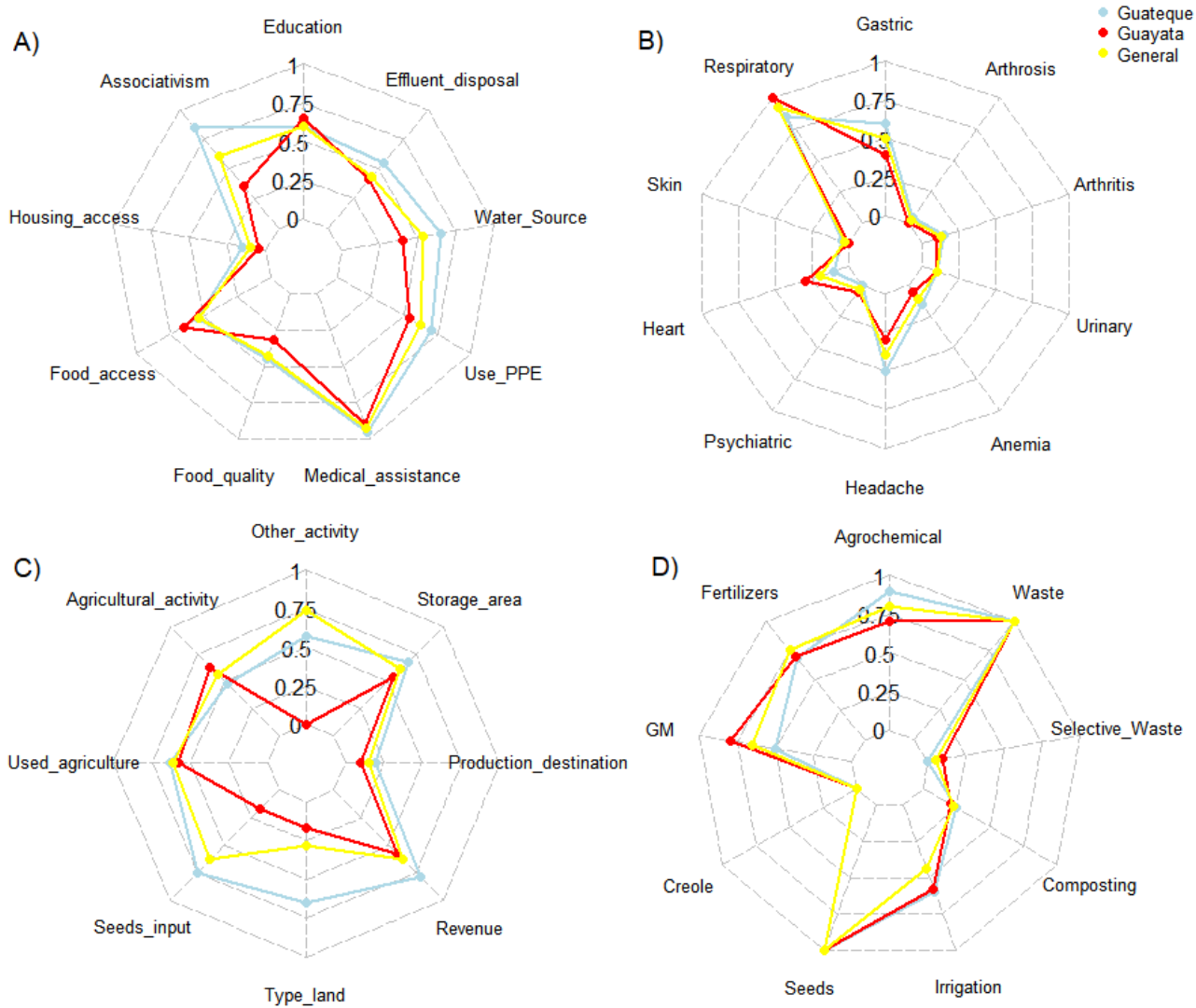


Figure 1

A), B) Social, C) economic, D) and environment sustainability indicators and its indices for the municipalities of Guateque and Guayatá in Boyacá (Colombia)

The analyses revealed that the peasants of Guateque and Guayatá have access to a partially sustainable education (indicator 1 S – social), and most peasants in the two municipalities reported that the lands used for family farming are their own –sustainable indicator (indicator 2 S) (Figure 1A).

The analysis of social indicators also revealed that peasants have access to food (indicator 3 S) and satisfactory food quality (indicator 4 S). Most peasants use between COP\$100,000 and COP\$300,000 per month to buy food, which corresponds to between 10 % and 30 % of the local minimum wage in 2022 (COP\$1,000,000). In addition, most peasants consider that the quality of food available for their families is good or average.

