Journal of Food Composition and Analysis 130 (2024) 106126

Contents lists available at ScienceDirect

Journal of Food Composition and Analysis

journal homepage: www.elsevier.com/locate/jfca

Multi-criteria decision analysis applied to Brazilian grapevine genotype selection

Matheus Sandrey Costa de Matos Lessa [a], Thiago Magalhães Amaral [b,*,1], Patrícia Coelho Souza Leão [c], Jefferson T. Oliva [d]

[a] Universidade Federal do Vale do São Francisco, Avenida José de Sá Maniçoba, s/n – Centro, Petrolina, PE CEP 56304-205, Brazil
[b] Universidade Federal do Vale do São Francisco, Avenida José de Sá Maniçoba, s/n – Centro, Petrolina, PE CEP 56304-205, Brazil
[c] Embrapa Semiárido, Rodovia BR-428, Km 152, s/n - Zona Rural, Petrolina, PE 56302-97, Brazil
[d] Universidade Tecnológica Federal do Paraná, Via do Conhecimento, Km 1 - Caixa Postal 571, Pato Branco, PR CEP 85503-390, Brazil

ARTICLE INFO

Keywords:
Grape genotypes
Promethee
Multi-Criteria Decision Analysis
Grape
Decision Making
Decision

ABSTRACT

Developing new table grape cultivars that exhibit high yield and superior fruit quality is imperative to meet the escalating demands of the consumer market in the Lower-Middle São Francisco River Valley. The primary objective of Embrapa Semiárido's Active Germplasm Banks (AGB) for grapes is the conservation of Vitis sp. germplasm under semi-arid climatic conditions to make it available for research, particularly for the breeding and development of novel grape cultivars. This study aims to use Multi-Criteria Decision Analysis (MCDA), specifically the Preference Ranking Organization Method for Enrichment Evaluation (Promethee) II, to rank the grape genotypes of the Embrapa Semiárido's AGB, considering multiple criteria to define the primary grape varieties for the breeding program. The decision maker (DM) participated in all process stages, from validating qualitative and quantitative criteria to evaluating the criteria weights, and the decision matrix had 106 seeded and 50 seedless grape genotypes with 14 criteria. For visual analysis, we generated the GAIA Plane using the Visual Promethee Software. In the group of seeded grape cultivars, the three top-ranked genotypes were 'Italia Clone I′, 'Dona Maria', and 'Italia Muscat', while in the seedless group, the best-rated were 'BRS Ísis', 'BRS Linda', and 'BRS Morena'. Our research demonstrated, for the first time, the evaluation of grape genotypes using MCDA method with qualitative and quantitative criteria.

1. Introduction

The Lower-Middle São Francisco River Valley was the source of around 27% of the grapes produced in Brazil and represented over 94% of the grapes produced in the Northeast region of Brazil in 2020 (IBGE - Instituto Brasileiro de Geografia e Estatística, 2020). In terms of exports, the states of Bahia and Pernambuco have been dominant since 2002, accounting for approximately 99% of Brazil's grape exports and generating a significant economic impact of US$ 107 million in 2020 (MDIC – Ministério da Indústria, 2021).

In this context, the breeding of grape genotypes and the supply of new cultivars to the production sector are increasingly necessary, as grape growing is one of the most critical production chains of irrigated agriculture in the region; and decision-making involves diverse agents, alternatives, and criteria, as well as the complexity of the production process. In this context, the success of grape breeding programs depends on the genetic diversity present in the grape Active Germplasm Banks (AGB), with variability for different morphological and agronomic traits (Leão et al., 2020a).

Morphological and agronomic evaluation of grapevine genotypes highlights the cultivars with desirable traits linked to yield, number of bunches, size and shape of the bunch, berry weight and diameter, pulp texture, flavor, sugar content, the presence of seeds, and other aspects. In this sense, several criteria for evaluating organic products allows the decision maker to use Multi-Criteria Decision Analysis (MCDA) methods (Dragincic et al., 2015).

Thus, the MCDA methods evaluate alternatives according to the DM preferences, increasing the credibility of selection or ordering by considering multiple criteria (Hornická and Brožová, 2013; Ostovare and Shahraki, 2019; Tohidi et al., 2020). Among the outranking-type

* Corresponding author.
E-mail address: thiago.magalhaes@univasf.edu.br (T.M. Amaral).
[1] https://orcid.org/0000-0003-3642-5054

https://doi.org/10.1016/j.jfca.2024.106126
Received 18 September 2023; Received in revised form 2 February 2024; Accepted 23 February 2024
Available online 29 February 2024

MCDA methods, the Preference Ranking Organization Method for Enrichment (Promethee) family is quite popular due to its flexibility and ease of performance and understanding, reflecting the importance of each criterion to indicate the best ordering of alternatives through pair-by-pair comparisons (Vieira et al., 2019; Nassereddine et al., 2019; Mousavi and Lin, 2020; Tong et al., 2020; Sousa et al., 2020; Greco et al., 2021; Kheybari et al., 2021; Sotiropoulou and Vavatsikos, 2021; Wang et al., 2022; Sang et al., 2022;). An application of Best Worst Method (BWN) and extended Promethee II is applied to corn cultivation location selection for bioethanol production in Kheybari et al., (2021).

In the literature, studies were applied in the evaluation of grape genotype cultivars that use descriptive and multivariate statistical methods aided by the analysis of variance (ANOVA) and post-hoc tests, Principal Component Analysis (PCA), repeatability and heritability coefficients, and other statistical methods for genetic diversity analysis and comparative evaluation and selection of superior cultivars (Xu et al., 2017; Sales et al., 2019; Navarro et al., (2019); Leão et al., 2020b; Navarro et al., 2021).

There have been some studies on the applications of MCDA methods in agriculture and agroindustry (Siskos et al., 2001; Kalogeras et al., 2005; Passuello et al., 2012; Dragincic et al., 2015; Yalew et al., 2016; Emamzadeh et al., 2016; Lian and Ke, 2016; Caffi et al., 2017; Fabjanowicz et al., 2018; Paul et al., 2020; Bartzas and Komnitsas, 2020; Ustaoglu et al., 2021; Anupam et al., 2021; Martínez and Poveda, 2022). However, publications regarding the selection of genotypes or cultivars of agricultural species for plant breeding using multi-criteria analysis methods are rare in the literature. In contrast, there are no applications or studies of non-compensatory methods, such as the family of Promethee or *Élimination et Choix Traduisant la Realité* (ELECTRE) methods for evaluation of cultivars to solve ordering or ranking problems.

From what has been stated, the problem arises: how to select and rank grape genotypes for *fresh grape* consumption that are conserved in the Embrapa Semiárido's AGB using the outranking method and considering qualitative and quantitative criteria?

Thus, the present study aims to apply the PROMETHE II method to order and select table grape genotypes from mean data obtained from 2002 to 2020 of morphological and agronomic and physical-chemical variables of the fruit of a group of table grape genotypes conserved in the Embrapa Semiárido's AGB.

We selected the Promethee II method in this study because it can address situations where decisions are based on evaluating alternatives considering multiple criteria. Its flexibility also influenced its choice, being applied to several contexts and problems. This method is attributed to its capability to incorporate the decision maker's preferences, conduct sensitivity analysis, and provide clear and understandable results, thereby facilitating the interpretation and communication of decisions (Mousavi and Lin, 2019; Greco et al., 2021; Bari and Karande, 2021). Furthermore, the selection of this method is justified by its previous successful applications in agricultural contexts, as demonstrated in Kheybari et al. (2021) and Burak et al. (2022), and in the context of food, as shown in Govindan et al. (2017) and Poissant et al. (2023). It is important to note that Promethee II is specifically employed for cases involving ordering or ranking (Greco et al., 2021), aligning with the nature of the problem addressed in this study. Promethee II is one of the outranking-based methods which has become acceptable because of its more straightfoward mathematical properties (Bari and Karande, 2021).

2. Materials and methods

2.1. Research design

The study developed here is classified as exploratory, and it has a qualitative-quantitative approach using data from 156 grapes genotypes recorded in the database from 2002 to 2020 (Yalew, 2016; Leão et al., 2020; Ustaoglu et al., 2021). It is also exploratory as it mathematically analyzes the objective and subjective preferences of the decision-maker (Campos, 2011; Bairagi and Munot, 2019).

In this work, we use a case study to seek new methods of selecting grape genotypes present in the grape Embrapa Semiárido's AGB, considering multiple criteria. This work is also a descriptive research because it intends to establish a decision-making process for selection of table grape genotypes for a plant breeding program from criteria, which the decision maker determines.

The data provided have mean values obtained from grape genotypes over 28 production cycles from 2002 to 2020 from an experimental area at the Mandacaru Experimental Field, Juazeiro, BA. The grapevines were grown in the espalier (vertical) trellis vine training system, in which four plants represent each genotype in the field. Drip irrigation is used, and the application of nutrients through fertigation is based on the needs identified from leaf and soil analysis.

2.2. Phases of the study

This study was divided into three phases, as illustrated in Fig. 1. In Phase 1, the problem and the goal were identified. Then, a literature review was carried out to characterize and contextualize the importance of the theme and to define the MCDA method to be applied. In Phase 2, the decision matrices were developed based on the criteria definition and their respective weights through interviews conducted with the decision maker and the organization of the data from the grape Embrapa Semiárido's AGB tabulated through Microsoft Excel®. Next, in phase 3, the Promethee II method was applied to obtain the ranking of the grape genotypes through the Visual Promethee Academic® software. Finally, sensitivity was analyzed, results were discussed, and conclusions were drawn.

2.3. Preference ranking organization method for enrichment (PROMETHEE) method

The Promethee method, from the French school, was developed by Brans and Vincke in 1985 and can be applied to different decision-making problems. It has different versions and applications, such as Promethee I, II, III, IV, V, VI, TRI, Fuzzy, and others (Tong et al., 2020). The Promethee II outranking method was selected in this study due to its stability, ease of understanding, and usefulness in resolving ordering problems (Sousa et al., 2020).

The method is based on the outranking of alternatives, that is, in pair-by-pair comparisons of alternatives concerning each criterion, following the orientation of maximization or minimization to recommend the best option (Nassereddine et al., 2019). In addition, it is not compensatory since good performance in one criterion will not compensate the lack of performance in another.

