PRACTICAL METHOD FOR TABLE GRAPE SELECTION USING MULTICRITERIA DECISION ANALYSIS

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ABSTRACT

The São Francisco Valley (Pernambuco-PE, Brazil) is of great importance for the local economy, since the region represents a large portion of Brazilian production and export of fresh grapes. Traditional methods of feasibility analysis involve only cost or productivity analyses, but for the grape growers there must be techniques and methods that assist decision making involving other criteria with characteristics of the grape. Yet, there is a noticeable lack of multi-criteria methods that assist the grower in making decisions for selection of commercial table grape cultivars for the feasibility analysis. Thus, the aim of the present study is to select table grape cultivars through multiple criteria, using a new method for eliciting scale constants: the Flexible and Interactive Tradeoff (FITradeoff), for the purpose of assisting a rural producer to expand production while minimizing inconsistencies in the decision-making process. With the assistance of a decision maker, the Decision Matrix and Consequence Table were constructed on Microsoft Excel® – composed by 11 criteria and 3 alternatives, all closed source grape cultivars (with patents). Then, the data were applied on the FITradeoff software for the ranking problematic. Thus, it was possible to arrive at a ranking of the best alternatives, where the cultivar Timpson (SNFL) (U2) was found to be the optimal solution proposed for the rural producer. The application of FITradeoff provided a satisfactory result with little time and effort spent, leading to a final suggestion for the decision maker. In addition, at the end of the process, it provided graphical visualization of the performance and dominance of each criterion selected, as well as a ranking of the grape cultivars through the Hasse Diagram, with the order of the best alternatives. Ordering the grape genotypes considering Multi-Criteria Decision Analysis methods is crucial to selection of commercial table grape cultivars. The method can be applied to other segments of agriculture that require multi-criteria evaluations.

Key words: multi-criteria decision, commercial grapes, feasibility analysis, Pernambuco, Brazil

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RESUMEN

El Valle del São Francisco (Pernambuco-PE, Brasil) es de gran importancia para la economía local, ya que la región representa gran parte de la producción y exportación brasileña de uva fresca. Los métodos tradicionales de análisis de viabilidad implican únicamente análisis de costos o de productividad, pero para los viticultores deben existir técnicas y métodos que ayuden a la toma de decisiones que involucren otros criterios con características de la uva. Sin embargo, hay una carencia notable de métodos multicriterio que ayuden al productor a tomar decisiones para la selección de cultivares comerciales de uva de mesa para el análisis de factibilidad. Por tanto, el objetivo del presente estudio fue seleccionar cultivares de uva de mesa a través de múltiples criterios, utilizando un nuevo método para obtener constantes de escala: el Compensación Flexible e Interactiva (*FITradeoff*), con el fin de ayudar a un productor rural a expandir la producción y minimizar las inconsistencias en el proceso de toma de decisiones. Con la ayuda de un tomador de decisiones, la Matriz de decisión y la Tabla de consecuencias fueron construidas en Microsoft Excel®, compuestas por 11 criterios y 3 alternativas, siendo todos los cultivares de uva de fuente cerrada (con patentes). Luego, los datos fueron aplicados en el software *FITradeoff* para la problemática del ranking. Así, se pudo llegar a un ranking de las mejores alternativas, donde se encontró que el cultivar Timpson (SNFL) (U2) es la solución óptima propuesta para el productor rural. Además, al final del proceso el estudio proporcionó una visualización gráfica sobre el desempeño y dominancia de cada criterio seleccionado, así como un ranking de los cultivares de uva a través del Diagrama de Hasse, ordenando las mejores alternativas. Ordenar los genotipos de uva considerando métodos de análisis de decisión multicriterio es crucial para la selección de cultivares comerciales de uva de mesa. El método se puede aplicar a otros segmentos de la agricultura que requieran evaluaciones multicriterio.
Palabras clave: decisión multicriterio, uvas comerciales, análisis de factibilidad, Pernambuco, Brasil