In the two municipalities, the indicators referring to the primary water source (indicator 5 S) and the main destination of domestic effluents (indicator 6 S) were partially sustainable (Figure 1A). The peasants related water quality with its origin, with 45 % reporting that their main water sources are springs. Furthermore, 87.5 % of the peasants stated that the liquid effluents from their homes are directed into septic tanks.

The indicator referring to access to health treatment (indicator 7 S) was unsustainable (Figure 1B). Most peasants from Guateque and Guayatá reported that the main form of disease treatment in their families is using homemade medicines, which highlights the limited access of peasants to health services in the municipalities. Furthermore, the two municipalities have a high incidence of respiratory diseases —unsustainable incidence (indicator 8 S)— and the other diseases had a partially sustainable or sustainable incidence (indicators 9, 10, 11, 12, 13, 14, 15, 16, and 17 S).

Producers in Guayatá use few personal protective equipment (PPE) during the application of products for fertilization and/or control of insects —partially sustainable incidence (indicator 18 S) (Figure 1A)—. Due to their larger production areas, producers in Guayatá seem to be somewhat more prepared to deal with different management and protection techniques than those in Guateque. In Guateque, the use of PPE was unsustainable.

In Guateque only 15 % of the interviewees reported participating in some association —an unsustainable incidence (indicator 19 S)—; however, in Guayatá, this index is 65 % (partially sustainable) (Figure 1A).

3.3. Sustainability indicators: «economic dimension»

Guateque showed 12.5 % of its indicators characterized as sustainable, 62.5 % characterized as partially sustainable, and 25 % characterized as unsustainable (Figure 1C). Therefore, the economic dimension of Guateque can be classified as unsustainable. On the other hand, Guayatá had 37.5 % of sustainable indicators, 50 % characterized as partially sustainable, and 12.5 % unsustainable (Figure 1C). Therefore, the economic dimension of Guayatá can be classified as partially sustainable. Our data and index calculation can be access in the supplementary material (S2).

Agriculture is the primary source of income for most families interviewed (75 %). However, some people reported that the retirement benefit was their main source of income, with agricultural activity and/or livestock being a complementary income. Some peasants performed additional activities that they considered temporary (indicator 1 Ec —economic—). This indicator was unsustainable in Guayatá, since 90 % of the peasants said they performed a complementary economic activity. Overall, none of the interviewees reported having a labor contract to develop works in the field when this activity is performed in other farms.

The analysis of the indicator referring to the number of families interviewed working with agricultural activities (indicator 2 Ec) in the two municipalities was partially sustainable, *i.e.*, the activities depend mainly on family labor, with more than half (42.5 %), if not all family members (27.5 %), performing the activities. Most farms did not have permanent (75 %) and/or temporary employees (42.5 %), with farms that count on this type of labor having less than three or up five employees, especially on a temporary basis.

Most peasants (75 %) stated that the members of their families with ages from eighteen to thirty-five years have no interest in continuing agricultural activities in the rural area, and most peasants (87.5 %) reported that some family member of this age has already left the field and migrated to the city.

Most farms in Guateque have rural properties areas smaller than 1 hectare (55 %), followed by farms with areas ranging from 1 to 5 hectares (32 %). In Guayatá, most farms have from 1 to 5 hectares (60 %), followed by farms with less than 1 hectare (30 %). Half of the peasants in the two municipalities informed that approximately 50 % of the total area of their properties is used to grow various food crops and/or coffee (indicator 3 Ec), followed by 27.5 %, who informed that approximately $\frac{1}{4}$ of the total area of their farms is used for agriculture, and 22.5 % who said that $\frac{3}{4}$ of the total area is occupied with food production.

The destination of the food produced was an indicator considered sustainable (indicator 4 Ec), with 85 % of the peasants reporting that the food produced in their properties is meant for self-consumption and sale (Figure 1C). In the cases when peasants grew coffee (7 in Guateque and 15 in Guayatá), more than half of the cultivated area corresponds to coffee plantations. Although other types of food are cultivated, these crops are primarily meant for self-consumption, representing about 80 % of cases.

The indicator referring to this type of land use (indicator 5 Ec) was only partially sustainable for Guateque, where only 35 % of the peasants reported growing coffee associated with polyculture. In contrast, the indicator was sustainable in Guayatá, where 75 % reported growing coffee in association with other food crops. The main food crops cultivated in the Department are potato, corn, wheat, and cassava.