From a set of alternatives $a_i \in A$, with $i = \{1, 2, \ldots, n\}$, of criteria j and of preferences from the DM, considered as weights, given by $w_j = \{1, \ldots, m\}$, with $j \in J = \{1, \ldots, m\}$, it is possible to structure the decision matrix with the sum total of the weights, which is provided by $\sum_{j=1}^{m} w_j = 1$. Then the preference function $P_j = \{a_i, a_{i'}\}$ is determined for each criterion, which assumes values from 0 to 1 based on six preference functions: (1) usual, (2) U-shape, (3) V-shape, (4) level, (5) linear, and (6) Gaussian. The performance of each alternative to a criterion $g_j(a_i)$ is given through pair-by-pair comparisons expressed by $F_j(a_i, a_{i'}) = \left[g_j(a_i) - g_j(a_{i'}) \right]$ (Greco et al., 2021).

According to Mousavi and Lin (2019), the degree of outranking of an alternative a_i in relation to $a_{i'}$ is calculated for the difference function, given Eq. (1).

$$\pi(a_i, a_{i'}) = \sum\nolimits_{j=1}^{m} P_j(a_i, a_{i'}) w_j \quad (1)$$

The result obtained assists in the identification of the leaving flow (φ^{+}) for n alternatives, obtained by Eq. (2), i.e., how much a_i is preferable concerning other alternatives, and the entering flow (φ^{-}), expressed

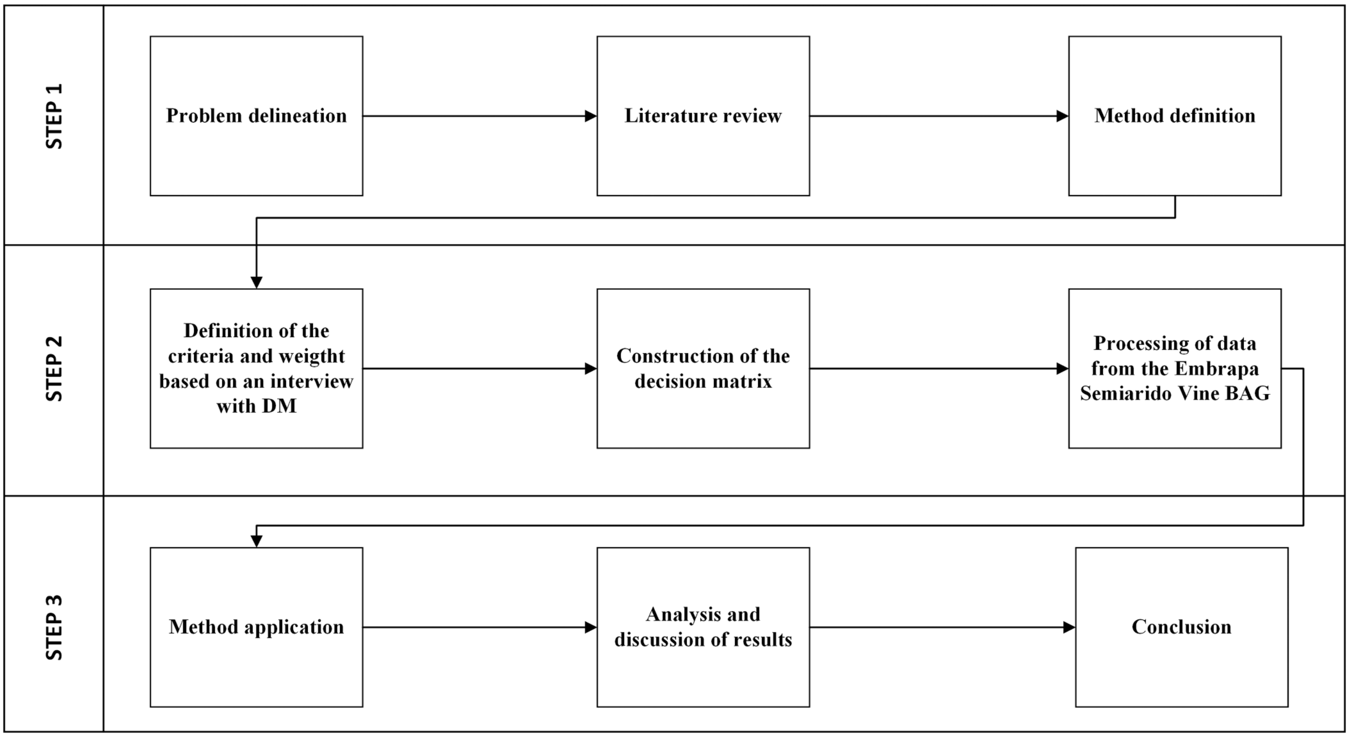


Fig. 1. Phases of the study.

in Eq. (3), corresponds to the preference for other alternatives in relation to a_i.

$$\varphi^{+}(a_i)=\frac{1}{n-1}\sum_{a_j\in A}\pi(a_i,a_j) \quad (2)$$

$$\varphi^{-}(a_i)=\frac{1}{n-1}\sum_{a_j\in A}\pi(a_j,a_i) \quad (3)$$

Thus, it is possible to provide a preordering of the alternatives through the net outranking flow (φ), given by Eq. (4).

$$\varphi(a_i) = \varphi^{+}(a_i) - \varphi^{-}(a_i) \quad (4)$$

The Promethee II method has diverse applications, such as in the evaluation of the comfort level in intensive care units (Vieira et al., 2019), the review of web services of five-star hotels (Ostovare and Shahraki, 2019), the analysis of emergency or disaster response systems (Nassereddine et al., 2019), foreseeing credit risks (Mousavi and Lin, 2019), and alternatives for reducing water consumption in residences (Sousa et al., 2020). The studies of Kheybari et al. (2021) and Burak et al. (2022) are recommended to understand how new hybrid methods involving Promethee II are being applied in agriculture. For a deeper understanding of the Promethee II method, reading the studies of Mousavi and Lin (2019) and Greco et al., (2021) is recommended.

2.4. Criteria of the decision matrix

The criteria adopted for developing the decision matrix were determined together with the DM, who, in this case, was a specialist in grape plant breeding from Embrapa Semiárido. The criteria, weights, and polarity to be adopted were defined, and the preference functions adopted varied according to the traits of the criterion, as shown in Table 1. The analysis was divided into two studies considering seedless and seeded grapes characteristics. Seeded grapes present higher average values for production components such as the number of bunches, mass and size of bunches and berries. In addition, for seedless grapes breeding, we choose, as parental, seedless grape varieties, which justifies the separation of the grape groups.

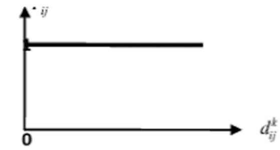
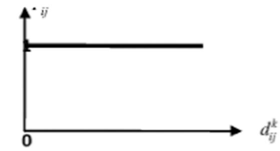
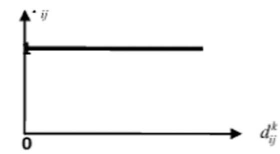
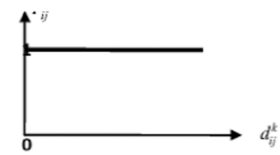
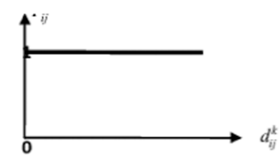
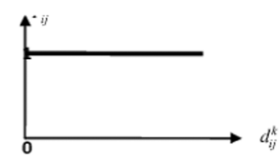
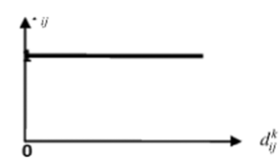
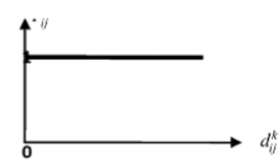
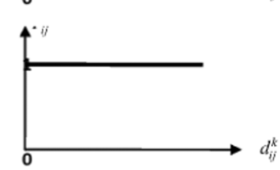
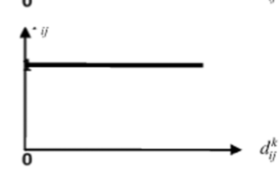
For the criteria that deal with aspects such as yield (kg/vine), including the number of bunches per vine, bunch weight (g), length (cm), and width (cm), as well as berry weight (g), length (mm), and diameter (mm); Total Soluble Solids content (ºBrix); and the ratio between Total Soluble Solids (TSS) and Titratable Acidity (TA), the usual preference function was adopted, because the better their rates are, the greater the degree of outranking among the alternatives. The chosen criteria are based on Leão (2019), Leão (2020a), and Leão (2020b). For the qualitative criteria (pulp consistency, berry shape, flavor, color), we used the 2nd Edition of the OIV Descriptor List for Grape and Vitis Species published by The International Organization of Vine and Wine that corresponds to: Berry Shape (OIV 223, UPOV 36, IPGRI 6.2.6); Color (OIV 225, UPOV 37, IPGRI 6.2.8); Pulp Consistency (OIV 235, UPOV 45); Flavor (OIV 236, UPOV 42, IPGRI 6.2.12) (The International Organization of Vine and Wine, 2009).

In contrast, for the pulp consistency criterion, the linear preference function was assumed for indifference value equal to 1 and preference value equal to 2, taking a variation in the indicators of up to four points, where 4 and 1 are the best and worst consistency, respectively. In addition, the level preference function was defined for the berry shape and berry color criteria, with preference values equal to 2.50 and 3 and indifference values equal to 2. For the flavor criterion, the U-shape preference function was adopted, with indifference equal to 1.50, where the flavor indicators ranged from 1 to 4, represented by neutral flavor up to special flavor.

2.5. Alternatives of the decision matrix

Two decision matrices were developed in this article through data supplied by Embrapa Semiárido through the grape active germplasm bank. In the first decision matrix, 106 different grape genotypes were used, with the trait of having seeds in the berry, shown in Table S.1; whereas the second decision matrix was formed by 50 grape genotypes that did not have seeds in the berry (seedless grapes) as shown in Table S.2. These matrices, presented as supplementary material (Tables S1 and S.2), were developed to determine the ordering of the grape genotypes

Table 1
Criteria, weights, polarity, and preference functions of the decision matrix.

