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SUPPLIER SELECTION IN A COFFEE-ROASTING PLANT: AN ANALYTIC HIERARCHY PROCESS APPROACH

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KEYWORDS

coffee, multiple-criteria decision making, AHP, supplier selection.

ABSTRACT

Companies are looking for reliable partners, including suppliers, that offer high-quality services. The decision-making process involves several stakeholders with different objectives that require different types of relevant criteria to be considered. This study used the Analytic Hierarchy Process (AHP), a multiple-criteria decision analysis and decision-making method, to select a new supplier for a coffee-roasting plant. For this, the type of coffee was selected, and the relevant criteria were established: percentage of extrinsic defects, loss in precleaning, price, and taste. Four different potential suppliers were compared in relation to all criteria using the AHP. We achieved our research objective by establishing an order of priority for the criteria and suppliers. As a result, supplier B was the leading supplier with a 35.29% priority, followed by suppliers A and D. Our findings show great potential for using a formal method in the decision-making process in the agro-industry and applying the AHP method in an important problem and in relevant plant culture. Furthermore, other problems in agricultural engineering can benefit from the reasoning steps employed.

INTRODUCTION

Corporations seek suitable suppliers who offer high-quality services. Supplier selection requires significant financial and human resources. Companies strive to distinguish, filter, assess, and analyze potential partners through this process, far beyond the basic task of hiring. Therefore, decision-making techniques in supplier selection is an important topic to study (Chai & Ngai, 2019). Making judgments in high-risk environments in confusing and uncertain circumstances renders decisions more vulnerable to distortion. Adopting more complex scientific decision-making methods may greatly assist (Haddad & Sanders, 2018). Multiple-criteria decision analysis and decision making is a field of operational research in which alternatives against multiple, often conflicting, criteria are analyzed (Ishizaka & Siraj, 2018).

Various studies in agriculture have used the Analytic Hierarchy Process (AHP) method. Pradhan et al. (2018) evaluated the impact of farmers' action research on the field. For this, they collected pre- and post-on-farm experiment preferences of farmers for conservation agriculture. Elleuch et al. (2019) used a combined approach based on the concepts of fuzzy multi-criteria decision-making methods and a mathematical optimization programming model for water allocation problems, using fuzzy AHP to calculate the criteria weights with experts' opinions. Zhang et al. (2020) also studied the water allocation problem using the AHP method to quantify upper level decision-makers' subjective judgment in a broader study to formulate sustainable water allocation schemas in arid agricultural regions.

In subsequent studies, Chai et al. (2013) and Chai & Ngai (2019) presented AHP and analytic network process methods as the dominant decision-making techniques in supplier selection, despite a decline in their use over the years.

Supplier selection in the Brazilian coffee industry is particularly relevant, given the importance of coffee to national and global economies. According to the

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International Coffee Organization (ICO), Brazil is the largest coffee producer and exporter in the world and the second-largest consumer. Brazil consumed 22 million 60-kg bags of coffee between October 2019 and September 2020 (ICO, 2020a). The ICO estimates that world coffee production between October 2019 and September 2020 corresponds to 168.55 million 60-kg bags (ICO, 2020b).

According to the Brazilian Coffee Industry Association (ABIC), Brazil's coffee industry went from producing 13.2 million bags of coffee in 2000 to 21.2 million bags in 2020 (ABIC, 2020a). The presence of qualitative factors that influence the selection of suppliers in a coffee-roasting plant, such as taste, justifies the use of AHP. Furthermore, it offers the possibility of placing both qualitative and quantitative factors in the hierarchical structure of the decision-making process (Chan et al., 2019).

This study aims to apply the AHP method to select a new supplier of a specific type of coffee bean responsible for providing the characteristic taste to a beverage intended for the domestic market in a coffee-roasting plant by introducing a formal method in the decision-making process, thus providing a superior means to previously based methods that primarily rely on the experience of decision makers.

MATERIAL AND METHODS

This section describes how data collection was performed using the AHP method to establish a straightforward supplier selection procedure that faithfully represents the actual coffee-roasting plant.

