Analysis of Technological Gaps for Agricultural Chains Through the Analytical Hierarchical Process – AHP

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***Abstract* – The technological advances experienced by some countries can revolutionary change the productivity and competitiveness of a wide range of economic sectors due to the opening of possibilities of new ways of doing things better; however, the state of advancement of technology in the respective sectors and countries must first be determined. The aim of the study was to identify the technological gaps in the different productive links of the banana production chain in Colombia, in comparison with different leading countries in the world, to establish the best practices in each of these links. The study was quantitative in nature and the Hierarchical Analytical Process - AHP was used as a multi-criteria tool for information processing and analysis. The study population corresponded to the countries with a banana production chain, and the sample corresponded to the 13 countries with the highest volume of production. Among the multiple existing comparison criteria, the following were selected for analysis: basic research, production volume, exported value, exported quantity and unit value of exports.**

As a result, it was obtained that Nigeria presents the greatest advances and conditions in the productive chain analyzed according to the established criteria. Likewise, a methodology was established that can be extrapolated to be used in the evaluation of national and international agricultural production chains within the framework of technological gaps.

***Keywords* – Technological gaps, research agendas, agricultural chains, analytical hierarchical process.**

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1. Introduction

Increasing the productivity and competitiveness of the country's agricultural chains is a challenge faced by different institutions such as the *Ministerio de Agricultura y Desarrollo Rural, the Corporación Colombiana de Investigación Agropecuaria – Agrosavia and the Ministerio de Ciencia, Tecnología e Innovación*, among others. Therefore, the identification of the problems and technological gaps in each of the links is a key activity that, framed in a long-term vision, will allow the planning, construction of policies and programs that promote the development of the agricultural and agro-industrial sector.

The advances experienced in the technological field, especially driven by artificial intelligence, in related fields such as machine learning, robotics and neural networks, and their impact on the appearance of new developments such as the internet of things, dark factories or factories systems, autonomous vehicles, and remote medical monitoring/diagnostic systems, among others [1], can revolutionize the productivity of a wide range of economic sectors by opening up possibilities for new ways of doing things [2].

The research agendas include these elements and are intended to serve as roadmaps for the different actors of the national agricultural innovation system to act around them and allow the fulfilment and achievement of their vision, definition of resources for research.

The identification of technological gaps is perhaps one of the key exercises for the construction of the agenda that, accompanied by technological surveillance processes, allows the identification of the best practices developed in countries that are a reference for their state of development and advances in the productivity and competitiveness of a specific agricultural chain.

Several authors developed the technology gap approach, which assumes a close relationship between economic growth rates and the growth rates of the technological level in countries [3], [4], [5]. Therefore, technological capacity in the economy is considered relevant. In this line, the technological gaps in productive sectors of different countries have been strongly linked to the quality of exports, finding a strong influence of technological development on the differentiated characteristics of the manufactured products [6], [7], [8].

The evaluation of criteria such as production and export of finished products for the selection of reference countries in the gap analysis is proposed; however, the evaluation and assessment of these criteria is done in a purely qualitative way [9]. Therefore, the proposed methodology sugessts the application of a MCDM Multicriteria Decision Method such as the Analytical Hierarchical Process – AHP that allows the evaluation of multiple "alternative" countries on multiple criteria "n criteria" through a matrix multiplication that it delivers a hierarchy of alternatives according to the level of compliance with mentioned criteria, making the selection of the referent(s) of the chain under study more precise.

2. Literature Review

The theoretical perspective from which the study was approached is presented below. In this case, the scope, and dimensions of the concept of technological gaps are exposed. Likewise, the dynamics of the Analytical Hierarchical Process are outlined as a criteria prioritization technique.

2.1. Technological Gaps

Before referring to technological gaps, it is necessary to address the concept of technological capacities, referring to the accumulated learning processes that contribute to the management of technology, improvement in management capacity and production and organization methods [10].

