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Purchase of agricultural inputs for grape production: a multicriteria-based mathematical approach

Compra de produtos agrícolas para produção de uva: uma abordagem matemática com base em multicritérios

Compra de productos agrícolas para la producción de uva: un enfoque matemático basado en multicriterios

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Abstract: *Table grapes are one of the most important commercial crops of the Lower-Middle São Francisco Valley. However, nutrient requirements of the crop, such as magnesium, and increased vine defenses through resistance inducers require careful consideration. The objective of this study was to use multicriteria methods to rank two types of agricultural inputs—magnesium sources and resistance inducers—for use on a table grape production farm in the Lower-Middle São Francisco Valley. The results enabled us to rank the best option for the magnesium source and the best resistance inducer. The study reveals that multicriteria decision making can be an important tool in the table grape production process, bringing benefits to producers, such as reduced agricultural input costs, without compromising quality in fruit development.*

Keywords: Multicriteria. AHP. TOPSIS. Grape.

Resumo: A uva de mesa é uma das culturas mais importantes do agronegócio no Vale do Submédio São Francisco, contudo, é uma cultura que exige diversos cuidados com relação aos seus nutrientes, como por exemplo o magnésio, e o aumento das defesas da videira, através dos indutores de resistência. O objetivo desse trabalho foi ranquear, através de métodos multicritérios, dois tipos de produtos agrícolas, fonte de magnésio e indutor de resistência, a serem utilizados em uma fazenda de uva de mesa no Vale do Submédio São Francisco. Os resultados obtidos neste trabalho permitiram ranquear a melhor opção para a fonte de magnésio e o melhor indutor de resistência. O estudo revela que a decisão multicritério pode ser uma ferramenta importante no processo de produção de uvas de mesa, trazendo benefícios ao produtor, como diminuição dos custos com insumos agrícolas, sem perder a qualidade no desenvolvimento do fruto.

Palavras-chave: Multicritérios. AHP. TOPSIS. Uva.

Resumen: *La uva de mesa es uno de los cultivos agroindustriales más importantes del Valle del Submédio São Francisco. Sin embargo, requiere una cuidadosa evaluación de sus nutrientes, como el magnesio, y el aumento de las defensas de la vid mediante inductores de resistencia. El objetivo de este estudio fue utilizar métodos multicriterio para clasificar dos tipos de productos agrícolas (fuentes de magnesio e inductores de resistencia) para su uso en una finca de uva de mesa en el Valle del Submédio São Francisco. Los resultados permitieron clasificar la mejor opción para la fuente de magnesio y el mejor inductor de resistencia. El estudio revela que la toma de decisiones multicriterio puede ser una herramienta importante en el proceso de producción de uva de mesa, aportando beneficios a los productores, como la reducción de los costos de los insumos agrícolas, sin comprometer la calidad del desarrollo de la fruta.*

Palabras clave: Multicriterios. AHP. TOPSIS. Uva.

Introduction

The Lower-Middle São Francisco Valley region, extending from northern Bahia to western Pernambuco, Brazil, has become a major agribusiness region by benefiting from irrigation projects made possible by the waters of the São Francisco River and from the establishment of the Parnaiba and São Francisco River Valleys Development Agency (Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba - CODEVASF). The São Francisco Valley enjoys a tropical climate and abundant sunshine throughout the year, and through the Brazilian Agricultural Research Corporation - EMBRAPA (Empresa Brasileira de Pesquisa e Agropecuária), techniques have been developed that allow crop production in this area. Annual production of nearly 1 million tons of fruit and annual revenues of nearly 2 billion Brazilian reals highlight the importance of fruit growing in the region. Grapes from the Valley represent 99% of the total volume exported by Brazil, including the Netherlands, the United Kingdom, and the United States as destinations (Sá & Lima, 2018; Nascimento, 2021; Souza Júnior et al., 2022).

The adaptation of grape cultivars to the climate of the Valley enables high yield and quality fruit. Grape breeding undertaken by EMBRAPA and other companies has increased the number of varieties available in the region, particularly of seedless grapes. Brazilian varieties include BRS Vitória and BRS Isis. According to Leão (2022), the BRS Vitória variety has a mean 120-day cycle, reddish color, and vestige of a seed, with a pleasing flavor. With a mean yield of 60 tons per hectare per year, it is nevertheless sensitive to rain at the end of its cycle, which may lead to splitting in the berry. The BRS Isis variety, in turn, exhibits a mean 105-day cycle, dark color, no seeds, and a pleasing flavor. Its yield capacity ranges from 50-60 tons per hectare per year (Leão, 2022).