Data collection and analysis

Data collection took place through partially structured interviews with the decision makers of the plant, during which pairwise judgments necessary for the use of AHP were preformed, assisted by the fundamental scale of Saaty (1980). In addition, we used forms filled out by the researcher that were available for consultation by decision makers to assist these judgments. Both interviews and forms are examples of questioning techniques (Gil, 2002). However, because of the flexible nature of the interview and the need to simultaneously fill in the form, we selected the joint application of both to avoid judgment that proved unsatisfactory.

We used the Row Geometric Mean Method (RGMM) to obtain the priority vectors for data analysis. The geometric consistency index (GCI) was used to assess the consistency of judgments. We based the method's choice on the practical applicability of the RGMM and the considerations made by Brunelli (2015), as already reported in the theoretical framework of this study. Data were analyzed using Microsoft Excel®.

AHP

AHP structures a complex decision process in hierarchical decision criteria and their associated priorities, balancing the interactions between the criteria and synthesizing the information in a priority vector representing the preferences among alternatives (Elleuch et al., 2019). It handles complex decisions that involve tangible and intangible elements (Dong et al., 2017).

In general terms, the AHP is a measurement theory used to obtain ratio scales from paired comparisons, either discrete or continuous, in hierarchical structures of various levels. These comparisons can be obtained from actual measurements or a fundamental scale that reflects the relative strength of preferences (Saaty & Vargas, 2012).

The fundamental scale allows comparisons to indicate how much more essential or dominant one element is over another concerning the defined criteria or properties. In cases of intermediate importance, we can use two, four, six, or eight values. Table 1 presents the fundamental scales used in this study.

TABLE 1. Saaty Fundamental Scale. Adapted from Saaty & Vargas (2012).

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
7	Very Strong importance	An activity is favored strongly over another; its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible affirmation order.

Hierarchical structure

The corresponding data were collected from specialists and decision makers through pairwise comparisons between alternatives with the aid of the fundamental scale, as illustrated in Table 1. Because two components are simultaneously considered, the conceptual complexity of the problem is reduced by pairwise comparison (Thomas & Reghunath, 2020).

The generated pairwise comparisons were placed in the square matrix

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

The diagonal elements of the matrix correspond to 1. If the value of the element (i,j) is >1, the criterion in the i^{th} row is better than the criterion in the j^{th} column. Alternatively, the criterion in column j is better than that in row i because the element (j,i) of the matrix is the reciprocal of the element (i,j); that is, if $a_{ij} = S$ represents the importance of criterion i over criterion j, then $a_{ji} = 1/S$.

Once the matrix is established, its priority vector must be obtained. There are several ways to obtain such a vector (Saaty & Vargas, 2012). The prioritization method estimates the priority vector $w = (w_1, \cdots, w_n)^T$, where $w_i \geq 0$ and $\sum_{i=1}^{n} w_i = 1$. The two most widely used methods are the eigenvalue method and the RGMM (Dong et al., 2008).

Prioritization method

While Saaty (1980) proposed using the eigenvalue method, emphasizing consistency, Barzilai (1997) defended the use of the RGMM, exposing problems in the application of the eigenvalue method, such as the multifaceted indeterminacy of solutions, rank reversal phenomena, scale transformations, and order of operations. Dong et al. (2008) and Herman & Koczkodaj (1996) demonstrated that the effects of these two prioritization methods are very similar. Dong et al. (2010) also stated that the processing time of the eigenvalue method corresponds to $O(n^2)$ whereas that of the RGMM corresponds to $O(n)$. Therefore, the RGMM has a shorter processing time.

Brunelli (2015) also highlighted the attractiveness of the RGMM for practical applications, considering how weights are expressed as analytic functions of the matrix's input. In addition, even the final weights of the entire hierarchy can be described as analytic expressions of the input of all matrices involved in the hierarchy, enabling certain types of sensitivity analyses to be performed efficiently. The RGMM is used in this study.

