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Technological capabilities in the agricultural production units of Passifloras in the Huila department

Las capacidades tecnológicas en las unidades productoras agropecuarias de las passifloras en el departamento del Huila

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Abstract

The following study focuses on evaluating the development of technological capabilities in the productive units dedicated to the cultivation of Passifloras in the Huila department. To accomplish this, the theoretical framework provided by CEPAL was employed, applying techniques of principal component analysis and the K-means algorithm to group the data obtained from the microdata of the Censo Nacional Agropecuario. The results revealed a low level of development in the technological capabilities from the evaluated productive units. It was identified that approximately 73% of these units had deficiencies in elements related to the effort indicator, in aspects such as the associativity among producers, the investment of economic resources in technology and equipment, as well as the implementation of soil improvement practices and pest control. On the other hand, as a notable strength, a significant participation was observed, averaging 55% of the productive units in the indicator of infrastructure. This included features such as the age of the machinery used and access to basic public services such as electricity and drinking water. These findings highlight the need for implementing policies and programs aimed at strengthening technological capabilities in Huila's agricultural sector, with a particular focus on promoting associativity among producers, investment in technology and sustainable agricultural practices, as well as modernization of agricultural infrastructure. This comprehensive approach is essential for promoting sustainable and competitive agricultural development in the region.

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Keywords: Technological capabilities; Main components; Agricultural development; Agricultural productivity; *Passifloras.*

Resumen

El siguiente estudio se centra en evaluar el desarrollo de las capacidades tecnológicas en las unidades productivas dedicadas al cultivo de pasifloras en el departamento del Huila. Para ello, se empleó el marco teórico proporcionado por la CEPAL, aplicando técnicas de análisis de componentes principales y el algoritmo de K-means para agrupar los datos obtenidos de los microdatos del Censo Nacional Agropecuario. Los resultados revelaron un bajo nivel de desarrollo en las capacidades tecnológicas de las unidades productivas evaluadas. Se identificó que aproximadamente el 73% de estas unidades presentaron deficiencias en elementos relacionados con el indicador de esfuerzo, en aspectos como la asociatividad entre productores, la inversión de recursos económicos en tecnología y equipos, así como la implementación de prácticas de mejoramiento del suelo y control de plagas. Por otro lado, como una fortaleza destacable, se observó una participación significativa, en promedio del 55% de las unidades productivas, en el indicador de infraestructura. Este indicador incluyó características como la antigüedad de la maquinaria utilizada y el acceso a servicios públicos básicos como electricidad y agua potable. Estos hallazgos subrayan la necesidad de implementar políticas y programas orientados a fortalecer las capacidades tecnológicas en el sector agrícola del Huila, con un enfoque particular en promover la asociatividad entre los productores, la inversión en tecnología y prácticas agrícolas sostenibles, así como la modernización de la infraestructura agrícola. Este enfoque integral es esencial para promover un desarrollo agrícola sostenible y competitivo en la región.

Palabras Clave: Capacidades tecnológicas; Componentes principales; Desarrollo agrícola; Productividad agropecuaria; *Passifloras*.

1. Introduction

The Huila department has an agricultural border defined, with a total area of 950,589.60 hectares, including cartographic limits with environmental or legal restrictions for agricultural use. This area represents 2.21% of the national agricultural limit and 47.93% of the department's total area according to UPRA (2022). It features a range of thermal floors: warm (5,537 km²), mild (7,731 km²), cold (5,307 km²), and the bioclimatic zone moorland (1,356 km²). The productive offer is determined by its agricultural structure with productive bets in agro-industry with technological base in special coffees, fruit crops, cacao, and tobacco.

Among the cultivated fruits in the Huila department, *Passifloras*, commonly known as passion fruits, occupy a prominent place. This genus of plants includes a wide variety of species, with a total of 164 registered in Colombia, of which 42 produce edible fruit and 6 are commercially cultivated. Some of the best-known species include Granadilla, Maracuyá, Cholupa, Gulupa, Curuba India, and Badea, according to Ocampo (2013).

Passifloras are perennial climbing plants characterized by their exotic flowers and fruits with a hard shell, and juicy, aromatic pulp. This crop has historically taken root in the region due to its ability to adapt to local climate and soils, as well as the growing national and international demand for its derived products. Besides its commercial value, *Passifloras* offer significant benefits in terms of nutrition and medicine, making them a crucial resource for the health and well-being of both the local and global populations. Therefore, the cultivation and efficient technological management of *Passifloras* play a fundamental role in the sustainable agricultural and economic development of Huila.

The average production of these plants in the department is 36,407 tons per year, with a cultivated area of 5,516 hectares and an average yield of 9.44 tons per hectare. The municipalities of Neiva, Algeciras, Rivera, Santa Maria, Suaza, La Plata, Garzón, and Campo Alegre stand out as the main producers due to their favorable agroecological conditions, according to agro-productive evaluations conducted in the region.

In the territorial configuration developed for Colombia by Ramírez and De Aguas (2017), it is identified that 81.7% of the national territory corresponds to rural areas, 14.7% to intermediate zones, and 3.6% to urban areas. However, the extensive rural area is not being optimally exploited. Predominant activities in this region, such as fishing, agriculture, livestock, and forestry, do not contribute significantly to the Gross National Product (GNP). This is explained by Gollin's (2010) thesis, which states that despite the size, agricultural economic activity is not

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leading in developing countries due to its low productivity compared to other economic sectors.

This productivity is represented as the association between the quantity of products obtained and the area of cultivated land. This yield can be negatively affected by various factors such as labor productivity deficiencies and a lack of scientific, technological, and administrative advances, which are closely linked to improvements both qualitatively and quantitatively in the skills and knowledge of the population engaged in agricultural activities, as well as in the area where the activity is carried out.

Strengthening technological capabilities emerges as the key to overcoming stagnation in agricultural productivity. According to Cohen and Levinthal (1990), cited by Lall (1992) and Bell and Pavitt (1993), these capabilities encompass the set of skills and resources necessary for an organization or individual to develop, acquire, adapt, and use technologies efficiently, resulting in a positive impact on increasing productivity. However, strengthening these capabilities cannot be undertaken without prior knowledge of their level of development and the specific state of each of their characteristics.