Criteria	Weight	Polarity	Preference function	
C1 - Yield	5.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C2 - Number of bunches per vine	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C3 - Bunch weight	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C4 - Bunch length	3.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C5 - Bunch width	3.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C6 - Berry weight	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C7 - Berry lenght	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C8 - Berry diameter	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C9 - Total Soluble Solids (TSS)	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	
C10 - Ratio TSS/TA	4.00	Maximize	**Usual-criterion** $P_{ij}^k = \begin{cases} 0 & \text{If } d_{ij}^k \le 0 \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^k > 0 \text{ (Strict preference)} \end{cases}$	

(continued on next page)

Table 1 (*continued*)

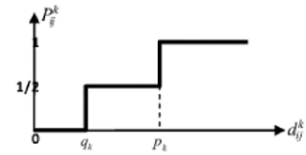
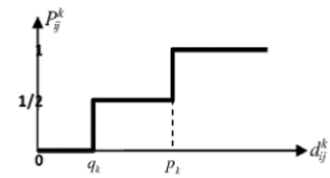
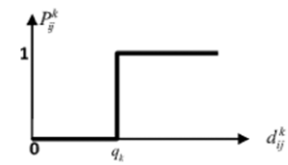
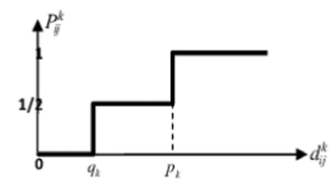
Criteria	Weight	Polarity	Preference function
C11 - Pulp consistency	4.00	Maximize	**Level - criterion** $P_{ij}^{k} = \begin{cases} 0 & \text{If } d_{ij}^{k} \le q_k \text{ (Indifference)} \\ \frac{1}{2} & \text{If } q_k < d_{ij}^{k} \le p_k \text{ (Weak preference)} \\ 1 & \text{If } d_{ij}^{k} > p_k \text{ (Strict preference)} \end{cases}$ 
C12 - Berry shape	3.00	Maximize	**Level - criterion** $P_{ij}^{k} = \begin{cases} 0 & \text{If } d_{ij}^{k} \le q_k \text{ (Indifference)} \\ \frac{1}{2} & \text{If } q_k < d_{ij}^{k} \le p_k \text{ (Weak preference)} \\ 1 & \text{If } d_{ij}^{k} > p_k \text{ (Strict preference)} \end{cases}$ 
C13 - Flavor	4.00	Maximize	U-Shape criterion or Quasi Criterion **Quasi - criterion** $P_{ij}^{k} = \begin{cases} 0 & \text{If } d_{ij}^{k} \le q_k \text{ (Indifference)} \\ 1 & \text{If } d_{ij}^{k} > q_k \text{ (Strict preference)} \end{cases}$ 
C14 - Color	2.00	Maximize	**Level - criterion** $P_{ij}^{k} = \begin{cases} 0 & \text{If } d_{ij}^{k} \le q_k \text{ (Indifference)} \\ \frac{1}{2} & \text{If } q_k < d_{ij}^{k} \le p_k \text{ (Weak preference)} \\ 1 & \text{If } d_{ij}^{k} > p_k \text{ (Strict preference)} \end{cases}$ 

Table 2
Mean, maximum, and minimum values for the seeded grape genotypes from the AGB.

Criteria	Average	Maximum		Minimum	
Yield (kg.vine^{-1})	2.98	14.68	Scarlet	0.64	Selection 1 (Planta 1)
Number of bunches per vine	16.62	41.21	Moscatel de Hamburgo	1.97	Selection 1 (Planta 1)
Bunch weight (g)	208.77	405.58	Itália clone I	46.83	Stover
Bunch length (cm)	13.69	20.17	Monte Serrat	8.29	Stover
Bunch width (cm)	8.70	13.53	Itália clone I	5.40	Blue Lake
Berry weigth (g)	3.98	7.77	Michele Palieri	1.35	Lake Emerald
Berry lenght (mm)	20.10	30.60	Seleção 2 (Planta 2)	11.10	Black July
Berry diameter (mm)	17.25	22.29	Michele Palieri	9.70	Black July
Total Soluble Solids (TSS) (°Brix)	17.02	22.95	Black July	12.47	Dominga
Ratio TSS/TA	56.60	87.85	Marengo Pirovano	23.63	Scarlet

concerning the 14 criteria.

3. Results and discussion

The mean values from 28 production seasons of the qualitative and quantitative morphological and agronomic traits of the genotypes in the grape Embrapa Semiárido's AGB are shown in Table A.1 and A.2. Considering the qualitative characteristics of all grape genotypes, there is a predominance for grapes with fleshy pulp (40.4%) and mucilaginous (32.7%) consistency, as well as the preponderance of genotypes with seeds (67.9%) and neutral flavor (67.3%). For berry shape, only 14.1% of the genotypes have an elliptical shape, while the rest is divided between ovoid (46.2%) and globular (39.7%). For the berry color, the grape genotypes exhibited high variability, with red (30.1%), yellowish green (27.6%), green (23.1%), and black (19.2%).

Descriptive statistics were obtained regarding each criterion determined by the decision maker, such as mean, maximum, and minimum values of the group of seeded grape genotypes, shown in Table 2. Similarly, analysis was made for the group of seedless grape genotypes, as shown in Table 3, allowing observation of the cultivars with the highest and lowest values in each one of the 14 different criteria.

The grape genotypes with maximum values in the criteria of bunch length, bunch width, berry length, berry weight, and berry diameter were: 'Mont Serrat', 'Itália Clone I', 'Seleção 2', and 'Michele Palieri'. Observing the group of seedless grape cultivars, the grape genotypes classified by minimum values were equal in all the criteria except for bunch weight, for which, according to Leão et al. (2019), the genotype with the lowest value in this criterion was 'Sulfolk Red Seedless', while in this study, it was 'Loose Perlete'. In the maximum values, the genotypes were similar in the criteria of the number of bunches, bunch weight, bunch length, berry length, berry diameter, and Total Soluble Solids (SS).

After the application of the Promethee II method in the decision matrix with seeded grape genotypes, it was possible to create the ranking by using Eq. (4), as shown in Table 4, which indicated the grape cultivars of the AGB preferable according to the net flow values, as shown in Fig. 2. The ten best-ranked genotypes were 'Itália Clone I', 'Dona Maria', 'Italia Muscat', 'Estevão Marinho', 'Itália', 'Michele Palieri', 'Red Globe', 'Monte Serrat', 'Black Pearl', and 'Itália Clone Diamante'.

Table 3
Mean, maximum, and minimum values of the seedless grape genotypes from the AGB.

Criteria	Average	Maximum		Minimum	
Yield (kg.vine^{-1})	1.77	6.17	BRS Isis	0.44	Catalunha
Number of bunches per vine	11.43	31.50	Adona	3.23	Catalunha
Bunch weight (g)	161.83	324.36	BRS Isis	80.45	Loose Perlete
Bunch length (cm)	13.71	18.01	CG 102295 (Moscatuel)	10.40	Reliance
Bunch width (cm)	8.20	11.75	Feal	5.37	Paulistinha
Berry weigth (g)	3.86	9.87	Fantasy Seedless	1.34	Sulfolk Red
Berry lenght (mm)	18.03	24.68	BRS Isis	13.07	Sulfolk Red
Berry diameter (mm)	14.94	18.95	CG 102024 (Dacari)	12.43	Catalunha
Total Soluble Solids (TSS) (ºBrix)	18.07	20.78	BRS Clara	14.81	Isaura
Ratio TSS/TA	37.25	77.79	CG 26916 (Baviera)	25.14	CG 102295 (Moscatel)

Using this outranking method allowed the recommendation of superior genotypes with greater assertiveness by considering both quantitative and qualitative criteria in the algorithm.

The morphological traits of the seeded grape genotypes exhibited a different response from the overall analysis of the AGB, showing that the considered best-classified genotypes had characteristics such as fleshy pulp consistency in all the ten best-ranked genotypes, and had an oval shape (80%) and globular shape (20%) of the berry, berry color of yellowish green and/or green (50%), black (30%), and red (20%) and, regarding flavor, the dominance of muscatel (40%) and neutral (40%), with special flavor being less common (only 20%).

The ordering of the seedless grape genotypes is shown in Table 5, following the net flow obtained in Eq. (4). The best-classified genotypes were 'BRS Ísis', 'BRS Linda', 'BRS Morena', 'Adona', 'BRS Clara', 'CG 102295', 'Crimson Seedless', 'Marroo Seedless', 'Princess', and 'BRS Vitória', according to Fig. 3. Concerning the morphological traits of the second decision matrix, the genotypes exhibited different traits compared to the first group, with crisp pulp (40%) and fleshy pulp (60%) consistency, berry color that was yellowish green and green (40%), red (30%), and black (30%), berry shape that was oval (70%), elliptical (20%), and globular (10%), and a predominance of neutral flavor (90%) among the ten best-classified genotypes.

The sensitivity analysis shows that even a relatively small change in one component of the criteria weight may affect the resulting order, as demonstrated in Table 6. The stability interval determines how significant this change may be to maintain the resulting order (Kuncova and Seknickova, 2022). According to Pinho (2019), sensitivity analysis of the weights allows verification of the possible variation intervals that the weights can adopt to ensure confidence to the decision maker upon analyzing the ordering obtained. For example, considering the Weight Stability Intervals for seeded grape genotypes, the criterion Berry shape can change by 100%, and the ranking remains the same. On the other hand, the criteria Color, Bunch length, and Bunch width are the most sensitive. The sensitivity analysis for seedless grape genotypes is similar, pointing to the Berry shape as the least sensitive criterion and Color as the most sensitive.

Table 6 shows that the stability ranges for both grape varieties are highly sensitive to changes (except for the 'Berry shape' criterion). The tool used in this work that illustrates changes in weights and rankings in Visual Promethee is the Walking Weights. For example, for seeded grape genotypes, if we make a change outside the range [3.61%; 4.06%] for the 'Color' criterion, the ranking will shift, allowing the decision maker to evaluate the robustness of the final ranking. For example, by altering the weight value of the 'Color' criterion by 5%, the ranking changes between Black Pearl (8th position) and Italia clone Diamante (9th position). Another critical analysis is related to the 'Yield' criterion. The decision maker can explore different scenarios by changing the yield weight (essential for any agricultural production) to 15%, 20%, etc. In other words, this weight gives a higher degree of importance. For instance, if the weight of this criterion increases to 20%, the position between Estevão Marinho (3rd position) and Italia Muscat (4th position) will interchange.

To understand the conflicts of the criteria and the weights related to them, we used the Preference Ranking Organization Method for Enrichment Evaluation Geometrical Analysis for Interactive Aid (Promethee-GAIA), a visual interactive technique for graphical analysis. GAIA Plane is a visible aid that assists in choosing alternatives and makes it easy to figure out complex decision-making problems (Bari and Karande, 2021).