During the grape production process, crop nutrition requires a great deal of attention to ensure good development. The following macro- and micronutrients are taken up by grapevines throughout the growth cycle: potassium (K), nitrogen (N), phosphorus (P), sulfur (S), magnesium (Mg), calcium (Ca), zinc (Zn), iron (Fe), boron (B), copper (Cu), and manganese (Mn). The amounts of these substances extracted and stored may vary according to factors such as the rootstock and management practices (Leão, 2020).

Grapevines are highly sensitive to magnesium deficiency, particularly in soils with some degree of acidity, and interveinal chlorosis of the leaves is one of the symptoms. Magnesium (Mg) assists in plant photosynthesis, carbohydrate transport, and pigmentation; a lack of Mg may lead to reduction in sugar content and desiccation of rachis, the darkening of which affects cluster appearance and, consequently, market value. Balanced application of fertilizers helps prevent nutrient shortages in plants (Alpendre et al., 2019; Ferreira et al., 2017; Santos, 2017; Machado & Santos, 2020).

Grapevines must not only be well-nourished, but overcome several pests to achieve full development. One way of combatting diseases is through application of agricultural chemicals, yet such products are harmful to the environment. Therefore, it is necessary to develop alternatives to these products, one alternative being resistance inducers. These products are able to stimulate plants, allowing them to protect themselves chemically and physically from some of these adversities (Cavalcanti et al, 2020; Santos & Leite, 2020).

Grapes have production costs related to labor and inputs, and the latter have been affected from the war between Ukraine and Russia. According to the Institute for Applied Economic Research (IPEA, 2022), the conflict between these two countries increased the price of several products, including agricultural inputs, with Brazil being one of the world's main importers of these products.

Ensuring good crop development while seeking alternatives to high input and production costs is a challenge, requiring decision making at several stages. Analysis of data from the company under study identified the resistance inducer it used was one of the costliest products. In addition, aiming to improve crop nutrition, the agricultural consultant on the farm recommended magnesium supplementation for the grapevines. Thus, the need arose to purchase two new products under different criteria. However, due to the large number of options on the market, choosing these inputs becomes complicated. Multicriteria decision making/analysis emerges as a tool capable of addressing this problem by using evaluations and calculations to define the most suitable products for the farm to acquire.

Multicriteria decision making/analysis allows agricultural product choices to be made not only regarding fertilization inputs, but also concerning other products. The aim is to resolve several types of problems through mathematical models by considering the criteria involved in the decision process. Using its various methods, it is possible to evaluate the market options that best fit the reality of the farm, seeking alternatives that meet all the criteria under analysis (Pereira, 2019; Knierim, 2021). Therefore, the aim of this study was to use multicriteria methods to rank two types of agricultural products, magnesium sources and resistance inducers, to be used on a table grape production farm in the Lower-Middle São Francisco Valley in Petrolina, PE, Brazil.

Theoretical elements of the study

Multicriteria Decision Making/Analysis aims to identify the best possible solution to a problem according to criteria defined together with the decision-maker and applied through one of the methods, which are selected based on the purpose and requirements presented by the problem under analysis

(Jacomini, 2022). According to Gonçalves, Pinheiro, & Freitas (2003, p. 2), the key elements in the decision-making processes are:

> "1) to obtain answers to questions faced by a decision-maker in a decision-making process; 2) to provide transparency to any potential decision; and 3) to increase the consistency among the evolution of a decision-making process, its aims, and the value system underlying the process."

There are several methods for solving decision problems and they are divided into two major schools: the American school, which is more objective and is called Multicriteria Decision Making (MCDM), and the European school called Multi Criteria Decision Analysis (MCDA), which adopts a more subjective approach to decision-making problems (Souza & Jerônimo, 2015; Santos et al., 2025). The Multicriteria decision methods standardize decision making through mathematical modeling, where each method has its own specific model within its family, whether it be the single synthesis criterion, outranking, or interactive approach. Among the most widely known methods are the Analytic Hierarchy Process (AHP); PROMETHEE; ELECTRE I, II, and TRI; FITRADEOFF; and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), among other methods (Guarnieri, 2015).

Analytic Hierarchy Process (AHP)

The AHP is a simple and practical method developed by Thomas Lorie Saaty that can be used on a wide range of problems, whether qualitative or quantitative. In this method, problems are structured hierarchically to facilitate decision making, in which criteria and alternatives are compared and evaluated by the decision-maker using the Saaty scale (Souza et al., 2022). According to Leite et al. (2021), the Saaty scale represents the degree of importance of one criterion over another for the decision-maker, with values ranging from 1 to 9.