In Guateque, 75 % of the peasants reported that they purchased seeds (indicator 6 Ec). In Guayatá, the same indicator was partially sustainable, with 50 % of the peasants reporting that they acquired seeds (Figure 1C).

The indicator referring to exclusive storage area (indicator 7 Ec) in the two municipalities was partially sustainable, with 60 % of the peasants reporting that they have a storage area.

The main difficulties reported to food production include low labor availability, lack of technical assistance, few incentives and policies that benefit producers, and high costs with labor and inputs in the field, among others. The peasants of Guayatá also reported climate change and lack of encouragement for coffee producers as other production challenges. Although living in a region where agricultural activity is included in the central axes of municipal development

plans (Boyacá 2019), 85.5 % of the interviewees reported that they did not receive technical assistance from the municipality. Some members of the Municipal Committee of Coffee Producers said that technical assistance for coffee plantations is only obtained through the National Federation of Coffee Growers of Colombia (FNC). The peasants also said that technical assistance is an urgent need, since most do not have technical and/or professional training in the agricultural area and develop coffee farming based only on empirical knowledge. This need was identified in the Development Plants of Guateque and Guayatá. Workers of both city halls said the government had offered support to coffee production and family farming projects. However, the peasants consider that these assistance strategies are ineffective.

The outflow of production is mainly performed through direct sale to consumers in municipal and street markets, and sale to intermediaries or supermarkets. The peasants stressed that the main obstacles to commercialization are the lack of public policies for the rural sector, unfair and abusive prices established by intermediaries, lack of adequate infrastructure and transport, and insufficiency of buyers in municipal markets, among other factors.

The revenue obtained by the sale of agricultural products (indicator 8 Ec) was classified as «unsustainable» for Guateque and partially sustainable for Guayatá (Figure 1C). Overall, the peasants stated not having a fixed or even variable income to report, with the approximate income between COP\$100,000 and COP\$500,000 reported during the interview corresponding specifically to the time of harvest. Moreover, although no complementary financial activities were reported in most cases, the income for off-season months comes from roles such as housekeeping or day labor, economic assistance from family members living in urban centers, and other activities. Only those who said they were retired had an income higher than COP\$2,000,000/month, having better financial conditions and larger cultivation areas. From this perspective, when asked about the convenience of agriculture as the main economic activity, 67 % of the peasants interviewed said that their perception was that the cost/benefit relationship of their production is negative in financial terms.

3.4. Sustainability indicators: «environmental dimension»

Guateque had 33.33 % of its indicators characterized as sustainable, 33.33 % as partially sustainable, and 33.33 % as unsustainable (Figure 1D). Guayatá had 33.33 % of its indicators characterized as sustainable, 11.11 % as partially sustainable, and 55.55 % characterized as unsustainable (Figure 1D). Therefore, the environmental dimension of both municipalities can be classified as partially sustainable (our data and index calculation can be access in the supplementary material —S2).

The use of agrochemicals (indicator agricultural inputs, 1 En —environmental—) was unsustainable for the two municipalities, with 90 % of the peasants in Guateque and 70 % in Guayatá reporting that they used agrochemicals (Figure 1D). The indicator referring to the use

of fertilizers (indicator 2 En) was partially sustainable for Guateque and unsustainable for Guayatá, with 55 % of the peasants in Guateque and 70 % in Guayatá reporting the use of fertilizers.

The analysis of indicators showed that the use of creole (landraces) seeds (indicator 3 En) is sustainable for both municipalities, since 100 % of the peasants reported using these seeds in their properties. However, the indicator referring to the use of genetically modified seeds (indicator 4 En) was unsustainable for Guayatá and partially sustainable for Guateque (Figure 1D). Another weakness related to seeds was that the indicator referring to peasants' knowledge about the seed bank (indicator 5 En) native to the region was unsustainable for the two municipalities—all interviewees reported not knowing the existence of a seed bank.

Irrigation methods (indicator 6 En) was partially sustainable for the two municipalities, and plantations are naturally maintained with rainwater (Figure 1D). In this region of Colombia, rainfall is sufficient during most of the year. In the drier periods, peasants use irrigation methods whenever necessary. Among the irrigation methods used to supplement the crop water requirements, 45 % of the peasants in Guateque used sprinkler irrigation, and 5 % used drip irrigation. In Guayatá, 45 % of the peasants reported the use of sprinkler irrigation.