RGMM

As proposed by Crawford & Williams (1985), by using the RGMM, each component of the priority vector *w* is obtained by the geometric mean of the elements of the respective row of **A** divided by a normalization factor, thus ensuring that the sum of all components of *w* is equal to 1. The method for obtaining the element w_i is given as

$$w_i = \frac{(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\sum_{i=1}^{n} (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}} \tag{2}$$

where the normalization term is represented by

$$\sum_{i=1}^{n} (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}} \tag{3}$$

Furthermore, the priority vector *w* obtained through the RGMM can be equivalently determined, as demonstrated by Crawford & Williams (1985), as the following optimization problem:

$$\text{minimize} \sum_{i=1}^{n} \sum_{j=1}^{n} (\ln a_{ij} + \ln w_j - \ln w_i)^2 \tag{4}$$

subject to

$$\sum_{i=1}^{n} w_i = 1, \;\; w_i > 0 \; \forall i \tag{5}$$

where $(w_1, \cdots, w_n)$ are taken as decision variables.

Both the eigenvalue method and the RGMM allow the consistency of judgments to be measured. Therefore, inconsistency measurements can be used to improve the consistency of judgments (Saaty & Vargas, 2012). For example, a consistent matrix's elements a_{ij} have exact values $a_{ij} = \frac{w_i}{w_j}$ and satisfy the transitivity property $a_{ij} = a_{ik} a_{kj} \; \forall \; i, j, k = 1, 2, \ldots, n$ (Srdjevic, 2005).

GCI

Crawford & Williams (1985) introduced the GCI, which was reevaluated by Aguarón & Moreno-Jiménez (2003). The latter even bequeathed the GCI nomenclature to the index and established a theoretical relationship between C.R. and GCI, tested through regression analysis. Therefore,

$$\text{GCI} = \frac{2}{(n-1)(n-2)} \sum_{i<j} \log^2 e_{ij} \tag{6}$$

The element $e_{ij} = a_{ij} \frac{w_j}{w_i} \; i, j = 1, \ldots, n$ is the local quantification of the inconsistency for each entry a_{ij}. Aguarón & Moreno-Jiménez (2003) have also proposed thresholds associated with the GCI that allow an analogous interpretation of the tolerance level of inconsistency to that first presented by Saaty (1980) for the eigenvalue method; that is, a consistent matrix has $\text{C.R.} \leq 0{,}1$. The suggested thresholds are listed in Table 2.

TABLE 2. GCI thresholds.

Matrix dimension (*n*)	Consistency thresholds	
	GCI	C.R.
n = 3	0.31	
n = 4	0.35	0.1
n > 4	0.37	

The synthesis of the constructed model establishes a global priority of the alternatives, combining them through a weighted sum considering the weight of each criterion, represented by the priority vector *w* (Pereyra-Rojas, 2018). The alternative with the highest global priority should be considered the best choice.

RESULTS AND DISCUSSION

This study was conducted in a coffee-roasting plant located in Minas Gerais (Brazil). The plant has been operating since 1978. Its main activities include roasting, grinding, selling, and distributing coffee.

The main products of this medium-sized plant are roasted coffee, roasted and ground coffee, roasted and vacuum-sealed coffee, grains, and espresso coffee. The company already has a stable supply base, but it constantly receives offers from potential new business partners. Therefore, determining the viability of new suppliers is an ongoing issue. To select a new commercial partner, the process is based mainly on the practical experience of the decision makers and on tests conducted in the laboratory.

Business reality mapping

Figure 1 depicts the primary production stages of the plant, with a focus on the production of roasted and ground coffee and roasted and vacuum-sealed ground coffee.