It should be noted that the most important element in the comparison is always assigned an integer value from the scale, while the least important is the reciprocal of that value (Silva, 2007). If the row element is less important than the column element in the matrix, the reciprocal value is entered in the corresponding position of the matrix.

According to Pereira et al. (2022), the algorithm of the AHP method is defined by the following steps:

- Definition of the evaluation matrix:

$$X = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{1n} & \cdots & a_{xn} \end{bmatrix}$$

- Normalization of the decision matrix and calculation of the priority vector:

$$W_i = \left(\prod_{j=1}^{n} w_{ij}\right)^{\frac{1}{n}} \quad (1)$$

$$T = \frac{w_1}{\sum w_i} \quad (2)$$

- Calculation of λmax:

$$\lambda\text{max} = \text{T} \times \text{W} \quad (3)$$

- Calculation of the consistency index (CI):

$$CI = \frac{\lambda\text{max} - \text{n}}{(n-1)} \quad (4)$$

- Calculation of the consistency ratio (CR):

$$CR = \frac{CI}{CA} \quad (5)$$

The result of CR must not exceed 0.10 (10%). If that occurs, a new evaluation must be performed. The value of the Consistent Average (CA) is a random index that varies according to the size of the matrix, and it is tabulated in the literature (Pereira et al., 2022).

Technique for order of preference by similarity to ideal solution (TOPSIS)

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method allows the ranking and selection of alternatives and was proposed by Hwang & Yoon (1981). TOPSIS forms the positive ideal solution (the best results possible from each alternative) and the negative ideal solution (the worst values among the options) to then rank and choose the alternatives that are as near as possible to the positive ideal solution and farthest from the negative ideal solution (Lima & Carpinetti, 2015).

According to Ishizaka & Nemery (2013), the algorithm of the TOPSIS method is defined by the following steps:

- Definition of the decision matrix with n alternatives and m criteria. X = (x_{ia}), where i = 1,…,m and a = 1,...,n.
- Normalization of the matrix using Equation (6):

$$r_{ia} = \frac{x_{ia}}{\sqrt{\sum_{a=1}^{n} x_{ia}^2}}, \text{ where, } a = 1,....,n \text{ and } i = 1,...,m. \quad (6)$$

- Weighting of the normalized matrix: multiplication of the normalized value r_{ia} by its respective weight w_i.

$$v_{ia} = w_i \times r_{ia} \quad (7)$$

- Determination of the positive and negative ideal solutions:

$$A^+ = (v_1^+, \dots, v_m^+) \quad (8)$$

$$A^- = (v_1^-, \dots, v_m^-) \quad (9)$$

where $v_1^+ = max_a(v_{ia})$ for a maximization criterion, and $v_1^- = min_a(v_{ia})$ for a minimization criterion.

- Calculation of the distances from the ideal solutions:

$d_a^+ = \sqrt{\sum_i (v_i^+ - v_{ia})^2}$, where a = 1,...,$m$ (10)

$d_a^- = \sqrt{\sum_i (v_i^- - v_{ia})^2}$, where a = 1,...,$m$ (11)

- Calculation of relative closeness:

$$C_a = \frac{d_a^-}{d_a^+ - d_a^-} \quad (12)$$

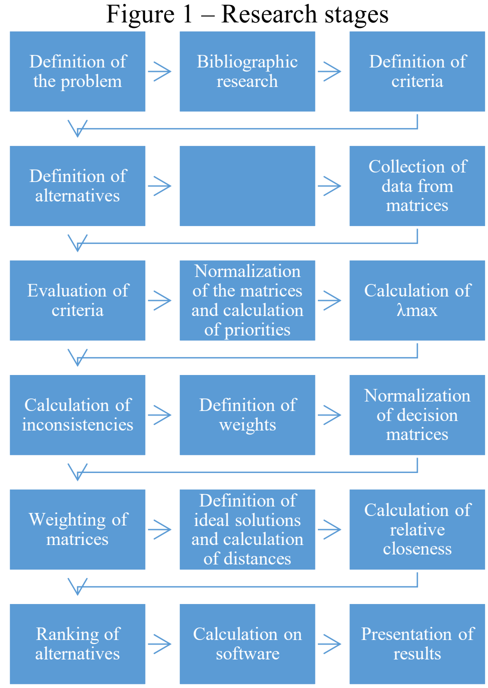
Following all the above steps, it is possible to arrive at the best values among the options selected and thus rank them according to their relative closeness.