In this context, and specifically concerning the productive sector analyzed in the research, technical improvement and market enhancement of productive units play a crucial role in the agricultural sector, particularly in *Passifloras* cultivation, when adopting a value chain approach. As mentioned by the Ministerio de Agricultura y Desarrollo Rural (Ministry of Agriculture and Rural Development) (2021), the dynamics in the country's agricultural production present four challenges: 1. In production-related terms, "promoting the development of technological packages for each of the production regions" (p. 13) and improving productive infrastructure. 2. Regarding product transformation, there is a lack of value-added centers and the adoption of innovative technologies for harvesting and post-harvest phases. 3. In marketing, the relevance of establishing associative processes is emphasized. 4. Finally, in consumption challenges, the importance of stimulating demand in international markets is highlighted.

These challenges are supported by the Strategic Plan for Science, Technology, and Innovation of Huila 2010-2032 by CODECYT-Huila (2010), where the characterization of skills in science, technology, and innovation (C+T+I) identifies the main disparities as the scarcity of scientists in the area, resources to support new technologies, and the underdeveloped institutional collaboration.

This situation is supported by Uribe Galvis and Contreras Pedraza (2021), who noted that a fundamental element for enhancing production and yields in *Passifloras* cultivation is scientific and technological capacity, which is assessed through educational levels in agriculture, concluding that existing training programs are not effectively articulated and often fail to meet their objectives.

In this context, the present research aims to establish the level of advancement in the technological capabilities of agricultural production units cultivating *Passifloras* in Huila. Its theoretical relevance lies in contributing to the understanding of technological capability levels, providing solid grounds for administrative decision-making, and offering the opportunity to strategically strengthen these capabilities, thereby boosting the productivity of the sector.

2. Methodology

The following research is of a mixed type according to Hernández *et al.* (2020), with a descriptive approach as outlined by Bernal (2010), since it analyzed the technological capability of the Passiflora sector in the Huila department by identifying elements and characteristics specific to the agricultural production units cultivating in the sector. This analysis allowed the categorization of these units into levels according to the development of their capabilities and demonstrated how these capabilities behave at the respective levels.

The unit of analysis includes all those Agricultural Production Units (APUs) cultivating Passifloras in the municipalities of Huila, which are within the boundaries of the agricultural frontier mentioned in the introduction.

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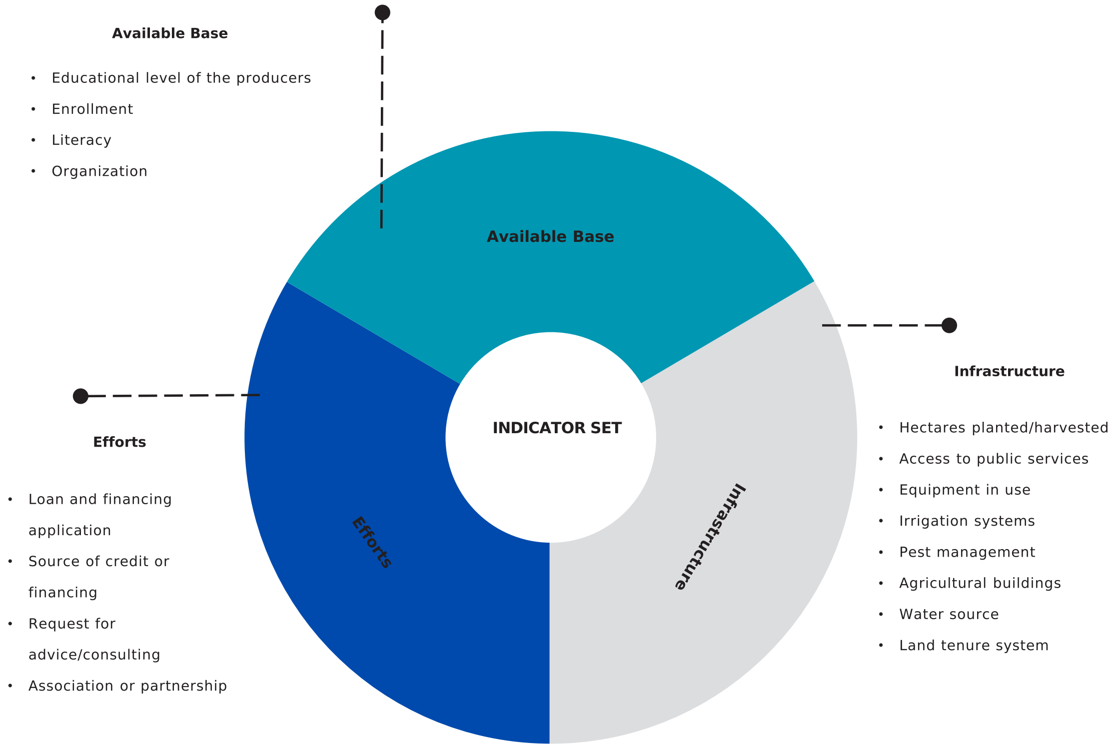
Figure 1. Technological Capability Indicators in Passifloras Production Units



Source: Authors' own elaboration adapted from (lugones *et al.*, 2007).

The data source used in this research is secondary data available from DANE, specifically the Censo Nacional Agropecuario (CNA) database (2014), which provides a broad range of georeferenced information about the agricultural sector at national level. APUs are those with a survey identifier and, therefore, the ones cultivating Passifloras within the sector, making them the study population.

In this context, to identify the factors impacting technological capability, the indicator approach proposed by Lugones *et al.* (2007) for technological capabilities in Latin America, developed at CEPAL, was used. The first indicator comprises the available base, which includes the knowledge, skills, and experiences contributed by individuals within an organization or group. This indicator covers crucial aspects such as educational level, literacy, and the acquisition of knowledge through consulting or technologies, among other factors evidenced in Figure 1.