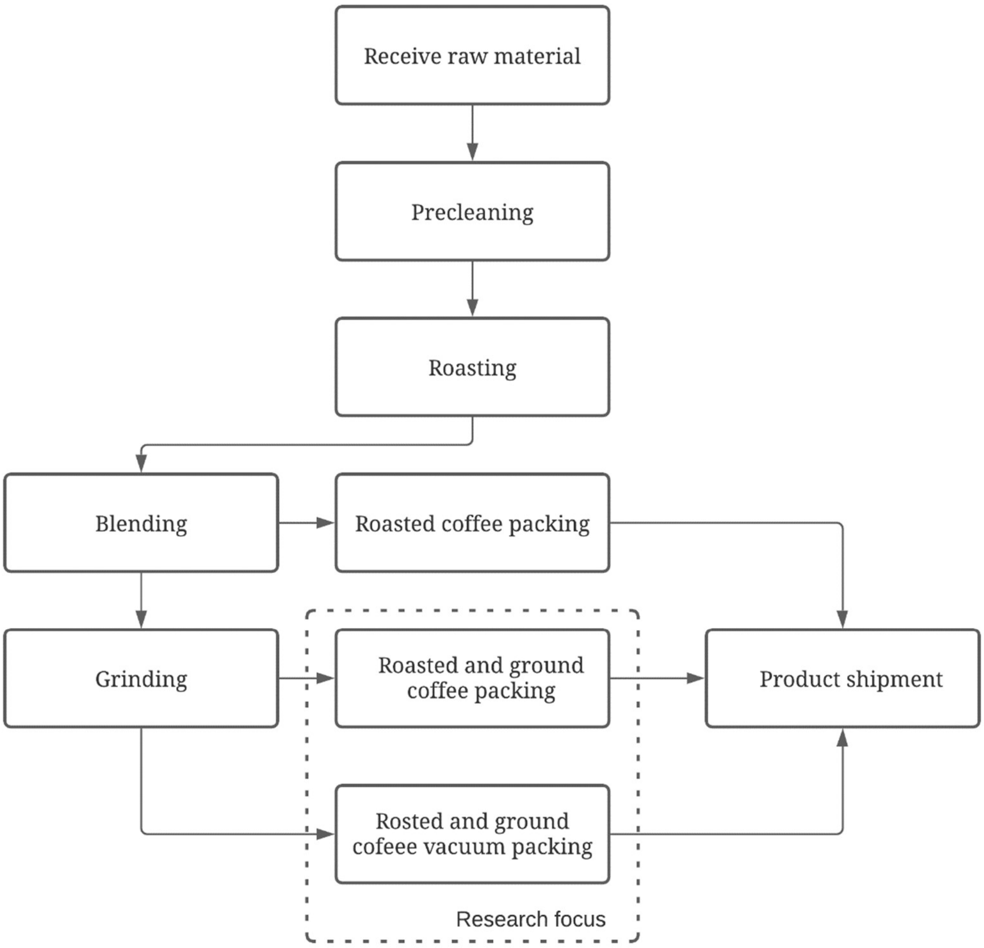

FIGURE 1.Production process.

The green coffee beans arrive in 60-kg bags and are stored as soon as they arrive at the plant. Precleaning is performed through a vibrating sieve to remove impurities from the raw material, such as sticks and stones. The coffee is then directed to the roasting sector. The roasting capacity for the green coffee is ~1600 kg/h. The percentage of coffee yield is calculated as the outgoing and incoming mass ratios. In the blending sector, different varieties of roasted coffee are mixed to form a blend according to the desired features of the final product. Its objectives include, among others, standardization of the product and cost optimization. Therefore, a specific recipe exists for each product. The blended roasted coffee is sent to packaging, while the roasted and ground coffee and the roasted and vacuum-sealed ground coffee still undergo the grinding process before being packaged.

Three types of coffee beans are used in the blend, and their primary function in the classification is adopted exclusively at the plant. Type X coffee gives the drink its classic flavor. Therefore, its flavor should stand out over other coffee varieties used in blends.

The primary function of type Y coffee is to optimize costs. It has a high percentage of cracked beans and a slightly inferior flavor to type X coffee, making it cheaper. Type Y coffee is used only in recipes intended for grinding because the intrinsic defect mentioned above prevents its use in roasted coffee, as the visual aspect is essential when it comes to ground coffee. However, broken beans do not interfere with the quality of the drink, allowing them to be used in roasted and ground coffee.