For visual analysis, we generated the GAIA Plane using the Visual Promethee Software for all 106 seeded grape genotypes (Fig. 4) and the 50 seedless grape genotypes (Fig. 5), considering the 14 criteria. However, the graphical quality was only 62.5% and 54.5%, respectively, which hinders the observation of all details on the red decision axis of the GAIA plane (also called π-axis) due to the high number of alternatives. Figs. 4 and 5 show the GAIA plane that depicts the direction of the π-axis and, the positions of alternatives (light blue) and the criteria (dark blue). In Fig. 4, we can see the superiority of the alternative Italia Clone I to the others through the direction of the π-axis. Additionally, Fig. 5 shows the alternatives to Italia BRS Isis' dominance over the others.

In addition to the graphical analysis, Figs. 6 and 7 present the Action Profile for Italia Clone 1 and BRS ISIS, ranking at the top for seeded and seedless grape genotypes, respectively. Fig. 6 highlights that criteria Bunch Weight, Bunch Length, and Bunch Width positively impacted the evaluation of Italia Clone 1, while the Number of Brunches and TSS had a negative influence. Fig. 7 shows that for BRS ISIS, the criteria with a positive impact were Yield, Bunch Weight, and Bunch Length, while TSS and Flavor had a negative influence. In gray is the value of φ, which ranges from -1 to $+1$.

It should be emphasized that the table grape market values cultivars without seeds (seedless), oval or elliptical berry shape, and crisp texture, and prefers green color, especially for export.

Therefore, the method analyzed is unlike other methods usually applied for selecting grape genotypes, such as descriptive and multivariate statistical methods (ANOVA and PCA), because it considers subjective aspects of the decision maker, which are essential for fruit evaluation. Although ANOVA and PCA are widely used statistical technique for comparing means between multiple groups and for dimensionality reduction and exploratory data analysis, they have some disadvantages, differently from MCDA methods, such as Promethee II. For example, ANOVA has assumption of normality, dependence on sample size post-hoc testing and PCA has a disadvantage of scale dependence, linear assumptions, and difficulty in dealing with categorical variables. An integrated approach of PCA and Promethee is detailed in Stankivic et al., 2021. Another possibility would be applying AHP to define weight values of the criteria evaluated in the grape genotype selection problem, as described in Navarro et al. (2021). However, the AHP method is considered a compensatory method.

The decision maker participated in all process stages, from validating qualitative and quantitative criteria to evaluating the criteria weights, and the decision matrix had 106 seeded and 50 seedless grape genotypes with 14 criteria. According to Marttunen et al. (2018) and Marttunen et al. (2019), the significance of objectives in MCDA is crucial, often quantified through the assignment of weights. Nevertheless,

Table 4
Ranking of the seeded grape genotypes.

Genotype	φ^+	φ^-	φ	Genotype	φ^+	φ^-	φ	Genotype	φ^+	φ^-	φ	Genotype	φ^+	φ^-	φ
1. Italia Clone I	0.50	0.67	0.17	28. Angelo Pirovano	0.15	0.47	0.32	55. Portuguesa Blanes	-0.01	0.39	0.40	82. Moscatel Grega	-0.19	0.31	0.50
2. Dona Maria	0.46	0.62	0.16	29. CG 4113	0.15	0.48	0.33	56. Black Magic	-0.01	0.38	0.40	83. Aurora	-0.20	0.31	0.51
3. Italia Muscat	0.44	0.62	0.18	30. Queen	0.14	0.46	0.31	57. Emperor	-0.02	0.38	0.39	84. CG40016 Damarim	-0.21	0.29	0.50
4. Estevao Marinho	0.43	0.61	0.18	31. Branca Salitre	0.14	0.46	0.32	58. Saint Jeannet	-0.02	0.38	0.40	85. Eumelan 394	-0.21	0.28	0.49
5. Italia	0.39	0.60	0.20	32. Marengo Pirovano	0.13	0.45	0.32	59. Perlona	-0.03	0.38	0.40	86. Niagara Rosada	-0.23	0.26	0.49
6. Michele Palieri	0.38	0.59	0.21	33. Muscat de Saint Vallier	0.13	0.46	0.33	60. H 4–49–100	-0.03	0.38	0.41	87. Madeleine Royal	-0.24	0.28	0.51
7. Red Globe	0.38	0.58	0.20	34. Moscatel Nazareno	0.13	0.47	0.34	61. Igawa	-0.04	0.37	0.41	88. August Giant	-0.24	0.27	0.51
8. Monte Serrat	0.34	0.56	0.22	35. Baresana	0.12	0.45	0.33	62. Seyve Villard 12327	-0.04	0.38	0.42	89. Favorita	-0.25	0.28	0.53
9. Black Pearl	0.31	0.56	0.25	36. Gros Colman	0.12	0.45	0.33	63. Don Mariano	-0.04	0.37	0.41	90. Orange Muscat	-0.25	0.28	0.53
10. Italia clone Dimante	0.31	0.56	0.24	37. Ferral	0.10	0.44	0.33	64. Golden Queen	-0.05	0.36	0.42	91. IAC 77526	-0.26	0.28	0.54
11. Brasil	0.31	0.54	0.24	38. Kyoho	0.09	0.45	0.36	65. Maria	-0.05	0.36	0.42	92. BRS Nubia	-0.27	0.25	0.53
12. Benitaka	0.30	0.54	0.23	39. Roni red	0.08	0.44	0.36	66. A1581	-0.05	0.38	0.43	93. CG 38049	-0.32	0.23	0.55
13. Moscato de Alexandria	0.30	0.55	0.25	40. Flame Tokay	0.08	0.42	0.35	67. A1118	-0.06	0.36	0.42	94. Dattier de Beirouth	-0.33	0.23	0.55
14. CG 90450	0.29	0.55	0.26	41. Kagina	0.07	0.42	0.35	68. Christmas Rose	-0.07	0.35	0.42	95. Liberty	-0.33	0.21	0.54
15. Moscatel de Hamburgo	0.28	0.54	0.26	42. A1105	0.06	0.42	0.36	69. Selecao 4 (Planta 4)	-0.07	0.37	0.44	96. CG 33716	-0.33	0.24	0.57
16. Muscat Caillaba	0.28	0.54	0.26	43. July Muscat	0.06	0.43	0.37	70. Dominga	-0.08	0.35	0.43	97. H 4–49–69	-0.34	0.24	0.57
17. Italia Melhorada (clone II)	0.27	0.54	0.26	44. California	0.05	0.42	0.37	71. Ceilad	-0.10	0.34	0.44	98. Dona Zila	-0.34	0.23	0.57
18. Piratininga	0.26	0.51	0.26	45. Impero	0.04	0.41	0.37	72. Panse Precose	-0.11	0.34	0.45	99. Scarlet	-0.34	0.21	0.55
19. Moscatel Rosada	0.25	0.53	0.28	46. Sovrano Pirovano	0.03	0.41	0.38	73. Seyve Villard 20365	-0.12	0.33	0.44	100. Golden Muscat	-0.34	0.22	0.56
20. Muscat Noir	0.25	0.53	0.28	47. Regina Roma	0.03	0.40	0.37	74. Himoronto	-0.12	0.34	0.46	101. Perla de Csaba	-0.37	0.21	0.58
21. Rosaky Rosada	0.23	0.50	0.27	48. Ferlongo	0.02	0.41	0.38	75. CG 28467 (Emperatriz)	-0.12	0.33	0.45	102. Seyve Villard 12375	-0.37	0.21	0.58
22. Soraya	0.23	0.50	0.27	49. Neo Muscat	0.02	0.41	0.39	76. Lake Emerald	-0.13	0.34	0.47	103. Stover	-0.44	0.16	0.60
23. Moscatel de JundiaÃ	0.22	0.51	0.29	50. Muscat Yerevan	0.02	0.41	0.39	77. Emperatriz	-0.13	0.32	0.46	104. Mars	-0.47	0.15	0.62
24. Cardinal	0.20	0.48	0.29	51. Early Muscat	0.01	0.41	0.40	78. Dattier Saint Vallier	-0.13	0.32	0.45	105. Blue Lake	-0.55	0.11	0.66
25. Beni Fugi	0.19	0.47	0.28	52. Juliana	0.01	0.41	0.40	79. Black July	-0.16	0.31	0.47	106. Tardia de Caxias	-0.59	0.09	0.68
26. Patricia	0.17	0.47	0.30	53. Selecao 1 (Planta 1)	0.00	0.41	0.41	80. Frakenthal	-0.16	0.31	0.47				
27. Selecao 2 (Planta 2)	0.16	0.49	0.33	54. Regina de Vigneti	-0.01	0.38	0.39	81. IAC 011631 Rainha	-0.17	0.31	0.47				

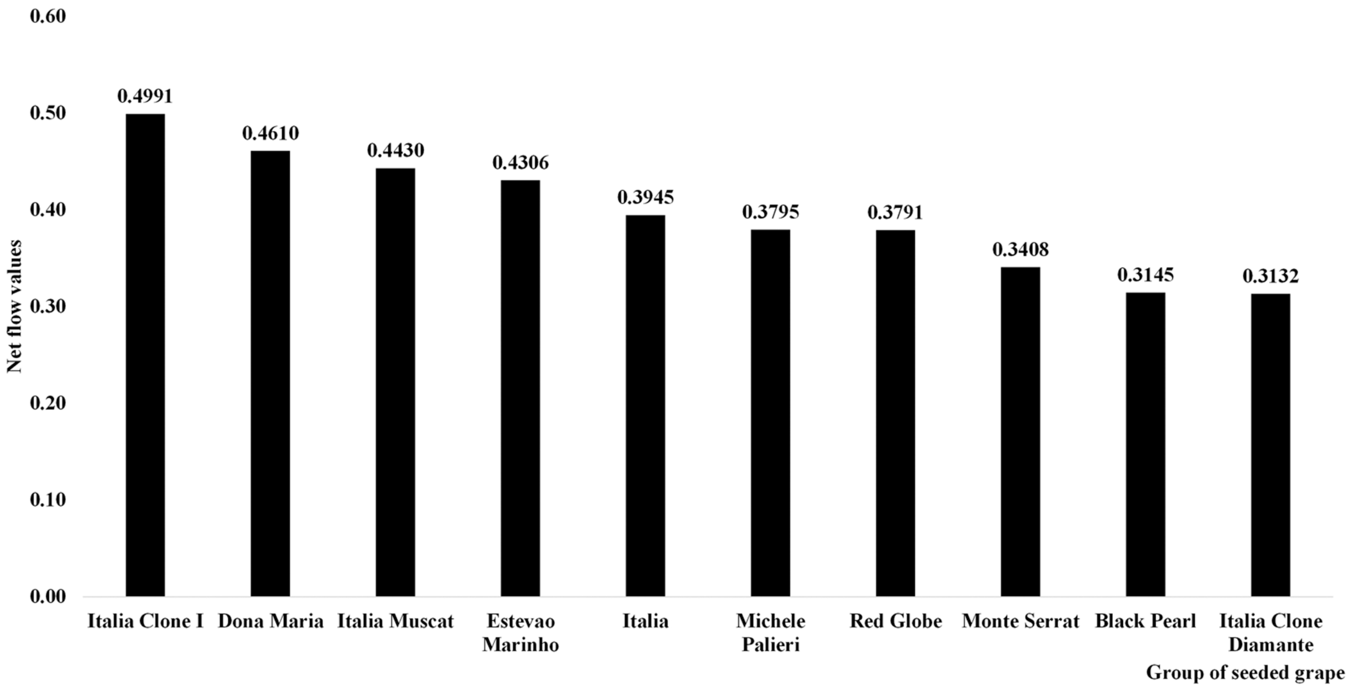


Fig. 2. Net flow values of seeded grape genotypes.