Then, as the second indicator, there is infrastructure, which aims to generate an understanding of the environment in which the productive activity takes place (Lugones *et al.*, 2007). This dimension provides signals about the level of sophistication of the production. It includes not only the infrastructure of the agricultural production units (APUs) but also the equipment used for the activity, access to public services, and other variables. Finally, the effort indicator aims to measure the efforts made by producers in each APU to enhance technological skills, such as associativity, access to credits, and others.

Based on the above and using the Python programming language, an exploratory analysis was conducted to understand and summarize the key characteristics of the dataset. This includes visualization, handling of missing data, trend and pattern analysis, data segmentation, study of relationships between variables, and assessment of data quality.

Accordingly, through variable engineering, the goal was to improve the performance of the employed methods and the quality of the analysis by creating, transforming, or

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selecting variables from raw data. In this step, Principal Component Analysis (PCA) was used to reduce the dimensionality of the dataset by extracting the most important linear combinations of the original variables, which helps eliminate multicollinearity and enables more effective graphical representation and study of the dataset.

For clustering, the K-means algorithm was used, which aims to divide a dataset into K clusters based on similarity. In other words, it grouped samples into clusters based on the most representative and significant original characteristics of the dataset, as mentioned by McQueen (1967), the creator of the method. The choice of the number of clusters is critical, and variable normalization is considered to avoid biases.

Finally, in determining the levels of technological capabilities within the APUs, an average score for each group was calculated based on the provided data and numerical values were assigned to represent capability levels as follows:

- **High:** This level shows an advanced approach to technology adoption, along with ongoing efforts to enhance productivity and efficiency. The interval for this level includes groups with a participation ranging from 75% to 100% of the APUs.
- **Medium:** Indicates a moderate degree of technology adoption and technological practices in the Passiflora production sector. Although some advanced methods might be applied, there is potential for improvement and expansion of technology use. This level encompasses groups with participation ranging from 50% to 74% of the APUs.
- **Low:** Indicates a limited level of technology adoption and technological practices in the Passiflora production sector. Traditional methods are likely used, with significant opportunities for improving efficiency through the adoption of more advanced technologies. The interval for this level includes groups with participation ranging from 25% to 49% of the APUs.
- **Very Low:** Exhibits an extremely low or null degree of technology adoption and technological practices in the Passiflora production sector. Challenges in accessing resources and technological knowledge may significantly impact productivity and market competitiveness. This level includes groups with participation ranging from 0% to 24% of the APUs.

3. Results

During the data examination phase, it was observed that some Agricultural Production Units (APUs) lacked information in the necessary variables. To address this, the *inner join* function in Python was used to select only those units where the variables of interest had information, resulting in a sample composed of 493 APUs.

Once the data was balanced, a correlation analysis was applied to the relevant variables for the set of indicators proposed. As shown in Table 1, which contains the correlation coefficients, highlighting the strength and direction of the direct connections between different variables, which values range from -1 to 1, where 1 indicates a perfect positive improvement, reflecting a positive complementary relationship. This means both variables increase proportionally, with an effect shown in the table with a color close to red. Conversely, a value of -1 indicates a perfect negative improvement, signaling a negative conflict relationship, therefore an inverse relationship, where one variable increases while the other decreases proportionally; this pattern is represented in the matrix with a color close to blue. Finally, a value of 0 indicates the absence of an amplification in the relationship between the variables.

Following this reasoning, a strong negative correlation (-0.95) is observed between the credit application and its approval, indicating that as the application amount increases, the probability of approval decreases, and vice versa. A similar trend is observed between general technical assistance and specific assistance in good agricultural practices.

Additionally, a significant positive relationship (0.50) is identified between credit approval and the purchase of inputs with those funds, suggesting that both variables increase proportionally. Furthermore, technical assistance in soil

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Table 1. Correlation matrix for variables associated with the technological capacities of the Passifloras production sector in Huila

Variable	P_S11P136	P_S11P137_SP1	P_S11P137_SP4	P_S6076_SP3	P_S6777_SP1	P_S6777_SP2	P_S11P134_SP1	P_S11P134_SP2	HIGHER_EDUCATION	AQUEDUCT	ELECTRICITY	SEWERAGE	HARVESTED AREA
P_S11P136	1	0,95	0,22	0,08	0,03	0,04	-0,02	0,02	-0,07	0,01	-0,06	0,04	-0,069
P_S11P137_SP1	0,95	1	0,18	0,06	0,05	0,07	-0,01	0,03	-0,06	0,02	-0,04	0,05	-0,074
P_S11P137_SP4	0,22	0,18	1	0,34	0,33	0,28	0,07	0,1	-0,05	0,03	0,02	0,06	-0,036
P_S6076_SP3	0,08	0,06	0,34	1	0,16	0,21	0,03	0,04	-0,04	0,05	0,03	0,06	-0,026
P_S6777_SP1	0,03	0,05	0,33	0,16	1	0,4	0,1	0,11	-0,02	0,06	0,08	0,07	-0,002
P_S6777_SP2	0,04	0,07	0,28	0,21	0,4	1	0,14	0,12	-0,02	0,07	0,11	0,09	0,032
P_S11P134_SP1	-0,02	-0,01	0,07	0,03	0,1	0,14	1	0,13	0,03	0,02	0,08	0,05	0,058
P_S11P134_SP2	0,02	0,03	0,1	0,04	0,11	0,12	0,13	1	0,05	0,06	0,07	0,07	0,064
HIGHER_EDUCATION	-0,07	-0,06	-0,05	-0,04	-0,02	-0,02	0,03	0,05	1	0,03	0,08	0,06	0,032
AQUEDUCT	0,01	0,02	0,03	0,05	0,06	0,07	0,02	0,06	0,03	1	0,1	0,09	0,018
ELECTRICITY	-0,06	-0,04	0,02	0,03	0,08	0,11	0,08	0,07	0,08	0,1	1	0,13	0,039
SEWERAGE	0,04	0,05	0,06	0,06	0,07	0,09	0,05	0,07	0,06	0,09	0,13	1	0,045
HARVESTED AREA	-0,069	-0,074	-0,036	-0,026	-0,002	0,032	0,058	0,064	0,032	0,018	0,039	0,045	1

Source: Authors' own elaboration from the CNA microdata (DANE, 2014).