Type Z coffee has been studied and prized for its visual aspect, as it is free of extrinsic defects, that is, everything that is not coffee. However, it should be used sparingly because its quality is of a lower grade. Its primary function is to standardize the purity, that is, to keep the impurity level below that established by ABIC (ABIC, 2020b).

An eventual supplier of type X coffee must offer a coffee that produces a quality drink, making flavor an evident and essential selection criterion. However, the aim of this study was to determine the proper relationship between taste and other relevant criteria in the selection process.

Establish overall objective

The objective was to choose a new coffee supplier. Therefore, this purpose corresponds to the first level of the hierarchical structure.

Establish relevant criteria

We defined the objective and identified the relevant criteria through interviews conducted with decision makers. The criteria corresponding to the second hierarchical structure level are the percent of extrinsic defects, loss in precleaning, price, and taste. This is similar to the study by Konopatzki et al. (2019), who used the defect number, cupping test, and pricing as variables to study the price and quality of coffee dried dehumidification by convection.

The taste criterion is relevant because the primary function of type X coffee is to establish the classic flavor of the product. This function requires that coffee type X be used in abundance in the recipes produced. In addition, to avoid exceeding the impurity threshold, the presence of extrinsic defects must be low, justifying the choice of extrinsic defects as a relevant criterion.

The loss in precleaning was also identified as a criterion of importance. The presence of a measure called price represents the search for the reduction of production costs in a direct and axiomatic way.

Identify alternatives

Alternatives were identified after defining the relevant criteria. For confidentiality reasons, we designated suppliers using generic terms. Table 3 presents data related to the criteria of extrinsic defects, loss in precleaning, and price. All quantitative data were obtained from the sampling units used in the plant's laboratory, while the price refers to the minimum acquisition unit, a 60-kg bag.

TABLE 3. Quantitative criteria.

Alternatives	Criteria		
	Extrinsic defects (%)	Loss in precleaning (%)	Price (R$)
Supplier A	0.53%	0.53%	345.00
Supplier B	0.52%	0.41%	350.00
Supplier C	0.67%	0.49%	340.00
Supplier D	0.47%	0.44%	320.00

We obtained the flavor criteria using sensory analysis, for which the data were qualitative. First, the decision makers tried a small sample of coffee from each supplier. They then issued their opinions through interviews and consequent pairwise judgments between the alternatives proposed by the AHP method. The structure of the AHP method used for supplier selection is illustrated in Figure 2.