Table 5
Ranking of the seedless grape genotypes.

Genotype	φ^+	φ^-	φ	Genotype	φ^+	φ^-	φ
1. BRS Isis	0.56	0.68	0.12	26. Dawn Seedless	0.01	0.41	0.39
2. BRS Linda	0.42	0.60	0.18	27. CG 102024 (Dacari)	0.01	0.39	0.38
3. BRS Morena	0.32	0.55	0.23	28. Fantasy Seedless	0.00	0.40	0.40
4. Adona	0.30	0.54	0.25	29. Venus	-0.01	0.42	0.43
5. BRS Clara	0.29	0.53	0.24	30. Saturn	-0.01	0.39	0.40
6. CG 102295 (Moscatuel)	0.23	0.50	0.27	31. Thompson Seedless	-0.03	0.38	0.41
7. Crimson Seedless	0.23	0.51	0.28	32. CG 87908	-0.09	0.36	0.45
8. Marroo Seedless	0.23	0.50	0.27	33. Canner	-0.09	0.36	0.44
9. Princess	0.23	0.51	0.28	34. Blush Seedless	-0.09	0.35	0.44
10. BRS Vitoria	0.20	0.51	0.31	35. Flame Seedless	-0.11	0.33	0.44
11. CG 26916 (Baviera)	0.18	0.47	0.29	36. Einset Seedless	-0.11	0.37	0.48
12. Ruby Seedless	0.18	0.47	0.29	37. Sultanina Moscato	-0.13	0.35	0.48
13. CG 39915	0.16	0.48	0.32	38. Reliance	-0.16	0.35	0.50
14. Neptune	0.14	0.50	0.35	39. Delight	-0.17	0.31	0.48
15. Bronx Seedless	0.14	0.49	0.35	40. Isaura	-0.23	0.27	0.50
16. Fiesta	0.13	0.46	0.33	41. CG 87746	-0.23	0.31	0.54
17. Feal	0.12	0.46	0.35	42. Lakemont Seedless	-0.25	0.30	0.55
18. Jupiter	0.12	0.46	0.34	43. Sultanina Branca	-0.28	0.25	0.54
19. CG 351 (Arizul)	0.11	0.44	0.33	44. Beauty Seedless	-0.30	0.25	0.55
20. Perlette	0.10	0.48	0.38	45. Catalunha	-0.32	0.24	0.55
21. Centenial Seedless	0.07	0.43	0.36	46. Rodi	-0.35	0.22	0.57
22. Sugraone	0.07	0.43	0.36	47. Loose Perlete	-0.39	0.20	0.59
23. CNPUV 8	0.04	0.42	0.37	48. Himrod Seedless	-0.41	0.20	0.61
24. Emerald Sedless	0.02	0.41	0.39	49. Paulistinha	-0.42	0.20	0.61
25. CG 26858 (Passiga)	0.01	0.41	0.40	50. Sulfolk Red	-0.43	0.21	0.63

interpreting these weights can differ based on the chosen method. In MAVT (Multi-Attribute Value Theory), weights are scaling factors determining the relative added value linked to the impact range defined for each criterion in an individual decision. The performance of alternatives concerning each objective is then transformed to a defined scale (typically 0–1 or 0–100). Additionally, in the Analytic Hierarchy Process (AHP), the interpretation of the weights could be less clear considering the hierarchy. Marttunen et al. (2018) also highlight outranking methods, such as ELECTRE and Promethee, which focus on pairwise comparisons of alternatives and outranking relations, and Promethee does not provide any guidelines to determine the relative weights.

This study assigned the weights on a scale from 1 to 5 and then normalized, as the Promethee II method utilizes relative weights. According to Table 1, Yield had the highest relative importance weight (5), while Color had the lowest (2). All criteria had a "Maximize" polarity but with different preference functions based on the decision maker's preferences.

One limitation of our work is related to the 'Yield' criterion. The characteristic of being 10% (5/52) of the total weight was an unintentional consequence of the weighting procedure. It could have a significantly higher weight than others, but this is a subjective DM assessment, making an issue when using a small scale (0−5) for criterion weights. One alternative is using a larger scale, such as 0–10 or 0–100, to correct the disparity among the criteria. However, high productivity is

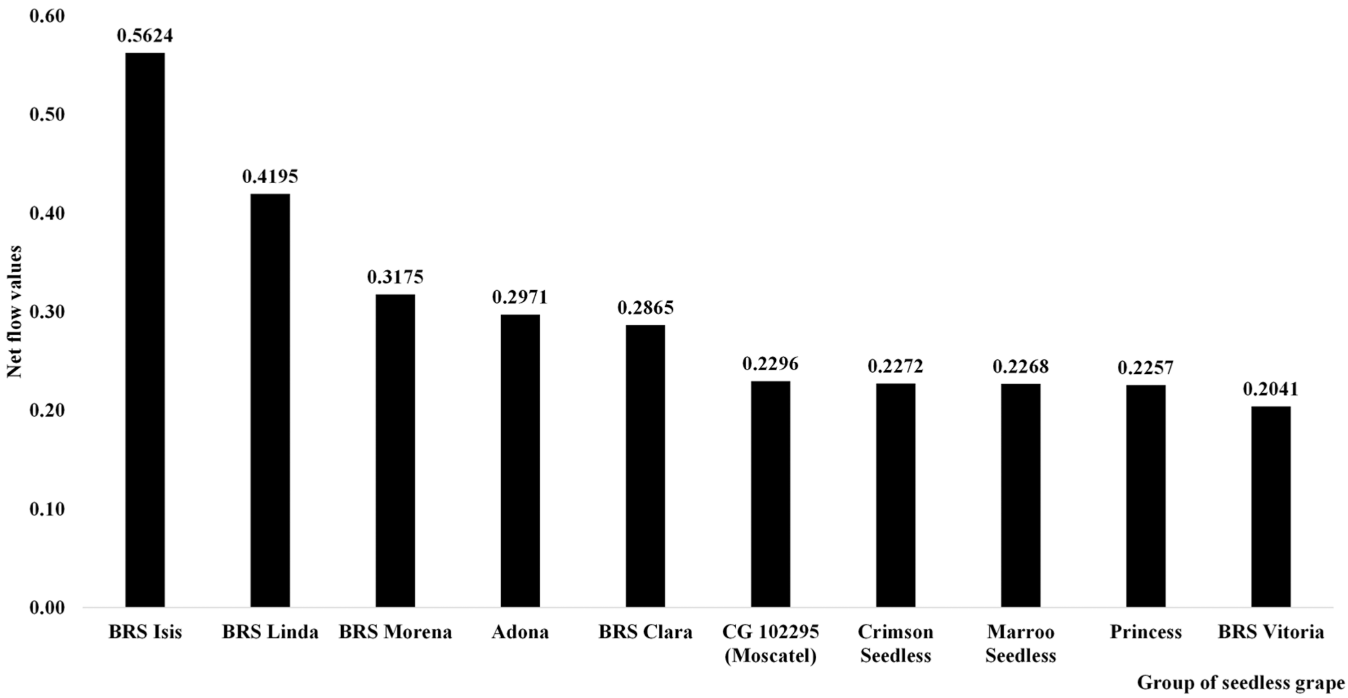


Fig. 3. Net flow values of seedless grape genotypes.

Table 6
Sensitivity analysis. Visual Promethee Software.

Criteria	Weight Stability Intervals (seeded grape genotypes)	Weight Stability Intervals (seedless grape genotypes)
Yield	[9.58%; 9.68%]	[9.62%; 9.66%]
Number of bunches per vine	[7.64%; 7.72%]	[7.69%; 7.88%]
Bunch weight	[7.67%; 7.74%]	[7.69%; 7.93%]
Bunch length	[5.66%; 5.84%]	[5.71%; 5.77%]
Bunch width	[5.70%; 5.82%]	[5.77%; 5.84%]
Berry weight	[7.62%; 7.75%]	[7.54%; 7.69%]
Berry lenght	[7.65%; 7.76%]	[7.59%; 7.69%]
Berry diameter	[7.58%; 7.77%]	[7.69%; 7.79%]
Total Soluble Solids (TSS)	[7.64%; 7.71%]	[7.62%; 7.69%]
Ratio TSS/TA	[7.64%; 7.78%]	[7.69%; 7.84%]
Pulp consistency	[7.65%; 7.99%]	[7.58%; 7.83%]
Berry shape	[0.00%; 100%]	[0.00%; 100%]
Flavor	[7.66%; 7.71%]	[7.55%, 7.80%]
Color	[3.61%; 4.06%]	[3.66%, 3.85%]

insufficient if the grape genotypes lack other desirable characteristics. For example, grape genotypes may be highly productive but have low Solid Soluble Content (sugar content) and high acidity; consequently, the production will be unfeasible – this is a plausible scenario. Another aspect related to 'Yield' is that the grape's genotypes may be highly productive, but the bunch is considered small, which is an undesirable trait for fresh fruits market. Moreover, the consumer does not prefer a bunch that is too small. Therefore, the weights assigned to other criteria are also crucial. A good example is BR ISIS (Fig. 7 with action profile for BRS ISIS), which ranked at the top because the criteria with a positive impact were Yield, Bunch Weight, and Bunch Length. Another way to correct this bias is using hybrid methods, such as AHP-PROMETHEE, where AHP is applied to choose the criteria weights (Trivedi et al., 2023). However, Marttunen et al. (2018) emphasize that hierarchical weighting appears to be influenced by the asymmetry bias, which may arise when a hierarchy exhibits variations in the number of sub-objectives among its branches and problem can be overcome by giving more attention during the eliciting weights phase.