In this sense, the three factors that stimulate the development of technological capabilities according to the author are: 1) Internal need for the development of new skills and information, where essentially the aim is to optimize productivity; 2) External factor that strongly influences the process; 3) Technological change that is continuously developing in almost all industries in the developed world [11].

The evaluation of the current state of development of the study chain at the local level is of vital importance to establish a baseline on which the advances in the short, medium and long term of the research agenda will be assessed and evaluated; however, it is necessary to establish the existing gaps between the productive chain and the development of leading countries in the production, transformation, research and commercialization of identical or homologous products to those of the productive chain; in this way it will be possible to obtain learning and establish the future challenges to face.

Gap analysis is a tool that is part of the prospective methodological models applied to the construction of research agendas in agricultural or agro-industrial chains. It should be clarified that there is a possibility that the competing or benchmark chain is not represented in a single country, but it is feasible that this is the sum of best practices from different competing countries in the defined analysis criteria [9].

A gap definition process follows the following steps: 1) identification of the objective of the gap analysis; 2) determination of the points or variables of comparison with which the best practices will be measured; 3) identification of the benchmarks in companies with the best practices for comparison; 4) determination of the method and source for data collection; 5) determination of the current performance gap between the leading countries and the country of study, in addition to identifying its opportunities and limitations worldwide [12], [9].

2.2. Analytical Hierarchy Process (AHP)

Decision-making methods with multiple MCDM criteria serve to support the decision-making process, especially when people find themselves in dilemmas derived from having multiple feasible alternatives at a time when it is required to choose the most optimal alternative [13]. This type of problematic situation arises in the daily management, in cases such as the choice of a job, the selection of a supplier company, the physical location of the factory, among others [14].

MCDM problems can be classified into two main categories: Multiple Attribute Decision Making MADM or Multiple Objective Decision Making MODM, depending on the purpose and types of data [13], [14].

The characteristic that differentiates the MADM lies in the fact that they are used when there are limitations in the number of predetermined solution alternatives.

The alternatives are associated with a level of achievement of the attributes (which may not necessarily be quantifiable) based on which the final decision will be made. The final selection of the alternative is made with the help of inter-attribute and intra-attribute comparisons.

Among the methods with the greatest acceptance and the most widespread use for decision making are the Analytical Hierarchy Process (AHP). This is a research method that supports rational decision making based on different factors of a qualitative order [15]. This tool has, within its qualities, the possibility of offering a range of solutions to both qualitative and quantitative problems. The method comprises 3 main steps, (i) development of the hierarchical structure of the problem in terms of general results, criteria, and alternatives, (ii) defining priorities through pairwise comparison and (iii) consistency review so that the judgment is sufficiently valid [16].

Given its versatility, this method presents multiple application options, which several authors have used for the selection of optimal technologies at an industrial and governmental level among other [17], [18], [19]. A case related to the prioritization of agricultural chains is described by Montoya et al. [20] by applying AHP.

3. Materials and Methods

The research carried out was of a quantitative nature, in which the Analytical Hierarchical Process (AHP) was used [21] since it corresponds to a multi-criteria tool used in different fields of knowledge [22], [23] and one of the most widely used worldwide [24]. Thus, the method performs the evaluation of the alternatives, which for the present study corresponded to the impacts generated by the Quimbo, by pairwise comparisons with respect to each criterion (see Figure 1). The steps of the AHP application process are described below according to Saaty [15].

3.1. Design of the Hierarchical Tree of Criteria and Alternatives

As a starting point for the application of an AHP, the general objective or point of convergence of the criteria hierarchy levels must be clearly defined, likewise, the criteria and sub-criteria must be defined. These must be independent, and their importance must not depend on the elements in the next lower level of the hierarchy. Finally, define the alternatives to be evaluated. Below is the layout structure.