In the two municipalities, the selective waste collection (indicator 7 En) was sustainable, with 100 % of the peasants in Guateque and 90 % in Guayatá saying they separated their waste. However, the indicator referring to solid waste collection by the municipality (indicator 8 En) was unsustainable for both municipalities, since all interviewees reported that the city halls do not collect this type of waste in rural properties. As a result, domestic solid waste is usually buried or burned. In Guateque, 40 % of the peasants said they bury pesticide packaging waste. In Guayatá, 65 % of the interviewees said they bury waste, whereas 15 % said they burn this material.

On the other hand, most peasants use composting (indicator 9 En, 75 % in Guateque and 80 % in Guayatá) and employ feces of cattle or chickens for this process (20 % in Guateque and 40 % in Guayatá). The rural population interviewed showed an important interest in using organic residues. However, in all cases ($N = 40$), the activity is addressed as an empirical practice, with knowledge transmitted by previous generations and no technical assistance.

4

Discussion

4.1. Coffee farming in Guateque and Guayatá

In Guayatá and Guateque, men and women are involved in agriculture; however, women are involved in many other activities. Men appeared in a higher proportion as heads of family, responsible for managing the financial resources and decisions regarding agricultural practices

(Oviedo-Celis & Castro-Escobar 2021). However, women have significant participation in agricultural practices, contributing to achieving higher productivity, income, and family well-being. However, these female peasants still face an overload of responsibilities socially attributed to them as they conciliate the workday in the field with other domestic chores and childcare, tasks that are virtually under their full responsibility. The overload of demands and the lack of appreciation for the female contribution in the field restrict the position of female peasants to other spaces and leadership positions and from enjoying the same opportunities given to men. The indigenous women from the rural areas of the Department of Nariño (Colombia) also face restrictions related to gender disparity. In addition, they face several factors that affect their autonomy in a scenario like our study region, *e.g.*, low education levels and a lack of appreciation for their work (Sinclair *et al.* 2022). In Sucre (northern Colombia), there is a significant female participation in agriculture despite male predominance, highlighting that women have a positive influence on agricultural decision-making, playing a significant role in the contributions, social empowerment, and efforts for a rural environment with more equalitarian conditions (Diaz *et al.* 2021). One of the pillars of the Action Plan for the Decade of Family Farming is precisely promoting gender equality and the role of rural female leadership since women play a crucial role in the eradication of hunger and poverty in rural regions, thus ensuring more productive, sustainable, and inclusive food systems (FAO & IFAD 2019).

In Colombia, 30 % of coffee producers are women (Federación Nacional de Cafeteros de Colombia 2021), thus requiring policies aimed at female empowerment in this activity. From this perspective, aiming to promote female empowerment and entrepreneurship, the coffee company Procafecol, headquartered in Bogotá, released in 2021 the product line «Mujeres Cafeteras», giving more visibility to the importance of female coffee producers (Federación Nacional de Cafeteros de Colombia 2021). However, the studied region lacks other movements more directed toward women, even though female participation there is higher than the national average. During the conduction of the project, only one class organization was identified, the Association of Rural Women of Guayatá, with little power at these days. We shall return to this movement when addressing the issue of agricultural organizations during the analysis of social indicators.

Interviewees with higher levels of education are more qualified for their activities and represented the families with a better economic situation. People who start growing coffee after retirement from other activities can be considered part of the new peasantry, *i.e.*, the population that returns to the field to dedicate themselves to agriculture or, in some cases, arrive in rural areas seeking a lifestyle away from the urban environment and end up adopting agriculture as their economic activity. There are also young people who intend to use agriculture as a food production system based on sustainability (Van der Ploeg 2008).

Regarding the age of the family members of the peasants interviewed, the incidence of few children and young people in cities, allied to the mean age of the interviewees, suggests an aging population, agreeing with the 2018 census, which showed a 23.93 % increase in the aging

index in the last thirteen years in Boyacá, increasing from 26.99 % in 2005 to 50.92 % in 2018 (DANE 2018).

Coffee production in Boyacá still does not have an important representation in the total agricultural scenario of Colombia since, even though coffee has been traditionally grown in the country for more than sixty years, the industrialization of coffee production in Boyacá has only been boosted in the last few years (Avellas *et al.* 2023). Considering the area used for coffee cultivation and the volume produced in the Tenza Valley region, where Guateque and Guayatá are located, this product does not look become a commodity. In the Departments of Caldas, Quindío, and Risaralda, for example, coffee is considered a commodity, since its sale representativeness and contribution to the region's trade balance reaches more than 50 % (Zambrano 2003). However, the progressive growth in cultivated areas in the last few years in the Department of Boyacá and the apparent intention of increasing production can make coffee a representative product in the region soon.