The most complex part of the evaluation for the DM was choosing the preference functions for each criterion. In the Promethee II method, there are six preference functions, and defining the functions and choosing the values of Thresholds, Q: Indifference, P: Preference, and S: Gaussian is not a trivial activity. However, this problem was overcome with the assistance of the Visual Promethee Software and the support of the authors throughout the evaluation. Finally, the DM analyzed all graphical results, sensitivity analysis, and rankings for both grape groups, emphasizing the importance of using Promethee II and the GAIA Plane when compared to traditional methods such as ANOVA and PCA for evaluating grape genotypes. The DM also mentioned that the method is crucial for grape breeding programs, being easily understood and replicable in other studies in the field of agriculture.

The present article used concepts of outranking through pair-by-pair comparisons between different alternatives to determine an ordering of grape genotypes present in the germplasm bank through Promethee II. It is focused on simultaneous qualitative and quantitative criteria, allowing, for example, comparison of varieties with and without seeds or considering grape flavor. The robustness of the method results in more comprehensive results by considering numerous alternatives. In this study, all the grape genotypes categorized for *fresh* (table grape) consumption present in the database of the grape Embrapa Semiárido's

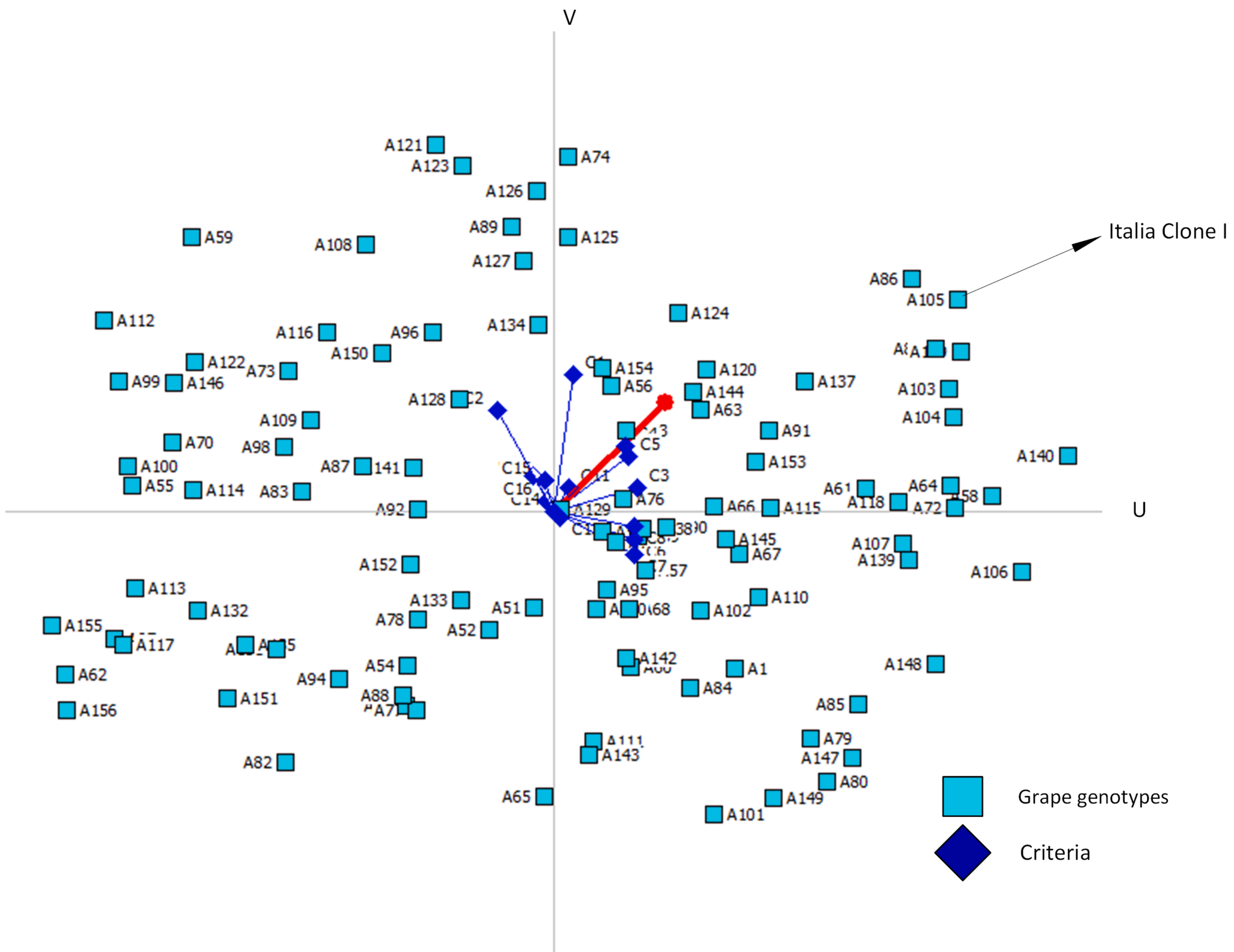


Fig. 4. GAIA Plane for seeded grape genotypes. Visual PrometheE Software.

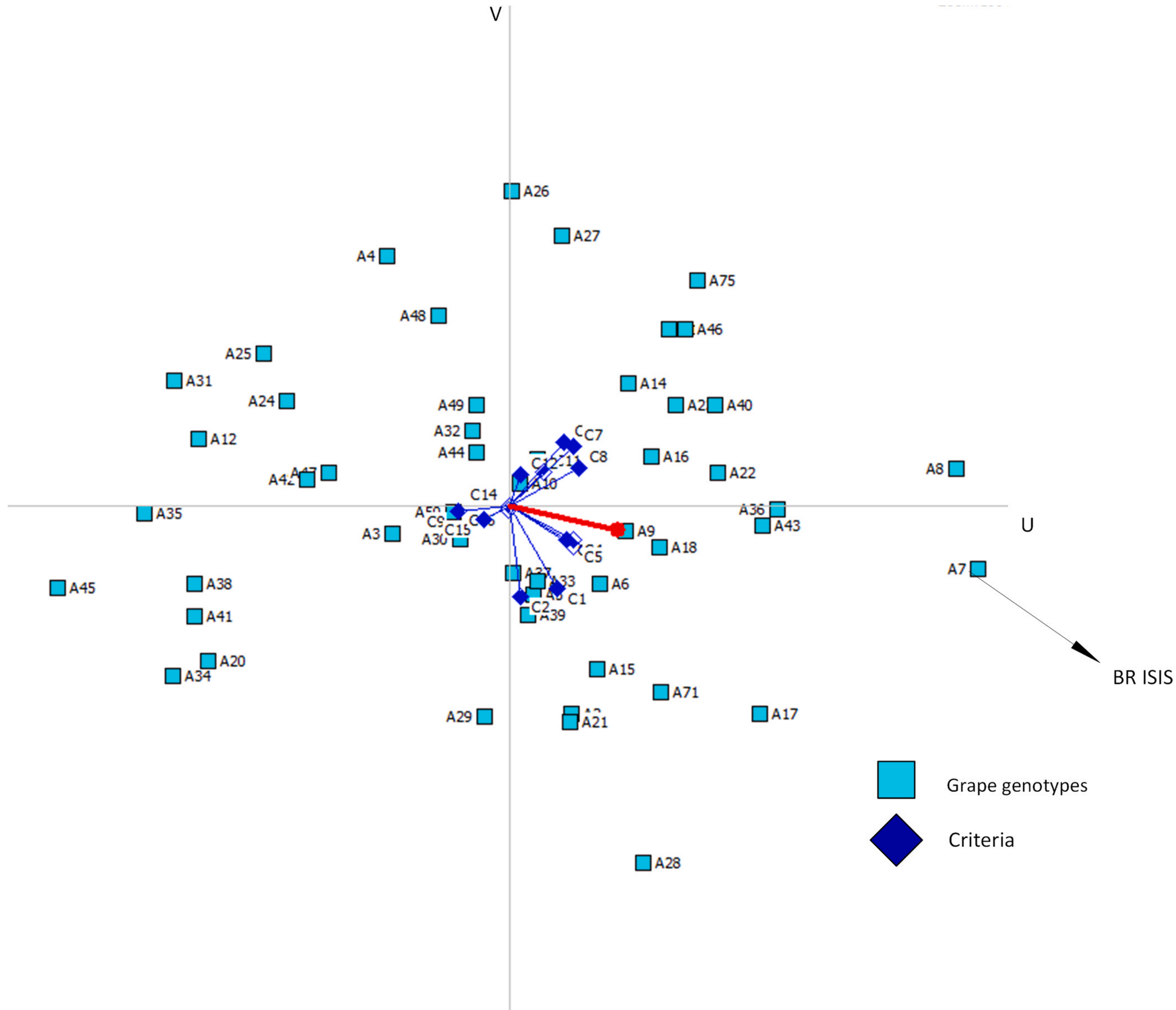


Fig. 5. GAIA Plane for seedless grape genotypes. Visual Promethee Software.