Methodological elements of the study

The study was conducted on a small farm in the Madre Tereza Project in Petrolina, PE, which produces table grapes of the BRS Vitória and BRS Isis varieties for export and the domestic market. This is an applied, quantitative, bibliographic, and case study.

This study is divided into 17 stages (Figure 1), beginning with definition of the problem to be addressed (Step 1), followed by a bibliographic review (Step 2) as a foundation and context for the study.

Figure 1 – Research stages



Source: Prepared by the authors (2024)

After the first two stages, the criteria to be used were chosen together with the decision-maker (company owner) and the agricultural consultant responsible for prescribing the products required for the soil and crop quality to be in optimal conditions, that is, well-nourished and free of disease.

The products considered have technical characteristics outside of the scope of knowledge of production engineering, requiring the participation of a qualified and experienced professional, in this case, the agricultural consultant of the farm. Since this professional works with these products on other farms, this know-how allows accurate assessment of what each one of these products is able to deliver.

Next, alternatives were chosen, once more with the assistance of the consultant, prioritizing the best options on the market according to the needs and reality of the farm. The input brands were differentiated using the designations Product A, B, C, D, and E for the magnesium source, and Product 1, 2, 3, and 4 for the resistance inducer. Subsequently, data were collected for the decision matrices through consultations with suppliers (issues of price, delivery time, and payment terms) along with the consultant (technical questions regarding products) and through evaluations made by the owner of the organization using the Likert scale.

After definition of the decision matrix, the weights of the criteria were determined using the AHP method, which was performed as follows: evaluation of the criteria by the decision-maker using the Saaty scale; normalization of the matrices and calculation of the priority vectors; calculation of the λmax; and calculation of the inconsistencies (which aim to evaluate the consistency of the results), as shown in Equations (1) to (5).

After application of the AHP, the TOPSIS method was used through the following stages: normalization of the decision matrices; weighting of the matrices; definition of the ideal solutions; calculation of distances; calculation of relative closeness; and ranking of the options, as shown in Equations (6) to (12). All calculations were performed on Microsoft Excel and validated on free 3DM software from the Instituto Militar de Engenharias (IME), developed by Bozza et al. (2020). The values obtained were compared and then presented to the decision-maker. The use of the AHP and TOPSIS methods proved to be suitable in other studies, such as in Caiado et al. (2016) and Tedesco et al. (2019). In addition, according to the same authors, AHP enables evaluation of the criteria to obtain the priorities, eliminating the need for the decision-maker to arbitrarily assign criteria weights, whereas TOPSIS makes it possible to work with quantitative criteria through aiming to rank the alternatives under analysis, which is the aim of this study.

Presentation and discussion of the results

After the initial stages, the criteria to be analyzed were defined, indicating whether they were to be maximized or minimized. Some criteria, such as cost, are preferentially as low as possible, whereas for criteria such as product effectiveness, the ideal is to be as high as possible.

The magnesium source input included the following criteria:

- Magnesium concentration: considering that magnesium is the substance that needs to be supplemented in grapevines, the higher its concentration, the better for the producer;
- Dosage: the lower the dosage of a product, the lower its cost per application, constituting a criterion to be minimized;
- Flexibility of payment terms (payment deadline or even possible discounts): for a smaller company, as in this case, greater payment flexibility helps maintain a healthy cash flow;
- Product effectiveness: product quality must be maximized; therefore, the greater its effect, the

better its result;

- Cost: the lower the product cost, the better for financial health. This is a classic criterion for minimization;
- Delivery (quality, reliability, and delivery time): having the right product, at the right time and without packaging problems ensures that its application schedule will not be affected (delayed or postponed). Therefore, the greater the delivery strength of the supplier, the better;
- Yield: the number of applications that the product provides. The greater the yield, the better, and as such, this is a criterion for maximization.

For the resistance inducer, the criteria were identical, except for magnesium concentration, which does not apply to this type of product. The alternatives were defined with the assistance of the agricultural consultant, prioritizing the products that deliver the necessary quality to the producer and that have already achieved credibility in the market.

To define the weight of each criterion, the AHP method was used, beginning with data collection to construct the evaluation matrix. The criteria were evaluated by the decision-maker using the Saaty scale, comparing each criterion with the others according to their importance (values ranging from 1 to 9) to finally arrive at the weight of each criterion. The results of this evaluation are shown in Table 1.