In addition to improving peasants' income (Jezeer 2018), the increase in the coffee plantations of Guateque and Guayatá is also boosted by the attractiveness of consolidating this crop as an outstanding product in the region and by the greater possibility of commercializing coffee (Federación Nacional de Cafeteros de Colombia 2021). It is necessary to observe that replacing the cultivation of various species with a single crop can cause negative environmental consequences, *e.g.*, the degradation of natural resources, or the increased emission of greenhouse gases, among others. Furthermore, it can cause several socioeconomic impacts, including social conflicts and reduced supply of traditional foods. These factors leave families in a state of greater economic and food vulnerability, despite the perspective of improving the income and well-being of these farmers (Shaver *et al.* 2015, Charoenratana *et al.* 2021, Hanafiah *et al.* 2022).

About 90 % of the coffee-growing area in Boyacá is under shade (Federación Nacional de Cafeteros de Colombia 2022). Coffee agroforestry systems are more sustainable and contribute to the conservation of biodiversity, serving as connectors of forest fragments, storing carbon stocks, providing essential ecosystem services (*e.g.*, pollination, water supply, soil conservation, nutrient cycling, and others), contributing to climate regulation and the resilience of systems to climate change. Agroforests of shade-grown coffee important to local livelihoods; depending on the species associated of coffee production, they offer a myriad of resources that can be used for self-consumption and even as an alternative source of income, *e.g.*, fruit, timber, medicinal plants, and other goods. Furthermore, these systems are linked to the indigenous models of natural resource management, that way, they are of great cultural importance and preserve living cultures. Agroforestry systems have been considered to have great potential to conciliate environmental, social, cultural and economic objectives, thus contributing to the sustainable development of these regions (Harvey *et al.* 2021, Jezeer 2018, Toledo & Moguel 2012).

In the Tenza Valley region, coffee is grown in association with fruit trees, which is an important and positive point regarding environmental and socioeconomic aspects. However, the trees associated with coffee grow have been reduced to a mere shading function, with ripe, uncollected fruits often being wasted. The products generated by shade trees are often neglected, which reduces the potential of these systems (Jezeer 2018) to produce a variety of goods that can be consumed by households and/or sold on the market, such as shade-grown coffee agroforests of the Sierra Norte of Puebla (Mexico), called *kuojtakiloyan* (Toledo & Moguel 2012). And potentially it results in the propagation of insects, such as the South American fruit fly (*Anastrepha fraterculus*). The Tenza Valley showed a higher infestation index of this plague in the monitoring conducted in 2010 (ICA 1997). There are also records of the Mediterranean fruit fly (*Ceratitis capitata*) in Boyacá, as well as the development of projects to control its propagation in fruit crops (ASOHOFrucol 2016). This scenario reinforces the perception of peasants and inhabitants of the Tenza Valley, as they stated that the fly has negatively affected fruit plantations in the region, including cherimoya, orange, and guava (Zambrano *et al.* 2022).

The reduction in the diversity of food crops represents a risk for food sovereignty and impact the regional food culture in the Tenza Valley region, since the local population is increasing its dependency on crops from other regions and imported products (Zambrano *et al.* 2022). Maintaining a diversity of subsistence crops associated with commercial crops proves to be of fundamental importance to guarantee the family's food supply and, thus, the objective of food security (Morris *et al.* 2013). On the other hand, even though coffee farming has increased in the region, the industrialization of the activity still needs to be a reality for all. Grain processing until the drying stage is still handmade by peasants in 85 % of cases. In 90 % of the families, stages such as roasting, grinding, and packing are performed by the company CANNOR, located in Guayatá. This scenario is justified by the specialty type of coffee produced in the Tenza Valley region, requiring adequacy to some parameters, that ensure a coffee of higher quality, which is more appreciated by consumers (Valencia 2007).

4.2. Sustainability indicators: «social dimension»

The «social dimension» of Guateque and Guayatá can be classified as «partially sustainable». The results revealed that education strategies must be strengthened in rural areas (indicator 1 S). Different factors influence low education levels in rural areas, *e.g.*, the lack of school infrastructure, the low appreciation by family members regarding education, and the precarious economic conditions that force young people to drop out of school, among other issues (Balam *et al.* 2019). The education level influences the knowledge of farmers and is an essential element for decision-making regarding land use and management, including the adoption of more sustainable agricultural practices. Therefore, low education levels become a limiting factor (Diaz *et al.* 2021).