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management is positively correlated (0.3) with technical assistance in post-harvest management, indicating a joint increase. A strong positive correlation (0.17) is noted between individuals with higher education and the use of organic fertilizer, denoting a close relationship. Finally, a strong positive recommendation (0.2) is observed between the presence or absence of electricity and water supply, suggesting a close relationship between these variables.

In this case, to reduce the number of dimensions in the dataset, between 2 and 10 principal components were applied. However, it was identified that two principal components from the set of 111 variables offer better cohesion and higher quality of clustering. These two components capture most of the information or variation present in the original data, achieving the reduction as shown in Table 2.

In addition, Table 3 presents the representation coefficients of the relevant variables for each indicator in relation to the two principal components identified earlier, where each component is formed as a linear combination of the original variables. Also, the coefficients indicate the strength and direction of each variable's contribution to the corresponding component.

Consequently, positive coefficients contributed to increasing the component's value, while negative coefficients had the opposite effect.

Based on this theoretical context and after applying the K-means algorithm, nine (9) distinct clusters were identified within the data that shared characteristics or properties among themselves. However, as shown in Graph 1, which displays the result of applying the elbow method, aimed at evaluating cohesion between groups and determining the optimal number of clusters to form. So, increasing the number of clusters reduces the distance value, which is the sum of each group squared distances within many partitions. As a result, it was decided to work with the first 4 groups.

Table 2. Values of the principal components

Axis	Eigenvalues	Accumulated Inertia
Component 2	[1,38 0,65]	2,033
Component 3	[1,38 0,65 0,57]	2,6
Component 4	[1,38 0,65 0,57 0,5]	3,31
Component 5	[1,38 0,65 0,57 0,5 0,42]	3,53
Component 6	[1,38 0,65 0,57 0,5 0,42 0,39]	3,92
Component 7	[1,38 0,65 0,57 0,5 0,42 0,39 0,34]	4,26
Component 8	[1,38 0,65 0,57 0,5 0,42 0,39 0,3]	4,56
Component 9	[1,38 0,65 0,57 0,5 0,42 0,39 0,3 0,28]	4,85
Component 10	[1,38 0,65 0,57 0,5 0,42 0,39 0,3 0,28 0,19]	5,12

Note: Is observed that as the number of components increases, the variation explained by each component gradually decreases, and the smaller eigenvalues indicate that those components are less important in terms of explaining the variability in the data.

Source: Authors' own elaboration based on principal component analysis applied to the CNA microdataIt.

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Table 3. Coefficient of representation of variables concerning the utilized components

variables	Component 1	Component 2
Loan application	0,00034	-0,39596
Credit Approval	-0,00037	0,20633
Use of funds: Purchase of inputs	0,02995	0,2648
Use of funds: Purchase of Equipment	0,2	0,15
Use of funds: Crop Installation	-0,01673	0,09759
Use of funds: Other purposes	-0,00504	0,02036
Soil improvement with organic fertilizer	-0,04685	0,01424
Soil improvement with chenical fertilizer	0,05327	0,12155
Soil improvement with acidity corrector	0,003	0,01579
No soil improvement applied	-0,037	-0,07457
Manual pest control	-0,04934	0,1796
Organic pest control	-0,00977	0,03685
Chemical pest control	0,03528	0,0117
Mechanized pest control	-0,02214	0,04128
Pest control with genetically modified plants	0,28	0,3
% producers belonging to cooperatives	0,01893	0,06959
% producers belonging to a producer association	-0,03381	0,14347
% producers belonging to research centers	-0,25	0,18
Own tenure of the property	-0,01709	-0,01202
Operating personnel	0,00246	0,01423
% people with higher education	-0,01587	-0,00707
% people who are literate	0,18	0,25
% of APUs that recieved technical assistance	-0,24083	-0,19074
Technical assistance in good agricultural practices	0,26662	0,18122
Technical assistance in soil management	-0,0184	0,0417
Technical assistance in post-harvest management	-0,01403	0,0273
Equipment less than 5 years old	-0,01165	0,00396
Equipment older than 5 years old	0,00012	-0,00035
Electricity	0,01019	0,00738
Sewerage	-0,04529	-0,05438
Aqueduct	0,01393	-0,20989
Average area of the APUs	-0,00983	-0,00589

Source: Authors' own elaboration based on principal component analysis applied to CNA microdata.

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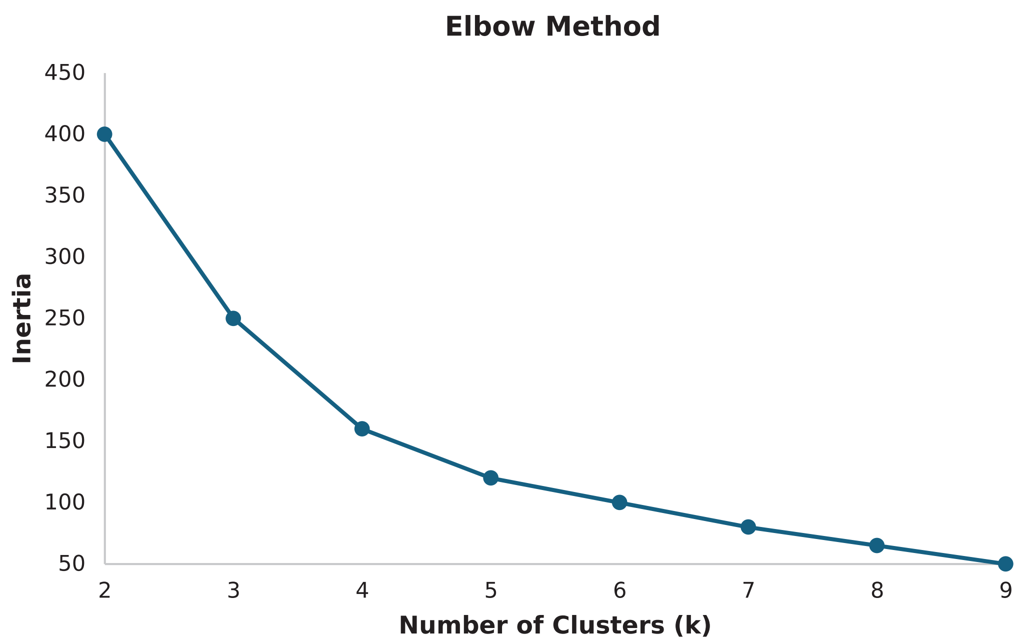
Graph 1. Inertia between groups using the elbow method



Source: Authors' own elaboration based on clustering applied to the CNA microdata.