Table 1 – Magnesium source evaluation matrix

	Magnesium concentration (w/v %)	Dosage (L ha⁻¹)	Payment flexibility	Product effectiveness	Cost (R$ L⁻¹)	Delivery (Reliab/Qual)	Yield (No. of applic L⁻¹)
Magnesium concentration (w/v %)	1.00	7.00	3.00	0.14	1.00	7.00	7.00
Dosage (L ha⁻¹)	0.14	1.00	0.20	0.11	0.14	1.00	0.50
Payment flexibility	0.33	5.00	1.00	0.14	0.25	6.00	3.00
Product effectiveness	7.00	9.00	7.00	1.00	6.00	9.00	7.00
Cost (R$ L⁻¹)	1.00	7.00	4.00	0.17	1.00	9.00	5.00
Delivery (Reliab/Qual)	0.14	1.00	0.17	0.11	0.11	1.00	0.33
Yield (No. of applic L⁻¹)	0.14	2.00	0.33	0.14	0.20	3.00	1.00

Source: Prepared by the authors (2023).

The diagonal of Tables 1 and 2 is filled in with the value of 1, since it is a comparison between the same criteria; thus, it indicates equivalent importance. In the other evaluations, product effectiveness stands out, which received a score of 9 (absolute) compared to dosage and delivery, and 7 (very strong) in relation to magnesium concentration and payment flexibility. In both Table 3 and Table 4, product effectiveness, cost, payment flexibility, and magnesium concentration (a criterion specific to the magnesium source) were the most highly rated criteria compared to the others. In other words, from the decision-maker's perspective, these criteria are more important than the others.

Table 2 – Resistance inducer evaluation matrix

	Dosage (L ha⁻¹)	Payment flexibility	Product effectiveness	Cost (R$ L⁻¹)	Delivery (Reliab/Qual)	Yield (No. of applic L⁻¹)
Dosage (L ha⁻¹)	1.00	0.20	0.11	0.14	1.00	0.50
Payment flexibility	5.00	1.00	0.14	0.25	6.00	3.00
Product effectiveness	9.00	7.00	1.00	6.00	9.00	7.00
Cost (R$ L⁻¹)	7.00	4.00	0.17	1.00	9.00	5.00
Delivery (Reliab/Qual)	1.00	0.17	0.11	0.11	1.00	0.33
Yield (No. of applic L⁻¹)	2.00	0.33	0.14	0.20	3.00	1.00

Source: Prepared by the authors (2023).

After defining the matrix, it was normalized so that its values ranged from zero to one, where each cell of the column is divided by the sum of the column. Subsequently, the priority vectors were calculated, which are the weights of the criteria, through the arithmetic mean of each row of the matrix. The normalized matrix, as well as the weights of the criteria, are shown in Tables 3 and 4.

Table 3 – Normalized matrix and priority vectors of the magnesium source

	Magnesium concentration (w/v %)	Dosage (L ha⁻¹)	Payment flexibility	Product effectiveness	Cost (R$ L⁻¹)	Delivery (Reliab/Qual)	Yield (No. of applic L⁻¹)	Priority Vector
Magnesium concentration (w/v %)	0.10	0.22	0.19	0.08	0.11	0.19	0.29	0.17
Dosage (L ha⁻¹)	0.01	0.03	0.01	0.06	0.02	0.03	0.02	0.03
Payment flexibility	0.03	0.16	0.06	0.08	0.03	0.17	0.13	0.09
Product effectiveness	0.72	0.28	0.45	0.55	0.69	0.25	0.29	0.46
Cost (R$ L⁻¹)	0.10	0.22	0.25	0.09	0.11	0.25	0.21	0.18
Delivery (Reliab/Qual)	0.01	0.03	0.01	0.06	0.01	0.03	0.01	0.02
Yield (No. of applic L⁻¹)	0.01	0.06	0.02	0.08	0.02	0.08	0.04	0.05

Source: Prepared by the authors (2023).

For the magnesium source, the criteria with the greatest weights were product effectiveness (0.46), cost (0.18), magnesium concentration (0.17), and payment flexibility (0.09). Dosage, delivery, and yield were considered less important from the decision-maker's perspective.