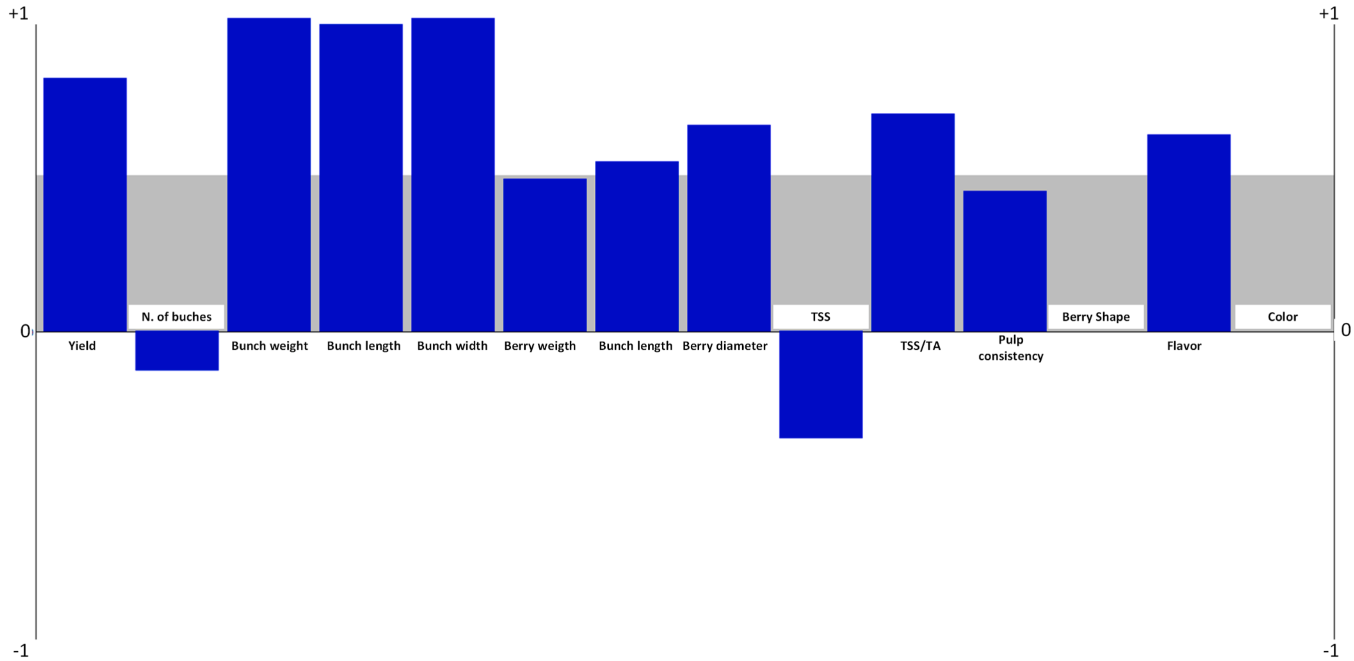


Fig. 6. Action Profile for Italia Clone 1.

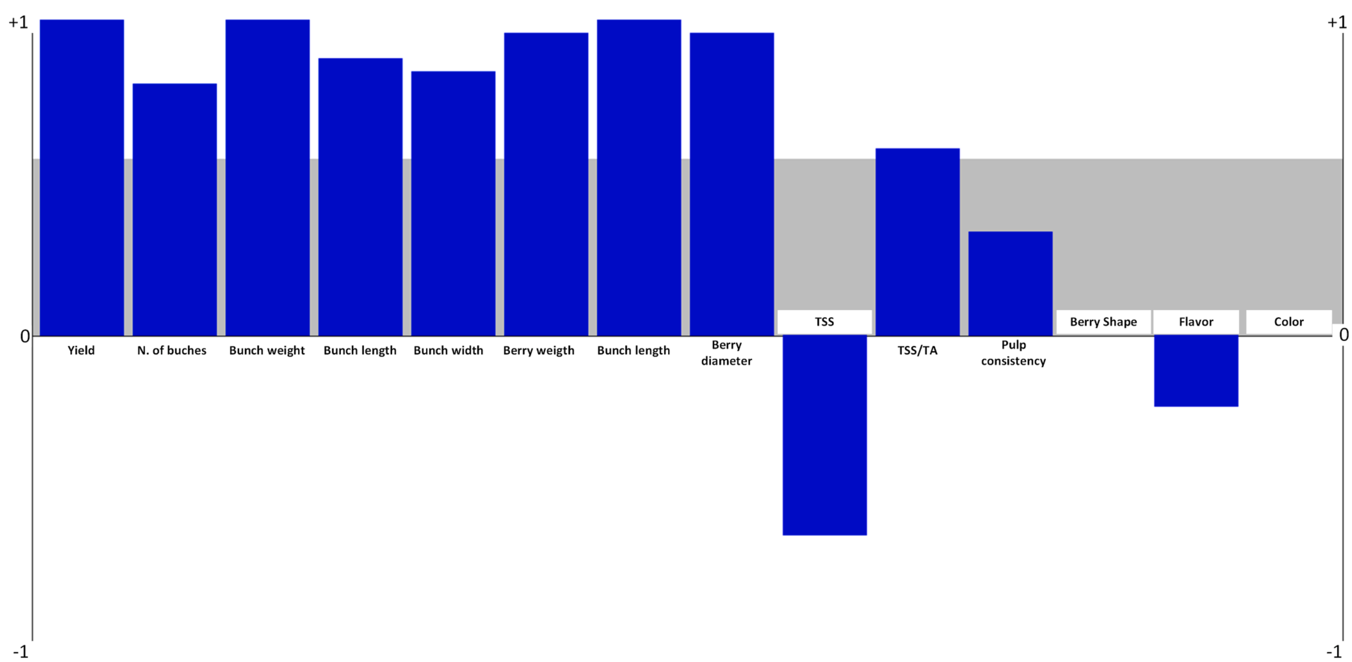


Fig. 7. Action Profile for BRS ISIS.

Active Germplasm Bank of Vitis sp. were used. Modeling grape genotypes using the Promethee Method has several practical implications for Embrapa: optimizing decision-making, enhancing breeding programs, and improving grape production's overall efficiency and sustainability.

4. Conclusion

In this study, we evaluated 156 grape genotypes present in the Embrapa Semiárido's AGB, from the perspective of 14 different qualitative and quantitative criteria, through the Promethee II method. From the MCDA, it was possible to consider both qualitative and quantitative aspects and weights determined by the DM, resulting in the ranking of the best grape genotypes from the germplasm bank.

The method demonstrated to be efficient in ranking grape genotypes. In other words, the method achieved its purpose with minimal waste of resources, time, and effort, being effective and practical during the process of ranking grape genotypes, indicating that 'Itália Clone I' and 'BRS Isis' had the best results of outranking, followed by 'Itália Muscat', 'Dona Maria', and 'Itália', showing consistency in the mean values of the morphological and agronomic aspects of the best genotypes ranked with the preferences of the decision maker. The Decision Maker evaluated the Decision Matrix in approximately 2 hours, and the Promethee methodology facilitated the analysis by considering the relative weights of the criteria, scales, and preference functions. The Visual Promethee software was crucial to process the data.

The results allow the use of the genotypes selected in studies of grape breeding performed by Embrapa, guiding the choice of parents with superior traits for carrying out genetic crosses. The main contribution of this work was to demonstrate how the Promethee II method can be used as an alternative to traditional methods of ANOVA and PCA for evaluating grape genotypes. One limitation of our study is that we did not compare seeded and seedless grapes directly. The result could have another ranking if all 156 grapes were evaluated together by Promethee II. This study can be applied to other areas of agriculture, given the importance of including subjective evaluations for the genotype ranking.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Matheus Sandrey Costa de Matos Lessa: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jefferson T. Oliva:** Writing – review & editing. **Thiago Amaral:** Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Patrícia Coelho Souza Leão:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank Embrapa Seminárido for providing data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2024.106126.

References

Anupam, K., Goley, P.K., Yadav, A., 2021. Chapter 19 - Effect of Normalization Protocol on Pulping Process Selection Using TOPSIS Multicriteria Decision-Making Method–A Case Study of Palm Oil Empty Fruit Bunches. Soft Comput. Tech. Solid Waste Wastewater Manag. 321–336.

Bairagi, V.; Munot, M.V. (2019), Research Methodology: a practical and scientific approach. Chapman and Hall/Crc, 320 p. eBook ISBN 9781351013277.

Bari, P., Karande, P., 2021. Application of PROMETHEE-GAIA method to priority sequencing rules in a dynamic job shop for single machine. Mater. Today.: Proc. 46, 7258–7264. https://doi.org/10.1016/j.matpr.2020.12.854.

Bartzas, G., Komnitsas, K., 2020. An integrated multi-criteria analysis for assessing sustainability of agricultural production at regional level. Inf. Process. Agric. 7, 223–232. https://doi.org/10.1016/j.inpa.2019.09.005.

Burak, S., Samanlioglu, F., Ülker, D., 2022. Evaluation of irrigation methods in Söke Plain with HF-AHP-PROMETHEE II hybrid MCDM method. Agric. Water Manag. Vol. 271 https://doi.org/10.1016/j.agwat.2022.107810.

Caffi, T., Helsen, H.H.M., Hossi, V., Holb, I.J., Strassemeyer, J., Buurma, J.S., Capowiez, S., Simon, S., Alaphilippe, A., 2017. Multicriteria evaluation of innovative IPM systems in pome fruit in Europe. Crop Prot. 97, 101–108. https://doi.org/10.1016/j.cropro.2016.12.009.

Campos, V. (2011), Modelo de apoio à decisão multicritério para priorização de projetos em saneamento. PhD thesis. Escola de Engenharia de São Carlos da Universidade de São Paulo.

Dragincic, J., Korac, N., Blagojevic, B., 2015. Group Multi-Criteria Decision Making (GMCDM) Approach for selecting the most suitable table grape variety intended for organic viticulture. Comput. Electron. Agric. 111, 194–202. https://doi.org/10.1016/j.compag.2014.12.023.

Emamzadeh, S.M., Forghani, M., Karnema, A., Darbandi, S., 2016. Determining an optimum pattern of mixed planting from organic and non-organic crops with regard to economic and environmental indicators: A case study of cucumber in Kerman, Iran. Inf. Process. Agric. 3, 207–214. https://doi.org/10.1016/j.inpa.2016.08.001.

Fabjanowicz, M., Bystrzanowska, M., Namieśnik, J., Tobiszewski, M., Płotka-wasylka, J., 2018. An analytical hierarchy process for selection of the optimal procedure for resveratrol determination in wine samples. Microchem. J. 142, 126–134.

Greco, S., Ishizaka, A., Tasiou, M., Torrisi, G., 2021. The ordinal input for cardinal output approach of non-compensatory composite indicators: the Promethee scoring method. Eur. J. Oper. Res. 288, 225–246. https://doi.org/10.1016/j.ejor.2020.05.036.

Govindan, K., Kadziński, M., Sivakumar, R., 2017. Application of a novel PROMETHEE-based method for construction of a group compromise ranking to prioritization of green suppliers in food supply chain. Omega 129–145. https://doi.org/10.1016/j.omega.2016.10.004.