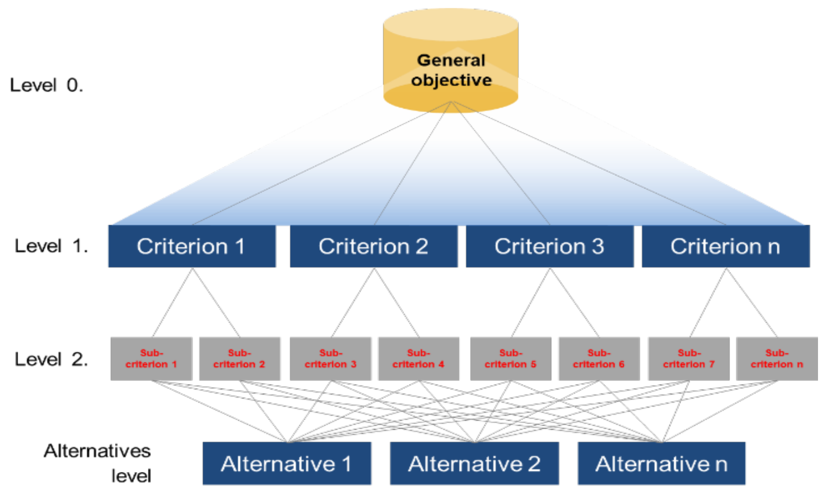

Figure 1. Hierarchical tree of criteria

3.2. Assigning Weights to Criteria

For each branch and subbranch of the tree, importance weights must be assigned with respect to the higher level they share, such that:

$$\sum_{i=1}^{m_1} w_1 = \mathbf{1}$$

where mi is the number of "children" criteria

This assignment can be applied through two methods, the first is a direct assignment where one or several experts participatively and by consensus assign the value of each criterion and sub-criteria, and second by applying the method of paired comparisons.

For the method of paired comparisons, the decision group can express their preferences between each pair of items evaluated according to the Saaty scale as "equally preferred", "moderately preferred", "strongly preferred", "very strongly preferred" or "extremely preferred"; these qualitative relationships can be qualified with values "1", "3", "5", "7" or "9", mean values can be applied when a compromise between adjacent values is needed.

Table 1. Saaty scale

Intensity	Definition	Explanation
1	Equal	Two activities contribute equally to the achievement of the objective. Matrix diagonal.
3	Moderate	Experience and expert judgment slightly favor one criterion over another.
5	Strong	Experience and expert judgment strongly favor one criterion over another.
7	Very strong	One criterion is much more favored than another. Its importance has been demonstrated in practice.
9	Extreme	The predominance of one criterion over another is absolutely and totally clear.
2, 4, 6 y 8	Mean values	When a compromise is needed between adjacent values. Not recommended

Matrix of cross comparisons: If n criteria are considered, the cross comparison of element i with element j appears in the entry aij of matrix A:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & & \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

The reciprocal values appear in the aji entry of matrix A for consistency.

Normalization, weight calculation, and consistency evaluation: Once matrix A is ready, the values of each column are added, and each element is divided by the sum of its column to obtain the normalized matrix N.

The weights of the criteria considered are obtained as the average of the respective row of the normalized matrix N (to evaluate alternatives).

To estimate the consistency, the eigenvalues (eigenvalues - λ) and eigenvectors (eigenvectors - x) of the matrix A are calculated as:

$Ax = \lambda x$

Consistency Index (CI):

$$CI = \frac{\lambda_{max} - n}{n-1}$$

Where n is equal to the number of criteria

Consistency Ratio (CR):

$$CR = \frac{CI}{IA}$$

AI: average IQ of approximately 500 random matrices. Known as random error.

Table 2. Random Error

Criteria	1	2	3	4	5	6	7	8
IA	0	0	0,58	0,90	1,12	1,24	1,32	1,41
Criteria	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
IA	1,44	1,49	1,51	1.54	1,56	1,57	1,59	

If an appraiser's consistency index (CI) measures appraiser error, the consistency ratio (CR) indicates observer error relative to random error.

• CR < 0.1 is accepted ("inconsistency" must be less than 10% of the random error).

• If the CR is higher, an attempt is made to improve the consistency based on additional information.

3.3. Assess the Alternatives Against the Criteria

Once the relative importance of the criteria has been defined, the importance of each of the alternatives is compared, the comparison of values is direct and consequently the percentages or relative weights are calculated based on these values and not on judgments or opinions.