Regarding housing access (indicator 2 S), land possession is very important, as it gives peasants greater safety to invest in their plantations and seek sustainable land use and management strategies that ensure food sovereignty and economic security for their families (Charoenratana *et al.* 2021).

In the two municipalities, the indicators referring to the primary water source (indicator 5 S) and the main destination of domestic effluents (indicator 6 S) indicate that improvements are required to ensure access to drinking water and basic sanitation in rural areas. In Colombia, 73 % of the population has access to safely managed drinking water services, whereas only 18 % have access to safely managed sanitation services.

The indicator referring to access to health treatment (indicator 7 S) was unsustainable. The main barriers to health care access in central Colombia are the long waiting times for the authorization of medical procedures and treatment, the problems related to insurance subscriptions, the expenses with consultations and treatment, geographic inaccessibility, and the non-resolution of health problems (Garcia-Subirats *et al.* 2014).

Guayatá had the indicator referring to using PPE (indicator 18 S) classified as partially sustainable. In Guateque, the use of PPE was unsustainable. In Marinilla (Colombia), family farmers' have inadequate and insufficient use of PPE, which potentiates exposure to agricultural inputs (Agudelo *et al.* 2013). Like the observations for the Department of Medellín in Colombia, the inadequate use of PPE by peasants in our study region could be associated with financial difficulties, due to the high cost of this equipment, the lack of adequate knowledge and training about safety practices and PPE use, and even the poorly applied policies to regulate and monitor the use of PPE (De Mesa 2020).

The indicator referring to associativism (indicator 19 S) reveals another weakness of smallholding in the municipality of Guateque and partially in Guayatá. According to the list of Solidarity Organizations for the Production of Food and Clothing in the Boyacá Region, two associations are officially registered with the two studied municipalities: the Association of Coffee Producers of Guateque —CAFEGUATOC— and the Association of Agricultural Producers of Guayatá. However, three other associations were identified in Guayatá: the Association of Rural Women, ASOCIABITA, and the Municipal Committee of Coffee Producers. In addition, three other associations were observed in Guateque: GANAGUATEQUE, the Association of Peasant Women of Guateque, and ASOVIGU —Association of Victims of Guateque—. The associations guarantee some training and help in some commercial negotiations.

The associativism increases the peasants' income during the food commercialization process (Rodríguez & Ramírez 2016). However, the obstacles to associativism and the lack of interest in associations hinder the access of peasants to different processes and projects aimed at strengthening the rural sector. The establishment of relationships of trust in the collective work and connections between different entities of the agricultural sector (government,

associations, cooperatives, peasants, etc.) can lead to the economic development of the territory in a more organized and effective way (Narváez *et al.* 2008).

4.3. Sustainability indicators: «economic dimension»

The «economic dimension» of Guateque can be classified as «unsustainable» and the economic dimension of Guayatá can be classified as «partially sustainable». In Colombia, the labor rights of peasant families are usually not guaranteed, and families do not have social protection, performing more than eight work hours per day, no vacation period, and with wages that do not correspond to the values established for the category according to the labor regulations of the country (Agudelo *et al.* 2013). In addition, field workers do not have clear political rules, which makes their work informal and does not generate a fixed income (Santacoloma-Varón 2015). Furthermore, most peasants had multiple income sources other than the sale of coffee and other crops. This makes rural workers the most vulnerable actors in the production chain, suffering from unfair social and labor conditions. Therefore, it is essential to recognize the social implications of agroecosystems to ensure real sustainable development (Jimenez-Soto 2020).

A weakness of the agricultural activities observed in the two municipalities is the aging of the population and the migration of younger people to cities. Better working opportunities and income conditions in urban centers are the primary motivations for this younger generation to choose not to remain in agriculture. And, because of the current socioeconomic conditions, younger people will continue to migrate to urban areas with no prospects of return, since working in the field is a challenging and underpaid way of life. This lack of generational continuity represents a great challenge for smallholding, since migration leaves less labor available for agricultural work; a factor that can result in reduced productivity and, consequently, lower income and food production for family consumption. In this way, migration has the potential to influence the local economy and culture and the dynamics of food security (affects indicator 2 Ec) (Harvey *et al.* 2021, Valbuena *et al.* 2021, Morris *et al.* 2013).