Table 4 – Normalized matrix and priority vectors of the resistance inducer

	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})	Priority Vector
Dosage (L ha^{-1})	0.04	0.02	0.07	0.02	0.03	0.03	0.03
Payment flexibility	0.20	0.08	0.09	0.03	0.21	0.18	0.13
Product effectiveness	0.36	0.55	0.60	0.78	0.31	0.42	0.50
Cost (R$ L^{-1})	0.28	0.31	0.10	0.13	0.31	0.30	0.24
Delivery (Reliab/Qual)	0.04	0.01	0.07	0.01	0.03	0.02	0.03
Yield (No. of applic L^{-1})	0.08	0.03	0.09	0.03	0.10	0.06	0.06

Source: Prepared by the authors (2023).

In evaluation of the resistance inducer, the main criteria were product effectiveness (0.50), cost (0.24), and payment flexibility (0.13). In other words, for the decision-maker and company owner, product effectiveness and cost are very important at the time of deciding on and selecting inputs, for both the magnesium source and the resistance inducer. After calculating the priorities, subsequent steps were determination of λmax and the inconsistencies of the values. These determinations were made by multiplying the weighted sum of each row of the matrix by the respective priority vector, and then calculating the arithmetic mean of the results of these multiplications to obtain the λmax (Table 5).

Table 5 – Calculation of λmax for the magnesium source

	Magnesium concentration	Dosage	Payment flexibility	Product effectiveness	Cost	Delivery	Yield	Weighted sum	Priority	Sum/Priority
Magnesium concentration	0.17	0.18	0.28	0.07	0.18	0.17	0.33	1.38	0.17	8.07
Dosage	0.02	0.03	0.02	0.05	0.03	0.02	0.02	0.19	0.03	7.34
Payment flexibility	0.06	0.13	0.09	0.07	0.04	0.15	0.14	0.68	0.09	7.27
Product effectiveness	1.19	0.24	0.65	0.46	1.06	0.22	0.33	4.16	0.46	9.02
Cost	0.17	0.18	0.37	0.08	0.18	0.22	0.23	1.44	0.18	8.10
Delivery	0.02	0.03	0.02	0.05	0.02	0.02	0.02	0.18	0.02	7.21
Yield	0.02	0.05	0.03	0.07	0.04	0.07	0.05	0.33	0.05	7.10
									λmax =	7.73

Source: Prepared by the authors (2023)

The λmax values can be seen in Tables 6 and 7. These values will be used to calculate the CI and CR, which can be performed using Equations (4) and (5) (Tables 7 and 8).

Table 7 – Calculation of the consistency index and of the consistency ratio for the magnesium source

N =	7	Matrix order
CI =	0.12	Consistency index
CR =	0.09	Consistency ratio

Source: Prepared by the authors (2023).

As the matrix of the magnesium source is of order 7, the CA value, according to Table 2, is 1.32. The consistency ratio for the magnesium source was 0.09, which is below the threshold of 0.10; therefore, the results can be considered consistent.

Table 8 – Calculation of λmax for the resistance inducer

	Dosage	Payment flexibility	Product effectiveness	Cost	Delivery	Yield	Weighted sum	Priority	Sum/Priority
Dosage	0.03	0.03	0.06	0.03	0.03	0.03	0.21	0.03	6.24
Payment flexibility	0.17	0.13	0.07	0.06	0.19	0.19	0.81	0.13	6.22
Product effectiveness	0.31	0.91	0.50	1.43	0.28	0.44	3.88	0.50	7.72
Cost	0.24	0.52	0.08	0.24	0.28	0.32	1.68	0.24	7.05
Delivery	0.03	0.02	0.06	0.03	0.03	0.02	0.19	0.03	6.08
Yield	0.07	0.04	0.07	0.05	0.09	0.06	0.39	0.06	6.13
								λmax=	6.57

Source: Prepared by the authors (2023)

To calculate the consistency ratio of the resistance inducer, a CA value of 1.24 was used, since the matrix is of order 6. If the CR values exceed the threshold of 10%, a new round of evaluation with the decision-maker is necessary until the inconsistency is eliminated (Table 9).

Table 9 – Calculation of the consistency index and consistency ratio for the resistance inducer

N =	6	Matrix order
CI =	0.11	Consistency index
CR =	0.09	Consistency ratio

Source: Prepared by the authors (2023)

The consistency ratio of the resistance inducer was 0.09, within the threshold value. As re-evaluation was not required, the weights obtained were validated and defined, and it was possible to proceed to the next stage. After definition of weights by the AHP method, the application of TOPSIS began, with the first step being collection of data for the decision matrices. The more technical criteria, such as product effectiveness, magnesium concentration, dosage, and yield, were obtained from the agricultural consultant and the product labels. The input costs were quoted by their suppliers. Payment flexibility and delivery were evaluated by the decision-maker using the Likert scale with scores from one to five, according to what each supplier offered. The values obtained are shown in Tables 10 and 11.