Hornická, A., Brožová, H., 2013. Continuity of Demarcation Process of the Regions for Concentrated State Support. Agric. -line Pap. Econ. Inform. Vol V (Number 3).

IBGE - Instituto Brasileiro de Geografia e Estatística. Levantamento Sistemático da Produção Agrícola. (2020), Retrived from: https://sidra.ibge.gov.br/tabela/5457#resultado. Accessed on: 02 out. 2020.

Kalogeras, N., Baourakis, G., Zopounidis, C., Dijik, G., 2005. Evaluating the financial performance of agri-food firms: a multicriteria decision-aid approach. J. Food Eng. 70, 365–371. https://doi.org/10.1016/j.jfoodeng.2004.01.039.

Kheybari, S., Javdanmehr, M., Rezaie, F.M., Rezaei, J., 2021. Corn cultivation location selection for bioethanol production: An application of BWM and extended PROMETHEE II. Energy 228, 120593. https://doi.org/10.1016/j.energy.2021.120593.

Kuncova, M., Seknickova, J., 2022. Two-stage weighted PROMETHEE II with results' visualization. Cent. Eur. J. Oper. Res 30, 547–571. https://doi.org/10.1007/s10100-021-00788-9.

Leão, P.C.S., 2019. Genetic resources for table-grape breeding in Brazilian tropical semi-arid regions. Acta Hortic., Int. Soc. Hortic. Sci. (ISHS) (1248), 81–86.

Leão, P.C.S. (2020a), Catálogo de Videiras (Vitis sp.) conservadas na Embrapa Semiárido: uvas para processamento. Petrolina: Embrapa Semiárido, 100 p. ISSN 1808-9992.

Leão, P.C.S., Nascimento, J.H.B., Moraes, D.S., Souza, E.R., 2020b. Agronomic performance of seedless table grape genotypes under tropical semiarid conditions. Crop Prod. Manag. 79 (3), 364–371. https://doi.org/10.1590/1678-4499.20200027.

Lian, J.W., Ke, C.K., 2016. Using a modified ELECTRE method for an agricultural product recommendation service on a mobile device. Comput. Electr. Eng. 56, 277–288. https://doi.org/10.1016/j.compeleceng.2015.11.014.

Martínez, C.I.P., Poveda, A.C., 2022. Characterization of cooling equipment in the food industry: Case study of the Colombian meat, dairy, and fruit and vegetable sectors. Environ. Dev. 41, 100693 https://doi.org/10.1016/j.envdev.2021.100693.

Marttunen, M., Belton, V., Lienert, J., 2018. Are objectives Hierarchy related biases observed in practice? A meta-analysis of environmental and energy applications of Multi-Criteria Decision Analysis. Eur. J. Oper. Res. 265 (1), 178–194.

Marttunen, M., Weber, C., Åberg, U., Lienert, J., 2019. Identifying relevant objectives in environmental management decisions: An application to a national monitoring program for river restoration. Ecol. Indic. 101, 851–866.

MDIC – Ministério da Indústria, Comércio Exterior e Serviços. ComexStat: exportações e importações em geral. (2021), Retrived from: http://comexstat.mdic.gov.br/pt/geral. Accessed on: 16 Oct. 2021.

Mousavi, M.M., Lin, J., 2020. The application of PROMETHEE multi-criteria decision aid in financial decision making: case of distress prediction models evaluation. Expert Syst. Appl. 159, 113438 https://doi.org/10.1016/j.eswa.2020.113438.

Nassereddine, M., Azar, A., Rajabzadeh, A., Afsar, A., 2019. Decision making application in collaborative emergency response: a new PROMETHEE preference function. Int. J. Disaster Risk Reduct. 38, 101221 https://doi.org/10.1016/j.ijdrr.2019.101221.

Navarro, J.P., Cañas, P.M.I., Morlaes, A.M., Gascueña, J.M., Vozmediano, J.L.C., Romero, E.G., Gutiérrez, I.H., Alonso, S.G., 2019. Phenolic compounds profile of different berry parts from novel Vitis vinifera L. red grape genotypes and Tempranillo using HPLC-DAD-ESI-MS/MS: A varietal differentiation tool. Food Chem. Vol. 295 (15), 350–360. https://doi.org/10.1016/j.foodchem.2019.05.137.

Navarro, J.P., Canas, P.M.I., Morales, A.M., Gascuena, J.M., Vozmediano, J.L.C., Romero, E.G., Gutierres, I.H., Alonso, S.G., 2021. Genotypic variation in phenolic composition of novel white grape genotypes (Vitis vinifera L.). J. Food Compos. Anal. 102, 103987 https://doi.org/10.1016/j.jfca.2021.103987.

Ostovare, M., Shahraki, M.R., 2019. Evaluation of hotel websites using the multicriteria analysis of PROMETHEE and GAIA: evidence from the five-star hotels of Mashhad. Tour. Manag. Perspect. 30, 107–116. https://doi.org/10.1016/j.tmp.2019.02.013.

Passuello, A., Cadiach, O., Perez, Y., Schumacher, M., 2012. A spatial multicriteria decision making tool to define the best agricultural areas for sewage sludge amendment. Environ. Int. 38, 1–9. https://doi.org/10.1016/j.envint.2011.07.013.

Paul, M., Negahban-azar, M., Shirmohammadi, A., Montas, H., 2020. Assessment of agricultural land suitability for irrigation with reclaimed water using geospatial multi-criteria decision analysis. Agric. Water Manag. 231, 105987 https://doi.org/10.1016/j.agwat.2019.105987.

Pinho, R.R. (2019), Modelo de apoio à decisão multicritério para seleção de fornecedores de folha de Flandres: um estudo de caso na empresa can. Master Thesis - Curso de Logística, Instituto Politécnico do Porto, Porto.

Poissant, R., Mariotti, F., Zalko, D., Membré, J.M., 2023. Ranking food products based on estimating and combining their microbiological, chemical and nutritional risks:

Method and application to Ready-To-Eat dishes sold in France. Food Res. Int. https://doi.org/10.1016/j.foodres.2023.112939.

Sales, W.S., Ishikawa, F.H., Souza, E.M.C., Nascimento, J.H.B., Souza, E.R., Leão, P.C.S., 2019. Estimates of repeatability for selection of genotypes of seedless table grapes for Brazilian semiarid regions. Sci. Hortic. 245, 131–136. https://doi.org/10.1016/j.scienta.2018.10.018.

Sang, X., Yu, X., Chang, C.T., Liu, X., 2022. Electric bus charging station site selection based on the combined DEMATEL and PROMETHEE-PT framework. Comput. Ind. Eng. 168, 108116 https://doi.org/10.1016/j.cie.2022.108116.

Siskos, Y., Matsatsinis, N.F., Baourakis, G., 2001. Multicriteria analysis in agricultural marketing: The case of French olive oil market. Eur. J. Oper. Res. 130, 315–331. https://doi.org/10.1016/S0377-2217(00)00043-6.

Sotiropoulou, K.F., Vavatsikos, A.P., 2021. Onshore wind farms GIS-Assisted suitability analysis using PROMETHEE II. Energy Policy 158, 112531. https://doi.org/10.1016/j.enpol.2021.112531.

Sousa, L.C.O., Bezerra, S.T.M., Amorim, J.M.B.S., Alves, I.M., Duarte, A.D., 2020. Avaliação de alternativas direcionadas à redução do consumo de água potável em residências: estudo de caso em Caruaru, PE, Brasil. Ambient. Construído 20, 465–487. https://doi.org/10.1590/s1678-86212020000400483.

Stankivic, J.J., Milic, V.J., Marjanovic, I., Janjic, J., 2021. An integrated approach of PCA and PROMETHEE in spatial assessment of circular economy indicators. Waste Manag. Vol 128, 154–166. https://doi.org/10.1016/j.wasman.2021.04.057.

The International Organization of Vine and Wine. Descriptor List for Grape Varieties and Vitis Species, (2009),2nd ed.; OIV: Paris, France. DOI 10.1016/j.wasman.2021.04.057.

Tohidi, A., Ghorbani, M., Karbasi, A.-R., Asgharpourmasouleh, A., Hassani-Mahmooei, B., 2020. "Comparison of Fuzzy Multi-Criteria Decision-Making Methods to Rank Business Strategies and Marketing Resources". ISSN 1804-1930 AGRIS -line Pap. Econ. Inform. Vol. 12 (No. 3), 101–114. https://doi.org/10.7160/aol.2020.120309.

Tong, L., Pu, Z., Chen, K., Yi, J., 2020. Sustainable maintenance supplier performance evaluation based on an extend fuzzy PROMETHEE II approach in petrochemical industry. J. Clean. Prod. 273, 122771 https://doi.org/10.1016/j.jclepro.2020.122771.

Trivedi, P., Shah, J., Moslem, S., Pilla, F., 2023. An application of the hybrid AHP-PROMETHEE approach to evaluate the severity of the factors influencing road accidents. Heliyon 9, e21187. https://doi.org/10.1016/j.heliyon.2023.e21187.

Ustaoglu, E., Simasn, S., Aydinoglu, A.C., 2021. Determining agricultural suitable land in peri-urban geography using GIS and Multi Criteria Decision Analysis (MCDA) techniques. Ecol. Model. 455, 109610 https://doi.org/10.1016/j.ecolmodel.2021.109610.

Vieira, E.M.A., Silva, L.B., Nascimento, J.A., Silva, J.M.N., Leite, W.K.S., 2019. Prioridade perceptiva e critérios de satisfação de atributos ambientais em Unidades de Terapia Intensiva. Ambient. Construído 19, 181–194. https://doi.org/10.1590/s1678-86212019000100300.

Wang, X., Li, Y., Xu, Z., Luo, Y., 2022. Nested information representation of multi-dimensional decision: An improved PROMETHEE method based on NPLTSs. Inf. Sci. 607, 1224–1244. https://doi.org/10.1016/j.ins.2022.06.053.

Yalew, S.G., Griensven, A., Zaag, P., 2016. AgriSuit: A web-based GIS-MCDA framework for agricultural land suitability assessment. Comput. Electron. Agric. 128, 1–8. https://doi.org/10.1016/j.compag.2016.08.008.

Xu, C., Yagiz, Y., Zhao, L., Simonne, A., Lu, J., Marshall, M.R., 2017. Fruit quality, nutraceutical and antimicrobial properties of 58 muscadine grape varieties (Vitis rotundifolia Michx.) grown in United States. Food Chem. 215, 149–15. DOI: 10.1016/j.foodchem.2016.07.163.