The Department of Boyacá has significant agricultural potential, due to its large rural area and diverse climatic and agroecological conditions, allowing the cultivation of a wide variety of agricultural products. However, factors such as the conformation based on smallholding and challenges typical of agriculture and rurality limit the productivity of these properties, often resulting in a scenario of production for self-consumption, with little excess for commercialization (Béland 2013, Boyacá 2019). A study conducted in Thailand showed that subsistence strategies aimed at cultivating diversified domestic food crops for self-consumption and sale or the cultivation of food crops associated with other economically viable crops are good strategies, as they promote higher food security, sustainability, and guarantee actual subsistence, with less risk of acquiring debts (Charoenratana *et al.* 2021). Likewise, it has been known, since past

times, that the diversification of coffee with other crops improves the income and food security of coffee-producing families (Ganry 1992) (related to indicator 5 Ec).

The incentive to use genetically modified seeds is based only on productive aspects (*e.g.*, higher yield) (indicator 6 Ec). However, this practice constitutes a risk factor for the preservation of creole seeds (landrace seeds), given the important role this variety plays in smallholding, due to its wide genetic variability and strong cultural identity. Creole seeds (landrace seeds) are more adapted to the territory, more resistant to pests, more resilient to environmental changes, have higher genetic diversity, and are more nutritious. Therefore, they are essential for the development of more sustainable and inclusive food production systems, by contributing to the conservation of the cultural and environmental identity of the territory, which are essential to ensure food sovereignty, in addition to being less dependent on agricultural inputs (reducing environmental impacts) and reducing costs for farmers, thus providing them with greater autonomy (Vidal & Escobar 2019).

In Colombia, commercialization is one of the main problems of agriculture, especially for smallholders (FAO 2021a). The fact that the revenue obtained by the sale of agricultural products was classified as «unsustainable» for Guateque and «partially sustainable» for Guayatá can be related to the greater participation of peasants in associations in Guayatá since, as mentioned before, associativism can facilitate the outflow of production, increasing the peasants' income. Income from agricultural activities occurs only during some months of the year, even for peasants who rely on mass-production, as it is the case of coffee production, with the harvest occurring from November to February (varying as a function of climatic events and other factors that influence the dynamics of plantations throughout the year) (related to indicator 8 Ec).

The rural area of Boyacá continues to be marked by high poverty and inequality levels, and peasants face challenging life conditions, due to their low income, high job informality, unemployment, and low education levels (Boyacá 2019). Field workers have no explicit policy norms; their work is considered informal and does not generate a fixed income (Santacoloma-Varón 2015). Furthermore, the multi-activity nature of the economy in the rural population is a characteristic observed in the overall scenario of the peasant economy in Latin America. The income resulting from agricultural activities is not sufficient, and sustenance for the months outside the harvest period must be obtained through livestock and/or other urban activities, even when they are also informal (indicator 1 Ec) (Ramírez-Juárez 2013).

Although smallholding does not provide a significant income for peasants in Guateque and Guayatá, it allows a certain food security level, since families use the core of their production for subsistence. This aspect provides plantations with great value for peasants, justifying why they will not totally abandon this agricultural activity. In Brazil, the peasants of Rio Grande do Sul face precarious working conditions, and there is some resistance regarding self-consumption agriculture, which, although not representing a significant source of income for peasant families, positively impacts food sovereignty and security (Grisa & Schneider 2008). To improve the

socioeconomic conditions of peasants, more structural interventions (at a political level) are needed for the development of rural areas and strategies that enable sustainable livelihoods and sustainable agroecosystems (Morris *et al.* 2013).

4.4. Sustainability indicators: «environmental dimension»

The «environmental dimension» of Guateque and Guayatá can be classified as «partially sustainable». The excessive use of agricultural inputs (indicators 1 En and 2 En) is associated with a diversity of environmental impacts, *e.g.*, soil degradation, compromising an essential component for the yield of agricultural crops and food quality, with great importance for food security, economic development, biodiversity, and ecosystem services (Li *et al.* 2022). The peasants also worry about the impacts of agricultural inputs on the environment and productivity, by relating the use of agrochemicals with reduced quality (82.5 %) and food availability (55 %) in the last five years. Furthermore, agrochemicals can impact human health, ranging from intoxication to the development of more severe problems (Lopes & Albuquerque 2018).

Improving water-use efficiency is essential to ensure more sustainable production systems, especially for crops such as coffee, which demand high water consumption. For that purpose, it is necessary to adopt better irrigation technologies and develop efficient water management strategies (indicator 6 En) (Ho *et al.* 2022).

In some of the properties, good practices of waste disposal are deficient in the planting, maintenance, and harvest processes as well as in the daily life of rural families. This situation risks human health and negatively impacts the environment and should receive the attention of government entities, thus ensuring adequate waste treatment and its final disposal (Mihai & Thaezadeh 2017). Composting should be maintained and encouraged, becoming a possible work and income strategy for the rural population (indicators 7 En and 8 En) (FAO 2007).