Now, by using the Silhouette coefficient, which aims to evaluate the degree of similarity of an individual compared to the rest of the individuals within their group, in contrast to those located in the nearest group, in other words, it provides an estimate of how well the samples are clustered within their respective groups and how separated the clusters are from each other. A value close to 1 indicates that the clusters are well-defined and separated, and that the individual is well-positioned within their respective cluster, while a value close to 0 suggests that the individual is on the border between two clusters. On the other hand, a value close to -1 indicates that the individual belongs to a different cluster rather than the one they are currently in.

For the case at hand, and consistent with Jambu's elbow, the first 4 groups, as shown in Graphic 2, had the best scores with a Silhouette coefficient ranging between 0.48 and 0.58, respectively. This allows us to infer that, although they are, on average, close to the mean, it indicates that the individual is in the appropriate cluster and that there are well-distributed elements within each of these groups.

So, to understand the relative contribution of the original variables to the formation of the components, the coefficients for each group and components within the dataset were analyzed (Table 4). For Component 1, Group One, which had a coefficient of 1.3, suggests that the original variables in this group had a modest and positive contribution, similar to Group Three's contribution. In contrast, Group Zero and Group Two, with values of -1.08 and -0.7, did not contribute to the component.

Next, to analyze the degree of proximity or similarity between the groups, with the distance between them being average, Graph 3 shows the dispersion of the groups across each of the two components with their respective centroid. This means that the midpoint of the objects allowed us to identify that Groups Zero and Two exhibited more variability in the data, while Groups One and Three were more concentrated around their respective centroids. At the same time, there was no observed overlap between the groups, and the scaling and normalization of the groups showed similar scales, with no dominant dispersion affecting group formation.

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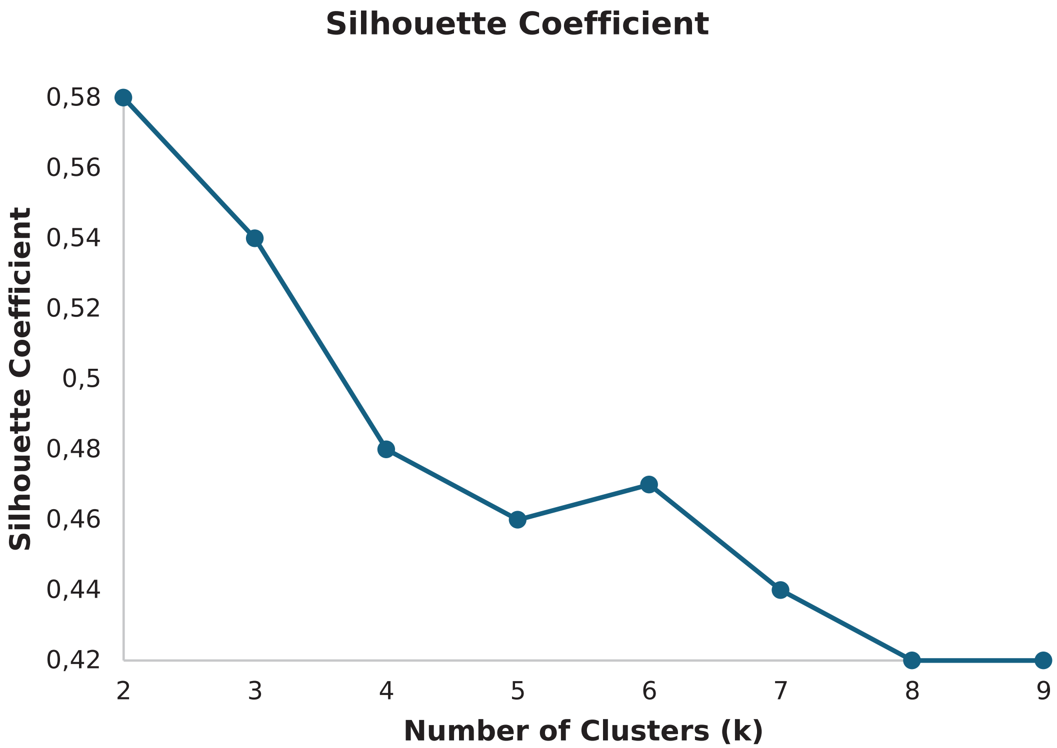
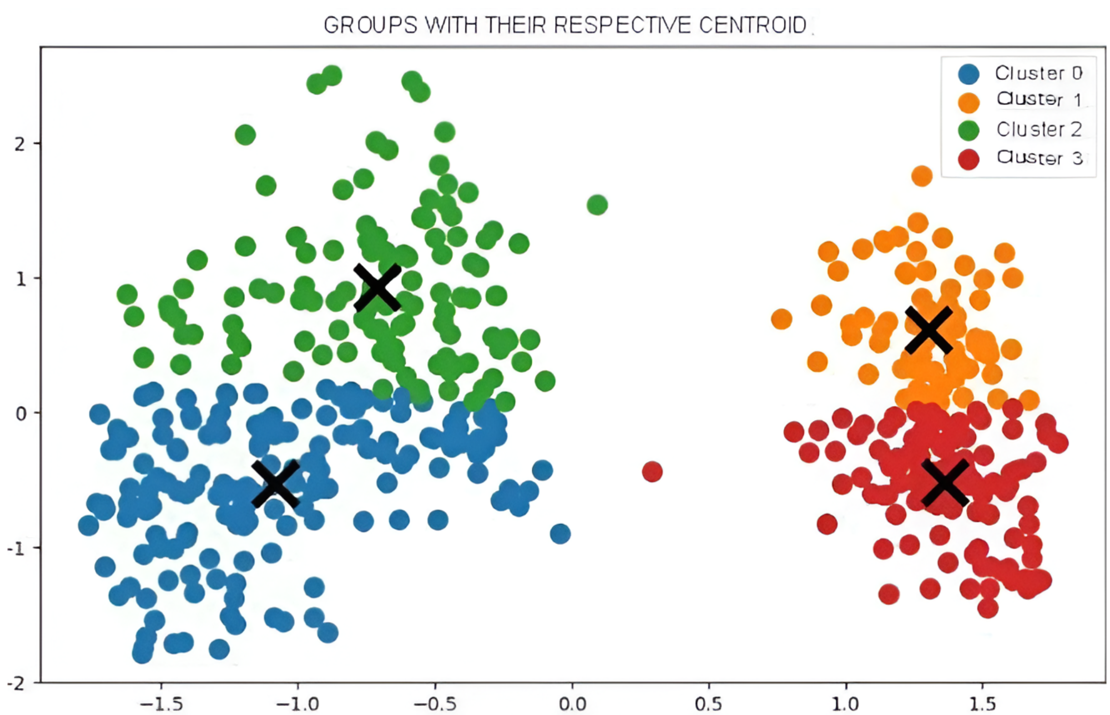
Graph 2. Quality of the obtained clusters using the silhouette coefficient