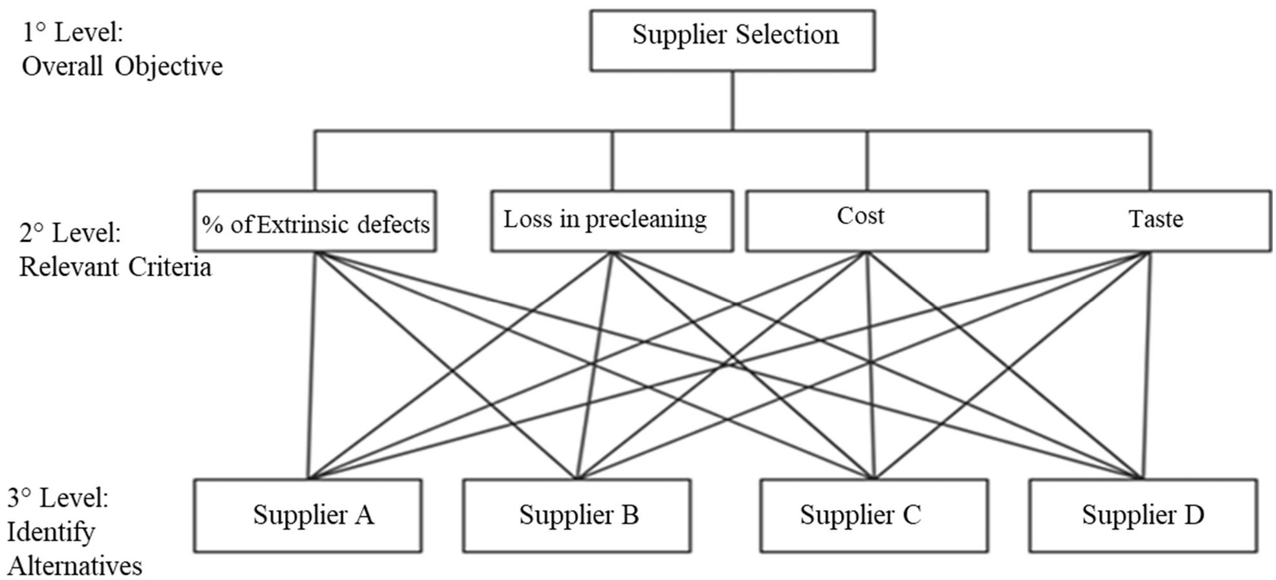

FIGURE 2. Schematic of the AHP method used for supplier selection divided into three levels: overall objective, relevant criteria, and identify alternatives.

Develop a matrix of pairwise comparison of criteria

Pairwise judgment between the criteria was then performed. This was done during the interviews and by filling out forms. Table 4 presents the results.

TABLE 4. Pairwise comparison of criteria.

Criteria	Criteria			
	Extrinsic defects	Loss in precleaning	Price	Taste
Extrinsic defects	1	5	2	1
Loss in precleaning	1/5	1	1/7	1/5
Price	1/2	7	1	1/3
Taste	1	5	3	1

Calculate normalized priority vector of criteria

The priority vector *w* was obtained using the RGMM by normalizing the geometric mean of each row of the matrix:

$$w \approx (0.3514\,, 0.0543\,, 0.2054, 0.3889)^T \qquad (7)$$

Table 5 presents the ranking of the criteria based on their importance. Again, the priority vector values were transformed into percentages for better comprehension.

TABLE 5. Criteria importance.

Criteria	Priority (weight)
Taste	38.89%
Extrinsic defects	35.14%
Price	20.54%
Loss in precleaning	5.43%

Calculate consistency of the pairwise comparison matrix

Finally, we judged the consistency of pairwise comparisons. As previously established, the GCI represents the consistency of judgments. To calculate the consistency mentioned above, matrix **E** was established:

$$\mathbf{E} \approx \begin{bmatrix} 1 & 0.77 & 1.17 & 1.11 \\ 1.29 & 1 & 0.54 & 1.43 \\ 0.86 & 1.85 & 1 & 0.63 \\ 0.9 & 0.7 & 1.58 & 1 \end{bmatrix} \qquad (8)$$

Where:

its elements $e_{ij} = a_{ij}\frac{w_j}{w_i}$ represent the local inconsistency of each element a_{ij} of matrix **A**.

The GCI was calculated using [eq. (6)]. The obtained value was GCI(**A**) ≈ 0.2734. Therefore, when comparing the value obtained with the threshold values illustrated in Table 4 for $n = 4$, judgment matrix **A** was deemed consistent because GCI $(\mathbf{A}) \leq 0.35$.

Calculate the local priority vector of alternatives concerning each criterion

The next level (third-level) calculations were then performed, judging the alternatives between themselves concerning each criterion.

The criteria extrinsic defects, loss in precleaning, and price contain quantitative data. Therefore, it was enough to harmonize and normalize them to obtain the priority vectors or local priorities, as given in Table 6.

TABLE 6. Priority vectors.

Alternatives	Normalized priority vectors (local priorities)		
	Extrinsic defects	Loss in precleaning	Price
A	0.2539	0.2184	0.2452
B	0.2588	0.2823	0.2417
C	0.2009	0.2362	0.2488
D	0.2864	0.2631	0.2643

For the taste criterion, owing to its qualitative nature, it was necessary to perform a new judgment and calculate its consistency, such as the judgment of the second-level matrix. Table 7 presents this decision.

TABLE 7. Pairwise judgment between alternatives concerning taste.