Table 10 – Magnesium source decision matrix

	Magnesium concentration (w/v %)	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})
	MAX	MIN	MAX	MAX	MIN	MAX	MAX
Product A	10.40	1.00	4.00	4.00	15.00	4.00	1.00
Product B	7.98	2.00	3.00	3.00	17.75	3.00	0.50
Product C	10.42	1.00	4.00	4.00	8.50	4.00	1.00
Product D	30.00	0.50	5.00	5.00	80.00	2.00	2.00
Product E	2.52	0.50	4.00	5.00	70.00	4.00	2.00

Source: Prepared by the authors (2023)

For the magnesium source, Product D exhibited the highest magnesium concentration and a minimum dosage, along with Product E. Regarding cost, Product C was least expensive. Products D and E also stood out in the effectiveness criterion, receiving an excellent evaluation.

Table 11 – Resistance inducer decision matrix

	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})
	MIN	MAX	MAX	MIN	MAX	MAX
Product 1	0.50	5.00	1.00	125.00	2.00	2.00
Product 2	1.00	5.00	3.00	49.00	2.00	1.00
Product 3	0.50	3.00	3.00	41.00	4.00	2.00
Product 4	1.00	2.00	2.00	129.90	3.00	1.00

Source: Prepared by the authors (2023)

For the resistance inducer, Product 3 was the least expensive, while also presenting the best delivery quality. Products 1 and 2 had excellent payment flexibility. In the effectiveness criterion, Products 2 and 3 received the best evaluations. Based on the collected data, normalization and weighting of the matrices were performed using formulas (6) and (7). Tables 12 and 13 show the values of the already weighted matrices, where their normalized values were multiplied by the respective weights of the criteria obtained from the previous method.

Table 12 – Weighted matrix for the magnesium source

	Magnesium concentration (w/v %)	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})
Product A	0.0515	0.0104	0.0413	0.1933	0.0244	0.0126	0.0145
Product B	0.0395	0.0207	0.0310	0.1450	0.0289	0.0094	0.0073
Product C	0.0516	0.0104	0.0413	0.1933	0.0138	0.0126	0.0145
Product D	0.1485	0.0052	0.0516	0.2417	0.1301	0.0063	0.0290
Product E	0.0125	0.0052	0.0413	0.2417	0.1138	0.0126	0.0290

Source: Prepared by the authors (2023)

The values obtained in the weighted matrices are required for the subsequent calculations and stages. The positive and negative ideal solutions are determined based on these values.

Table 14 – Weighted matrix for the resistance inducer

	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})
Product 1	0.0108	0.0821	0.1047	0.1559	0.0109	0.0401
Product 2	0.0216	0.0821	0.3142	0.0611	0.0109	0.0200
Product 3	0.0108	0.0492	0.3142	0.0512	0.0218	0.0401
Product 4	0.0216	0.0328	0.2094	0.1621	0.0164	0.0200

Source: Prepared by the authors (2023)

The subsequent stages were definition of the ideal solutions, calculation of distances and of relative closeness, and the ranking of alternatives. These determinations were made using formulas (8), (9), (10), (11), and (12). Tables 14 and 15 show the results.

Table 14 – Ideal solutions, distances, relative closeness, and ranking for the magnesium source

<table>
<tr><th></th><th>Magnesium concentration (w/v %)</th><th>Dosage (L ha^{-1})</th><th>Payment flexibility</th><th>Product effectiveness</th><th>Cost (R$ L^{-1})</th><th>Delivery (Reliab/Qual)</th><th>Yield (No. of applic L^{-1})</th></tr>
<tr><td>A+</td><td>0.15</td><td>0.01</td><td>0.05</td><td>0.24</td><td>0.01</td><td>0.01</td><td>0.03</td></tr>
<tr><td>A-</td><td>0.01</td><td>0.02</td><td>0.03</td><td>0.14</td><td>0.13</td><td>0.01</td><td>0.01</td></tr>
<tr><td colspan="4">DISTANCES</td><td colspan="4">RELATIVE CLOSENESS/RANKING</td></tr>
<tr><td></td><td colspan="2">D+</td><td>D-</td><td></td><td colspan="2">Relative closeness</td><td>Ranking</td></tr>
<tr><td>Product A</td><td colspan="2">0.11</td><td>0.12</td><td>Product A</td><td colspan="2">0.53</td><td>3</td></tr>
<tr><td>Product B</td><td colspan="2">0.15</td><td>0.10</td><td>Product B</td><td colspan="2">0.41</td><td>4</td></tr>
<tr><td>Product C</td><td colspan="2">0.11</td><td>0.13</td><td>Product C</td><td colspan="2">0.55</td><td>2</td></tr>
<tr><td>Product D</td><td colspan="2">0.12</td><td>0.17</td><td>Product D</td><td colspan="2">0.59</td><td>1</td></tr>
<tr><td>Product E</td><td colspan="2">0.17</td><td>0.10</td><td>Product E</td><td colspan="2">0.38</td><td>5</td></tr>
</table>

Source: Prepared by the authors (2023).