Source: Authors' own elaboration based on principal component analysis applied to the CNA microdata.

Graph 3. Dispersion of groups in the principal components



Source: Authors' own elaboration based on principal component analysis applied to the CNA microdata (DANE, 2014).

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Table 4. Quality of group representation in each component

Group	Component 1	Component 2
Group 0	-1,08	-0,53
Group 1	1,3	0,6
Group 2	-0,7	0,92
Group 3	1,36	-0,52

Source: Authors' own elaboration based on principal component analysis applied to CNA microdata.

Following this reasoning, Table 5 presents the quantity and percentage of APUs identified by group according to the sample taken in this study. The highest concentration of APUs is in Groups Zero, One, and Two, while Group Three contains only 15.62%.

In addressing the main focus of the study on the level of technological capabilities, it is understood that, as noted by Lugones *et al.* (2007), this involves describing the "broadest skills required to initiate a process of improvements leading to a path of sustained growth and development" (p. 11). According to the theoretical frameworks presented, this includes both innovation and absorption capacities. The first one, refers to the skills developed to generate new ideas, inputs, and inspirations, thus creating new knowledge both internally and externally. In contrast, the second focuses on the identification, assimilation, and utilization of this new knowledge. As outlined in Figure 1, this analysis should be based on the three indicators formulated: the available base, the efforts made toward increasing and consolidating, and the results achieved from existing conditions.

3.1. Efforts

In this context, the characteristics of the efforts indicator are presented in Table 6. From this observation, it can be stated that there is a prevalence of low levels across all analyzed groups, meaning that the effort is within a range of 25% to 49%.

Therefore, when analyzing this indicator, regarding credit requests and approvals, the availability of financial resources, and

Table 5. Distribution of UPAs by Clusters

Group	Number of APUs	(%)
0	172	34.89
1	125	25.35
2	119	24.14
3	77	15.62
Total	493	100.00

Source: Authors' own elaboration based on clustering applied to CNA microdata.

the group's ability to access financing for technological investments, it is evident that Group Zero had a low level of participation.

Meanwhile, the allocation of resources (purchase of inputs, equipment, crop installation, and other uses) is a characteristic that shows the extent to which groups allocated resources for acquiring inputs and agricultural technology. Groups Two and Three showed the most interest in this aspect, and although it is still classified as low, it is notable that 44% of the UPAs in the first group made efforts to allocate resources to meet this need, while Group Three represented 45% of the UPAs.

Similarly, in analyzing the use of organic, chemical, and acidity-correcting fertilizers for soil improvement, it is evident that chemical fertilizers were the most used, with a concentration of demand ranging from 70% to 92% of the population in each group applying this treatment.

Regarding pest control variables, the use of chemicals predominates, reaching high levels in Groups One and Two, with 80% and 78% of the population in each group, respectively.

Finally, in terms of associativity and access to technical and technological knowledge, the groups were positioned between the low and very low effort scales. Group Two experienced an effort condition between 25% and 49% (low), while the other groups were classified in the very low scale, ranging from 0% to 24%. Hence, there is room for departmental public policy to offer opportunities to improve these capabilities and, consequently, enhance

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Table 6. Results of the Efforts Indicator

Feature	Group 0	Group 1	Group 2	Group 3
	(%)			
Loan application	39,50	100,00	86,60	100,00
Credit Approval	39,50	100,00	86,60	100,00
Use of funds: Purchase of inputs	5,20	9,60	44,50	45,50
Use of funds: Purchase of Equipment	1,70	0,00	0,80	2,60
Use of funds: Crop Installation	2,30	1,60	17,60	10,40
Use of funds: Other purposes	1,70	1,60	5,00	3,90
Soil improvement with organic fertilizer	35,50	24,80	31,10	27,30
Soil improvement with chenical fertilizer	70,90	81,60	91,60	92,20
Soil improvement with acidity corrector	3,50	3,20	6,70	6,50
No soil improvement applied	15,10	8,00	3,40	1,30
Manual pest control	30,80	23,20	54,60	39,00
Organic pest control	13,40	9,60	12,60	13,00
Chemical pest control	70,30	80,80	78,20	72,70
Mechanized pest control	9,90	6,40	15,10	6,50
Pest control with genetically modified plants	0,00	0,00	0,00	0,00
Producers belonging to cooperatives	7,60	11,20	17,60	18,20
Producers belonging to a producer association	16,90	6,40	33,60	22,10
Producers belonging to research centers	0,00	0,00	0,80	0,00

Note: Very Low: 0% - 24% Low: 25% - 49% Medium: 50% - 74% High: 75% - 100%

Source: Authors' own elaboration created from data analysis extracted from the 2014 CNA (DANE, 2014).