Another favorable aspect in terms of environmental protection is that coffee plantations in Guateque and Guayatá are still managed under shade, which is a more sustainable system, because shade trees, when selected and managed adequately, can favor several environmental services, including soil fertility (Rigal *et al.* 2020).

Agriculture is responsible for most of the negative impacts on the land, soil, and water resources, especially when there is no appropriate management of resources and unsustainable management practices are adopted. The great challenge of agriculture is producing more food, to ensure food security and sovereignty, while reducing environmental and ecosystem impacts. From this perspective, it is essential to adopt more sustainable, inclusive, and resilient production practices, in view of climate change, and promote good governance of natural resources. Many strategies can be adopted for this purpose, including the integrated management of species that

cause damage to crops. However, any strategy should be based on the reality of each region, and all sectors of the food production chain should be involved in the process (FAO 2021b).

5

Final considerations

The importance of coffee production for the Department of Boyacá becomes evident, given that the two municipalities showed an increase in the areas used for coffee production and the number of plantations, even if acting differently in the production process. The municipality of Guateque has less organized producers and smaller production areas, whereas Guayatá has more organized and educated producers with larger production areas. Even with both municipalities still investing in polyculture associated with coffee production, a positive aspect in promoting more sustainable food systems, some weaknesses can be observed in the process.

The sustainability indicators showed that, regionally, the social dimension could be considered partially sustainable. We highlight the need for producers in Guateque to have a better organization, since the presence of associations or cooperatives is considered a good strategy for strengthening agriculture. Regionally, it is also essential to highlight the issue of access to health treatments, since the lack of adequate health services reduces life expectancy, leaving the farmer more time away from his activities, thus affecting agricultural production and income.

The regional economic dimension can be considered «unsustainable». Although we worked with dimension analyses independently, it is possible to analyze the relationship between them and evaluate the relevance of a systemic production process analysis. The «economic dimension» is an example that can relate the results observed in the percentage of products grown in each municipality with the relevance regarding the size of properties and the organization of producers. These factors and other dimensions highlight an advantage in the economic dimension for producers in Guayatá. However, the urgent need to correct evident weaknesses related to this dimension should be noted, as well as the need for technical assistance for better training and incentives regarding the continuous production of food items, guaranteeing the food supply in the off-season, which is vital for food security.

Finally, regarding the environmental dimension, the study identified that production is partially sustainable, and it was possible to identify very worrisome issues that deserve urgent attention. An important issue is the use of agrochemicals in both cities, especially Guayatá, that can impact the quality and number of products, putting at risk the food security and health of producers and consumers, as well as triggering negative environmental and socioeconomic impacts. The inadequate waste disposal of these products and other residues aggravates this scenario. Therefore, the public sector or the producers themselves should organize to reverse these practices, thus ensuring adequate treatment for the final disposal. Changes in these

actions can even add value to regional products and coffee, making them more attractive in the market.

On the other hand, there are production practices that deserve to be highlighted and encouraged, *e.g.*, production under shading with agroecological bases, predisposition to using fertilizers from composters, and using some creole (landraces) seeds. These practices should be strengthened and can be improved, for example, by making better use of fruits from tree species used for shading. Producers are clearly wasting this opportunity of using more products already available in their areas, which highlights the importance of technical support for integrated management aiming at increasing production and reducing the presence of parasites, thus improving peasants' income and life quality.

We present factors in the economic, social, and environmental dimensions that can strengthen sustainable practices and reduce practices with significant negative impacts, while carefully observing the transition process from the cultivation of diversified and traditional food crops in the region into coffee production in the municipalities of Guateque and Guayatá. It is thus essential to stimulate sustainable agricultural practices and develop strategies according to the reality of the rural area of the Tenza Valley.

Another critical point is the urgent need to promote gender equality in smallholding and the role of peasant women, ensuring women's rights and strengthening associations of rural women, since they contribute significantly to agricultural development and are crucial to achieving more production systems. Furthermore, it is necessary to adopt public measures to support the participation of younger people in family farming, preventing the exodus into urban centers and, thus, strengthening intergenerational family farming and mitigating problems related to the lack of labor in the field and the low yield of agricultural crops.

Finally, reaching sustainable food systems is something complex, and strategies for this transformation will only be effective when they approach a set of interconnected measures, that include social, economic, and environmental dimensions. For that purpose, all actors involved in agriculture (government, associations, peasants, and others) need to assume a purposeful role in these change efforts.

6

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