Analysis of the results showed that the best option for the magnesium source was Product D, with a relative closeness of 0.59, followed by Products C (0.55), A (0.53), B (0.41), and E (0.38).

Table 15 – Ideal solutions, distances, relative closeness, and ranking for the resistance inducer

	Dosage (L ha^{-1})	Payment flexibility	Product effectiveness	Cost (R$ L^{-1})	Delivery (Reliab/Qual)	Yield (No. of applic L^{-1})
A+	0.01	0.08	0.31	0.05	0.02	0.04
A-	0.02	0.03	0.10	0.16	0.01	0.02

DISTANCES			RELATIVE CLOSENESS/RANKING		
	D+	D-		Relative closeness	Ranking
Product 1	0.23	0.05	Product 1	0.19	4
Product 2	0.03	0.24	Product 2	0.90	1
Product 3	0.03	0.24	Product 3	0.88	2
Product 4	0.16	0.10	Product 4	0.39	3

Source: Prepared by the authors (2023)

For the resistance inducer, the results showed that the first option was Product 2, with a relative closeness of 0.90, followed by options 3 (0.88), 4 (0.39), and 1 (0.19). After calculations were made on Microsoft Excel, the data were validated on the 3DM software. The results obtained were identical to those from the spreadsheet developed with the aid of the algorithms of the methods. Table 16 shows the software values.

Table 16 – Results obtained using the 3DM software

Magnesium source					
Distances			Relative closeness/Ranking		
Alternative	D+	D-			
Product A	0.1103	0.1251	Product D	1º	0.5904
Product B	0.1503	0.1062	Product C	2º	0.5506
Product C	0.1097	0.1344	Product A	3º	0.5314
Product D	0.118	0.1701	Product B	4º	0.4139
Product E	0.1696	0.1028	Product E	5º	0.3772
Resistance inducer					
Distances			Relative closeness/Ranking		

Alternative	D+	D-			
Product 1	0.2344	0.0546	Product 2	1º	0.8972
Product 2	0.0272	0.2376	Product 3	2º	0.8794
Product 3	0.0328	0.2389	Product 4	3º	0.3927
Product 4	0.1621	0.1048	Product 1	4º	0.1888

Source: Prepared by the authors (2023)

Although it was the most expensive option among the magnesium sources, Product D had the highest concentration of Mg, as well as excellent effectiveness and optimal payment flexibility. In addition, it requires a lower dosage compared with the other products. Despite its high price, Product D delivers the desired quality (good magnesium supplementation), as well as positive performance in the remaining criteria; it is thus a good purchase option for the company.

In the decision regarding the resistance inducer, Product 2 had the second lowest cost, with average effectiveness and excellent payment flexibility, very near to Product 3. The company wishes to replace the inducer they currently use due to its cost. However, it cannot compromise quality or the other criteria. Therefore, Product 3 has characteristics that justify its purchase.

Final Considerations

Observation of the applications of the AHP and TOPSIS methods, together with the results obtained, confirms how selection of the most suitable alternative for the two inputs, both the magnesium source and the resistance inducer, has become a clearer process. This occurs because these methods allow determination of the importance of each criterion in the selection process, the options available, and the preferences of the decision-maker, ultimately enabling the best alternatives to be ranked through combination of these factors.

Therefore, this study demonstrates how useful multicriteria decision making can be for companies. When well applied, it carries benefits for organizations in solving complex problems, whether they be in making strategic decisions, selecting inputs for industrial or agricultural production, or reducing costs in production processes. Thus, in this study, it was possible to confirm the importance of MCDA in two situations: first, reducing costs associated with a resistance inducer, and second, supplementing the magnesium source to improve nutrition of the crop. Suggestions for future studies are to analyze new scenarios, analyze the sensitivity of the criteria, and check whether the agricultural product alternatives were, in practice, good choices for the decision-maker.

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