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productivity and commercialization of an activity with potential in both domestic and external markets, such as the cultivation of *Passifloras*.

3.2. Available base

Regarding the available base indicator, the rating scale ranges from very low (up to 24%), low (25% to 49%), medium (50% to 74%), and high (75% or more). The analysis of the properties constituting the available base indicator shows a predominance of a high level across all analyzed groups. Key characteristics include ownership of the property, with values recorded as high ranging from 78% in Group Zero to 90% in Group Four. This is followed by the percentage of UPAs that received technical assistance, primarily in areas such as advisory services and good agricultural practices, with high records in Groups One, Two, and Three, but low in Group Zero.

Continuing with the analysis of characteristics within this dimension, operational personnel, defined by the percentage of individuals actively involved in daily tasks of the UPA, including agricultural and management tasks, aged between 12 and 65 years, represent 87% in Group Zero and 81% in Group Three, as seen in Table 7.

Table 7. Results Obtained for the Available Base Indicator

Feature	Group 0	Group 1	Group 2	Group 3
	(%)			
Own tenure of the property	78	83	90	90
Operating personnel	87	86	88	81
People with higher education	2	1	1	0
People who are literate	38	37	37	35
Of APUs that recieved technical assistance	39,50	100,00	86,60	100,00
Technical assistance in good agricultural practices	35,50	99,20	77,30	100,00
Technical assistance in soil management	4,10	0,00	10,10	1,30
Technical assistance in post-harvest management	2,90	0,80	8,40	1,30

Note: Very Low: 0% - 24% Low: 25% - 49% Medium: 50% - 74% High: 75% - 100%

Source: Authors' own elaboration created from data analysis extracted from the 2014 CNA (DANE, 2014).

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Table 8. Results obtained for the infrastructure indicator available to UPAs

Features	Group 0	Group 1	Group 2	Group 3
	(%)			
Equipment less than 5 years old	72	59	62	69
Equipment older than 5 years old	50	59	61	56
Electricity	97	96	97	99
Sewerage	13	2	3	0
Aqueduct	62	66	41	35
Average area of the APUs	403165.5	127223.3	125442.8	124474.6

Note: Very Low: 0% - 24% Low: 25% - 49% Medium: 50% - 74% High: 75% - 100%

Source: Authors' own elaboration created from data analysis extracted from the 2014 CNA (DANE, 2014).

An interesting and partially supportive finding is the level of technological capabilities achieved in the Department, measured in percentage terms by group and the number of UPAs from the CNA microdata, referring to individuals with higher education and those who can read and write. In the first group, the model indicates that in Group Zero, 2% of the population has completed university, technical, or technological studies, while in Group Three, this figure is 0%, and in Groups One and Two, it is 1%. For the second group, the contrast is noteworthy and calls for specific public policy actions. On average, 36.75% of the population in the group and part of the UPAs report being literate, suggesting that around 63.25% might experience challenges in understanding and adopting new practices and technologies. This, along with the ratings observed in technical assistance for soil management and post-harvest handling, qualified as low, generally explains the absorption capacities from this dimension.

In this context, the infrastructure indicator has been examined concerning the accessibility of fundamental resources to address technological change processes. As shown in Table 8, the characteristic of machinery less than 5 years old is rated at a medium level, ranging from 72% to 69% of UPAs with machinery having a degree of obsolescence that is less than 5 years old, while the average for UPAs with machinery older than 5 years is 56.5%. This suggests that the groups and UPAs have made efforts to invest in equipment to enhance their technological capabilities.

In this context, the indicator for electricity shows that the percentage of UPAs with access to electricity for their activities is at a high level, with an average of 97.25% across groups. In contrast, only 4.5% of UPAs have access to sewerage or basic sanitation for proper wastewater management, with Group Zero reporting the best access indicator and Group Three the worst.

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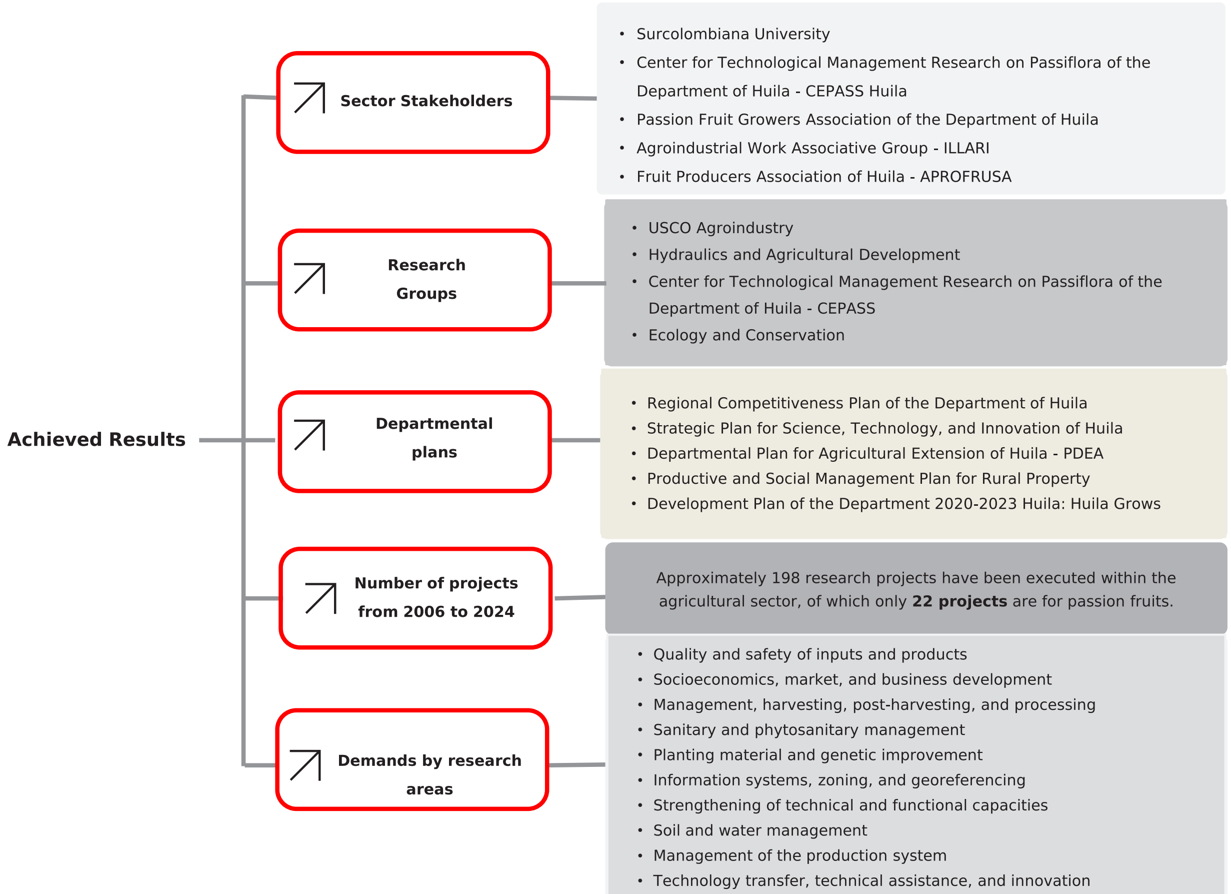
Figure 2. Results achieved based on existing capacities