For this, a mxn matrix must be obtained, which includes the eigenvectors of each of the m alternatives in each of the n criteria. In other words, the m vectors are included in an mxn matrix. Then we proceed to calculate the relative importance or ranking of the alternatives, using this matrix of mxn and the eigenvector of the n criteria of 1xn. The matrix is multiplied by the vector, resulting in a 1xm vector that has the relative importance or ranking of the alternatives (in this case the selected region or country).

4. Results

For the case study, an AHP was applied to the selection of a reference country, that is, a country that combines the criteria evaluated efficiently and develops the best practices in the sector, for the analysis of technological gaps in the productive chain of the bananas nationwide.

Thus, the practices that it developed were identified and allowed said country to improve the competitiveness of the productive chain. For this, the steps described in the methodology were applied.

4.1. Design of the Hierarchical Tree of Criteria and Alternatives

For the selection of the country of reference, 5 level 1 criteria were established:

❖ Basic research (# of articles): It is directly related to the ability to generate and accumulate knowledge about the needs of the agricultural chain and its potential exploitation to turn it into a source of competitive advantage.

❖ Production volume (Ton): it is related to the comparative advantage to produce a product at the level of performance and productivity variables.

❖ Quantity exported (Ton): It is directly related to non-local demand, that is, the ability to take the product or products of the chain to international markets, complying with international regulations for access to different countries.

❖ Value exported (thousands of USD): it is related to the surpluses generated through the links of the chain, where on the one hand the value addition flows and on the other the flow of income that is distributed in each link.

❖ Unit value of exports (USD/Ton): it is related to the average price paid by each destination country for exports and the attractiveness of the products in the chain to reach differentiated markets.

These were evaluated in the period corresponding to the year 2021, that is, all the reputable data correspond to that year. Only level 1 criteria were established to avoid mixing dependent variables. The hierarchical tree defined for the selection of the reference country in the analysis of technological gaps is shown below in Figure 2:

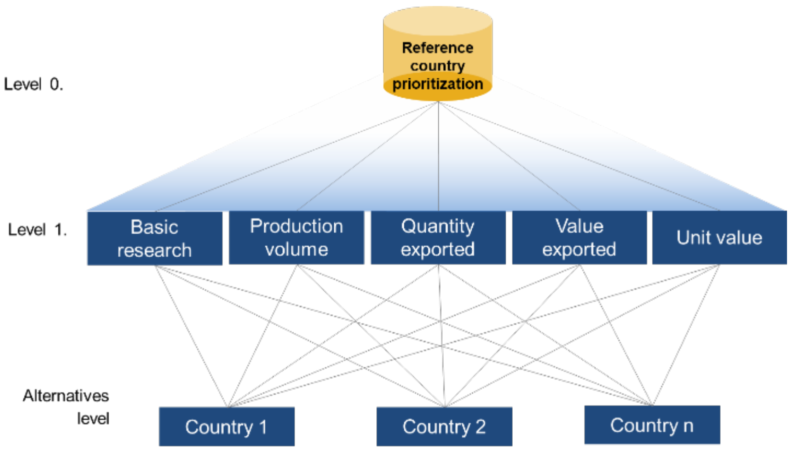

Figure 2. Hierarchical tree of criteria for the selection of the reference country

4.2. Assigning Weights to Criteria

For the assignment of weights to each one of the criteria, the method of Paired Comparisons was used.

Matrix of cross comparisons: The criteria were rated in pairs according to the Saaty scale (Table 1), a 5x5 matrix is obtained due to the number of previously defined criteria:

Matrix A:

$$A = \begin{bmatrix} 1 & 1 & 3 & 3 & 1 \\ 1 & 1 & 3 & 3 & 1 \\ 1/3 & 1/3 & 1 & 1 & 1/5 \\ 1/3 & 1/3 & 1 & 1 & 1 \\ 1 & 1 & 5 & 1 & 1 \end{bmatrix}$$

Normalization, weight calculation, and consistency evaluation: When you have the comparison matrix A, you must obtain the relative weights for each element, which is nothing more than a normalized eigenvector that is associated with the best judgment or the one with the highest eigenvalue, matrix N.