Alternatives	Alternatives			
	A	B	C	D
A	1	1/2	2	5
B	2	1	4	6
C	1/2	1/4	1	2
D	1/5	1/6	1/2	1

Therefore, the judgment matrix **S** obtained is as follows:

$$\mathbf{S} = \begin{bmatrix} 1 & 1/2 & 2 & 5 \\ 2 & 1 & 4 & 6 \\ 1/2 & 1/4 & 1 & 2 \\ 1/5 & 5 & 1/2 & 1 \end{bmatrix} \qquad (9)$$

Using the RGMM, the normalized vector of local priorities concerning taste was obtained, as listed in Table 8.

TABLE 8. Taste priority vector.

Normalized priority vector – taste	
A	0.2878
B	0.5066
C	0.1361
D	0.695

The $\mathbf{E_1}$ matrix obtained to calculate GCI(**S**) was as follows:

$$\mathbf{E_1} \approx \begin{bmatrix} 1 & 0.88 & 0.95 & 1.21 \\ 1.14 & 1 & 1{,}07 & 0.82 \\ 1.06 & 0.93 & 1 & 1.02 \\ 0.83 & 1.24 & 0.98 & 1 \end{bmatrix} \qquad (10)$$

GCI(**S**) was obtained using [eq. (10)] as follows: GCI(**S**) = 0.3282. This judgment was considered consistent because GCI$(\mathbf{S}) = 0.3282 \leq 0.35$

Calculate the global priority of each alternative

Once we delivered all the local priority vectors, it was possible to determine the global priority of each alternative from a weighted sum. The weights are the elements of the criteria-normalized priority vector. The decision matrix is presented in Table 9. The numbers were transformed into percentages to facilitate interpretation of the results.

TABLE 9. Decision matrix.

	Criteria				
Supplier	Extrinsic defects	Loss in precleaning	Price	Taste	Global priority
	35.14%	5.43%	20.54%	38.89%	
A	25.39%	21.84%	24.52%	28.78%	26.34%
B	25.88%	28.23%	24.17%	50.66%	35.29%
C	20.09%	23.62%	24.88%	13.61%	18.74%
D	28.64%	26.31%	26.43%	6.95%	19.62%

Therefore, the method indicates that supplier B should be prioritized in the selection of a new type X coffee supplier, as its global priority is more significant than all others, followed by suppliers A, D, and C.

Table 10 presents the performance of each alternative for each criterion, organizing them according to their preferences and illustrating the importance of each criterion relating to the others. The supplier selected (B) with the aid of the method is highlighted.

TABLE 10. Criteria and alternatives performance.

Criteria	Taste	Extrinsic defects	Price	Loss in precleaning
Weights	38,89%	35,14%	20,54%	38,89%
	Priority ranking			
	1st	2nd	3rd	4th
1st	B (50.66%)	D (28.64%)	D (26.43%)	B (28.23%)
2nd	A (28.78%)	B (25.88%)	C (24.88%)	D (26.31%)
3rd	C (13.61%)	A (25.39%)	A (24.52%)	C (23.62%)
4th	D (6.950%)	C (20.09%)	B (24.17%)	A (21.84%)

Supplier B is superior to the other suppliers in terms of taste, obtaining the first position quickly. Moreover, despite being the most expensive, which justifies its last position concerning the price criterion, supplier B still performs well in the second most crucial criterion, obtaining second place.

Supplier D is in the first position based on the percentage of extrinsic defects and price, and it is in the second position concerning the loss in precleaning. However, its poor performance with respect to taste, the criterion judged as the most important, makes it the third most viable option, as illustrated in Table 9, prioritized only for supplier C. Therefore, the method indicates that supplier B is the most suitable under these circumstances.

CONCLUSIONS

Making decisions in the business environment is a necessary process. However, the existence of different interests often complicates the situation. For example, selecting suppliers in a roasting plant requires both quantitative and qualitative data analyses.

This study focuses on applying the AHP method to select a new supplier for a specific type of coffee used in the blending production process. Therefore, we achieved our research objective by establishing an order of priority for the criteria and suppliers. As a result, supplier B was the leading supplier with a 35.29% priority, followed by suppliers A and D. Our findings show great potential for use as a formal method in the decision-making process in the agro-industry. Moreover, other problems in agricultural engineering can benefit from using the reasoning steps employed here.

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