Source: Authors' own elaboration adapted from Gobernaciòn del Huila (2022).

Finally, the water supply indicator shows a good performance in Groups Zero and One, with 62% and 66% of UPAs, respectively, having access to a potable water supply system, though at a medium level. In contrast, Groups Two and Three are at a low level, with an average access rate of 38% for the water supply system. This situation calls for actions from local government and producer organizations, to work together to improve sector infrastructure and ensure the quality and reliability demanded by consumers of these fruits.

3.3. Results achieved

The combination of research initiatives and specific projects for Passiflora activities in the Department of Huila reflects a solid effort to enhance technological capabilities in the sector. Implementing this comprehensive approach, coupled with strengthening such capabilities, provides the necessary foundation for sustainable growth and production innovation, covering not only Passifloras cultivation but also other related agricultural sectors.

In summary, from 2006 to 2023, the Department conducted a total of 198 research projects in the agricultural sector. Of these, 11.1% (22 projects) focused on Passiflora cultivation, addressing issues such as input and product quality and safety, agriculture socio-economic aspects, integrated management of the production system, and business development. The demand from various stakeholders for technology transfer, technical assistance, and innovation has been crucial in explaining the level of obtained results in strengthening the sector's technical and functional capabilities, as shown in Figure 2.

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4. Discussion

The assessment of technological capabilities in the Passiflora production sector has been the focus of several studies in recent years. Among them, Ocampo *et al.* (2020) found that the adoption of advanced technologies, such as climate monitoring sensors and automated watering systems, has been crucial for improving the productivity and sustainability of passion fruit cultivation in Colombia. This connection suggests that training and technical support are key factors in technological development in the Passiflora sector.

De la Rosa *et al.* (2020) highlighted that the implementation of Information and Communication Technologies (ICT) has allowed Passiflora producers to improve the planning and management of their crops, resulting in a significant increase in efficiency and a reduction in post-harvest losses.

In this context, one of the most relevant findings of our study is the positive correlation (0.3) between technical assistance in soil management and post-harvest handling. This result suggests that improvements in soil management not only optimize primary production but also facilitate the implementation of advanced techniques in post-harvest handling. González *et al.* (2023) support this observation, indicating that improvements in soil management practices lead to better final product quality, which facilitates the adoption of more sophisticated techniques in post-harvest handling.

On the other hand, Orrego *et al.* (2021) have emphasized the importance of technological innovation in the Passiflora sector to enhance productivity and competitiveness. Therefore, comparing the results obtained in this study with previous research can help identify consistent trends or significant differences in the sector's technological capabilities.

Additionally, the study reveals that production units receiving advice on good agricultural practices show significant improvements in their technological capabilities. Muñoz and Andrade (2024) also found that technical advisory facilitates the rapid and effective adoption of advanced agricultural technologies, supporting the transfer of knowledge and skills necessary for implementing new technologies and agricultural practices. This alignment suggests that technical advisory is a crucial factor for modernization and competitiveness in the Passiflora production sector.

However, a limitation of the study is that the data used come from the National Agricultural Census available since 2014, reflecting a nine-year gap. This situation calls for an update to reflect not only social changes and territorial evolution but also territorial development and, specifically, the technological environment and conditions of the agricultural sector.

Nonetheless, the efforts of the Secretariat of Agriculture and Mining of Huila, together with the Rural Agricultural Planning Unit (UPRA), to provide territorial entities with the Rural Property Social Ordering Plan (POSPR) are recognized. This plan identifies the vocation and suitability of land according to the agricultural frontier, allowing for the enhancement of technological capabilities in its three dimensions: absorption, effort, and results.

Updating these data and maintaining continuous monitoring is imperative for formulating effective strategies and accurately reflecting the current state and emerging needs of a vital sector for the region's economic development.

5. Conclusions

The results reveal a considerably low level of technological capability development in UPAs within the sector, indicating a clear deficiency in the effort indicator. This highlights the need to improve current conditions to foster innovation and efficiency in Passiflora producers' practices, leading to increased productivity.

To achieve this, it is necessary to promote the creation of strategic alliances with research centers, universities, and government entities to facilitate access to resources, innovation, and funding. Additionally, coordinated actions among various stakeholders are required to address

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deficiencies in education coverage and quality, particularly among producers with low levels of higher education and literacy.

Comparing our results with recent literature underscores the importance of technical advisory and the adoption of advanced technologies to improve the technological capabilities of the Passiflora production sector. Evidence suggests that interventions in technical advisory and soil management are not only beneficial on their own but also have positive effects on other critical areas such as post-harvest handling. Therefore, it is recommended to implement comprehensive technical assistance programs that address multiple aspects of agricultural management to promote sustainable and competitive development of the sector.

6. Conflict of interest

The authors declare no conflict of interest.

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