Matrix N:

$$N = \begin{bmatrix} 0{,}27 & 0{,}27 & 0{,}23 & 0{,}33 & 0{,}24 \\ 0{,}27 & 0{,}27 & 0{,}23 & 0{,}33 & 0{,}24 \\ 0{,}09 & 0{,}09 & 0{,}08 & 0{,}11 & 0{,}05 \\ 0{,}09 & 0{,}09 & 0{,}08 & 0{,}11 & 0{,}24 \\ 0{,}27 & 0{,}27 & 0{,}38 & 0{,}11 & 0{,}24 \end{bmatrix}$$

To estimate the consistency, the eigenvalues (eigenvalues - λ) and eigenvectors (eigenvectors - x) of the matrix A are calculated as: $Ax = \lambda x$

Consistency Index (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Matlab was used to calculate λmax:

A= [1 1 3 3 1; 1 1 3 3 1; (1/3) (1/3) 1 1 (1/5); (1/3) (1/3) 1 1 1; 1 1 5 1 1]

eig(A)

ans =

```
  5.2337 + 0.0000i
 -0.1168 + 1.0996i
 -0.1168 - 1.0996i
  0.0000 + 0.0000i
  0.0000 - 0.0000i
```

Solving:

CI= (5.23-5) / (5-1) = 0.06

Consistency Ratio (CR):
RC=IC/AI

For the calculation of AI, it was obtained from Table 2 for a criterion number equal to 5.

A1=1.12

$$CR = \frac{0{,}06}{1{,}12} = 0{,}05$$

CR < 0.1 is accepted ("inconsistency" must be less than 10% of the random error). The weights of the criteria considered are obtained as the average of the respective row of the normalized matrix N (to evaluate alternatives).

$$Average\ N = \begin{matrix} Basic\ research \\ Production\ volume \\ Value\ exported \\ Quantity\ exported \\ Unit\ value \end{matrix} \begin{bmatrix} 0{,}27 \\ 0{,}27 \\ 0{,}08 \\ 0{,}12 \\ 0{,}26 \end{bmatrix}$$

4.3. Assess the Alternatives Against the Criteria

For the evaluation of the alternative "countries" according to each one of the established criteria, the results previously obtained from a technological surveillance study where the respective information was identified for each country were considered. For the basic research criterion, the number of scientific articles generated by said countries in the evaluated period related to the "Plátano" or Banana study chain was obtained, for the volume of production criteria, through the FAOSTAT database, the value of production of each country reported in said database, for the criteria of exported value, exported quantity and unit value of exports, the TRADEMAP database was used for the year 2021 with the harmonized code "080390".

Table 3. Assessment of the criteria by country

Countries	Basic research 2021	Production volume (Ton)	Value exported (thousands USD)	Quantity exported (Ton)	Unit value (USD/Ton)
Uganda	124	9.200.000	448	526	852
Cameroon	155	4.973.713	51741	206.322	251
Congo	16	4.884.184	0	-	-
Ghana	135	4.722.772	96036	108.963	881
Philippines	12	3.149.093	1125936	2.425.858	464
Nigeria	657	3.123.939	1	1	1.000
Colombia	217	2.333.022	935860	2.103.077	445
Ivory Coast	29	2.126.265	199384	406.438	491
Myanmar	0	1.453.755	55480	65.404	848
Dominican Republic	5	1.075.527	218.096	357.802	610
Rwanda	3	907.640	203	41	4.951
Sri Lanka	13	813.730	1932	638	3.028
Ecuador	39	763.455	3393035	6.813.409	498

A mxn matrix is obtained, which includes the eigenvectors of each of the m alternatives in each of n criteria.

Table 4. Calculation of eigenvectors x country x criterion

Countries	Basic research	Production volume (Ton)	Value exported (thousands USD)	Quantity exported (Ton)	Unit value (USD/Ton)
Uganda	,08826	,23275	,00007	,00004	,05948
Cameroon	,11032	,12583	,00851	,01652	,01751
Congo	,01139	,12357	-	-	-
Ghana	,09609	,11948	,01580	,00873	,06155
Philippines	,00854	,07967	,18524	,19425	,03241
Nigeria	,46762	,07903	,00000	,00000	,06984
Colombia	,15445	,05902	,15397	,16840	,03108
Ivory Coast	,02064	,05379	,03280	,03255	,03426
Myanmar	-	,03678	,00913	,00524	,05924
Dominican Republic	,00356	,02721	,03588	,02865	,04257
Rwanda	,00214	,02296	,00003	,00000	,34578
Sri Lanka	,00925	,02059	,00032	,00005	,21149
Ecuador	,02776	,01931	,55823	,54558	,03478

We proceed to calculate the relative importance or ranking of the alternatives, using this matrix of mxn and the eigenvector of the n criteria of 1xn. The matrix is multiplied by the vector, resulting in a 1xm vector that has the relative importance or ranking of the alternatives (in this case the selected region or country).

$$\mathbf{M}_{\mathbf{m\ x\ n}}\ \mathbf{x}\ \mathbf{M}_{\mathbf{1x\ n}} = \mathbf{M}_{\mathbf{m\ x\ n}}$$

Solving:

$$M_{mxn} =$$

$$\begin{bmatrix} 0,260 & 0,290 & 0,0001 & 0,003 & 0,002 \\ 0,135 & 0,120 & 0,0229 & 0,035 & 0,030 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0,004 & 0,0193 & 0,0985 & 0,076 & 0,061 \\ 0,030 & 0,0180 & 0,7785 & 0,802 & 0,045 \end{bmatrix} * \begin{bmatrix} 0,27 \\ 0,27 \\ 0,08 \\ 0,12 \\ 0,26 \end{bmatrix}$$

$$M_{mxn} =$$

$$\begin{bmatrix} 0,088 & 0,237 & 0,0000 & 0,000 & 0,059 \\ 0,110 & 0,125 & 0,0085 & 0,016 & 0,017 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0,009 & 0,020 & 0,0003 & 0,000 & 0,211 \\ 0,027 & 0,019 & 0,5582 & 0,545 & 0,034 \end{bmatrix} * \begin{bmatrix} 0,27 \\ 0,27 \\ 0,08 \\ 0,12 \\ 0,26 \end{bmatrix}$$

The alternatives “Reference Countries” are shown below as a product of the Matrix Mmxn:

Table 5. Prioritization of countries Matrix mxn

Country	**Importance Weight**
Nigeria	0,165
Ecuador	0,135
Uganda	0,102
Colombia	0,099
Rwanda	0,095
Ghana	0,076
Philippines	0,071
Cameroon	0,071
Sri Lanka	0,062
Congo	0,036
Ivory Coast	0,036
Myanmar	0,026
Dominican Republic	0,026

The country selected as a reference for its evaluated “criteria” conditions is Nigeria with an aggregate score of 0.165, followed by Ecuador with 0.135, Uganda with 0.102 and Colombia with 0.099. The process determined for the development of the gaps exercise is the study of the performance of the chain in this country on the different links that compose it, and, in addition, the political conditions and other aspects that play a relevant role in its competitive development.

5. Conclusion

The selection of reference countries for the analysis of gaps applying the Analytical Hierarchical Process makes it possible to quantitatively evaluate the selection criteria against the alternatives and thus obtain more precise results based on the consensus of the parties involved, since it is not simply starting of a qualitative estimation but in a mathematical model that executes matrix multiplications that could hardly be carried out for more than two variables by a group of participating experts.

This tool is extremely versatile and applies to decision-making not only in the context of gap analysis, but also, a posteriori selection of technologies to be transferred to the chain, determination of transfer strategies, design of policies and transfer models technology among others.

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