RÉSUMÉ

La vallée du fleuve São Francisco (Pernambuco-PE, Brésil), est d'une grande importance pour l'économie locale, parce que la région représente une grande partie de la production et de l'exportation brésiliennes de raisins frais. Les méthodes traditionnelles d'analyse de faisabilité n'impliquent que des analyses de coût ou de productivité, mais pour les viticulteurs, il doit y avoir des techniques et des méthodes qui aident à la prise de décision impliquant d'autres critères avec les caractéristiques du raisin. Pourtant, il y a un manque notable de méthodes multicritères qui aident le producteur à prendre des décisions pour la sélection de cultivars commerciaux de raisins de table pour l'analyse de faisabilité. Ainsi, l'objectif de l'étude est de sélectionner des cultivars de raisin de table à travers de multiples critères, en utilisant une nouvelle méthode pour obtenir des constantes d'échelle : le compromis flexible et interactif (FITradeoff), dans le but d'aider un producteur rural à développer sa production tout en minimisant les incohérences. dans le processus de prise de décision. Avec l'aide d'un décideur, la matrice de décision et le tableau des conséquences ont été construits sur Microsoft Excel® - composés de 11 critères et 3 alternatives, tous des cultivars de raisin de source fermée (avec brevets). Ensuite, les données ont été appliquées sur le logiciel FITradeoff pour la problématique de classement. Ainsi, il a été possible d'arriver à un classement des meilleures alternatives, où le cultivar Timpson (SNFL) (U2) s'est avéré être la solution optimale proposée pour le producteur rural. L'application de FITradeoff a fourni un résultat satisfaisant avec peu de temps et d'efforts, conduisant à une suggestion finale pour le décideur. De plus, à la fin du processus, il a fourni une visualisation graphique des performances et de la dominance de chaque critère sélectionné, ainsi qu'un classement des cépages à travers le diagramme de Hasse, avec l'ordre des meilleures alternatives. Le classement des génotypes de raisin en tenant compte des méthodes d'analyse décisionnelle multicritères est crucial pour la sélection des cultivars commerciaux de raisin de table. La méthode peut être appliquée à d'autres segments de l'agriculture qui nécessitent des évaluations multicritères.
Mots-clés : décision multicritères, cépages commerciaux, analyse de faisabilité, Pernambuco, Brésil

RESUMO

O Vale do São Francisco (Pernambuco-PE, Brasil) é de grande importância para a economia local, pois a região representa grande parte da produção brasileira de exportação de uvas frescas. Os métodos tradicionais de análise de viabilidade envolvem apenas análise de custo ou de produtividade, mas para os viticultores deve haver técnicas e métodos que ajudem a tomar decisões que envolvam outros critérios como características da uva. No entanto, há uma

notável falta de métodos multicritério para ajudar o produtor a tomar decisões para a seleção de cultivares comerciais de uva de mesa para análise de viabilidade. Portanto, o objetivo deste estudo é selecionar cultivares de uva de mesa, por meio de múltiplos critérios, utilizando um novo método para obtenção de constantes de escala: a Compensação Flexível e Interativa (FITradeoff), a fim de auxiliar um produtor rural a expandir a produção e a minimizar inconsistências no processo de tomada de decisão. Com o auxílio de um decisor, foi construída a Matriz de Decisão e a Tabela de Consequências no Microsoft Excel®, composta por 11 critérios e 3 alternativas, todas cultivares de uvas de código fechado (patenteadas). Em seguida, os dados foram aplicados no software FITradeoff para o problema de classificação. Assim, chegou-se a um ranking das melhores alternativas, o que possibilitou constatar que cultivar Timpson (SNFL) (U2) é uma solução ótima proposta para o produtor rural. Além disso, ao final do processo, foi possível uma visualização gráfica do desempenho e da dominância de cada critério selecionado, bem como um ranking das cultivares de uva, por meio do Diagrama de Hasse, com a ordem das melhores alternativas. A ordenação dos genótipos de uvas, considerando métodos de Análise de Decisão Multicritério, é crucial para a seleção de cultivares comerciais de uva de mesa. Esse método pode ser aplicado a outros segmentos da agricultura que requerem avaliações multicritérios.
Palavras-chave: decisão multicritério, uvas comerciais, análise de viabilidade, Pernambuco, Brasil

1. INTRODUCTION

The *Vale do São Francisco* (São Francisco River Valley), in the semi-arid Northeast Region of Brazil, is internationally recognized for irrigated fruit growing, especially for the mango and grape crops, making it a relevant vector for the Brazilian economy (Maia, Ritschel & Lazzarotto, 2018). The region had a production volume of 384,179 metric tons in 2020 and represented approximately 99% of the grapes exported by Brazil (IBGE, 2021).

In this scenario, according to the Brazilian Ministry of Foreign Trade (Ministério da Indústria, Comércio Exterior e Serviços-MDIC), the *Submédio do Vale do São Francisco* (Lower-Middle São Francisco River Valley) was responsible for U$ 363.5 million of fresh fruit exported in 2020 (MDIC, 2020). Viticulture is substantially represented in this, with one of the largest portions of the irrigated agriculture of the Petrolina-PE and Juazeiro-BA commercial hub. In 2020, it had 10,268 ha of planted area for grapes dedicated to table grapes and wine production (IBGE, 2021). The Vale do São Francisco represents 13.7% of planted area of grapes in Brazil (IBGE, 2021).

Rural producers face difficulties in choosing commercial table grape cultivars, due to the large number of options available on the market. There are currently more than 20 table grape cultivars made available by private international genetic and breeding companies for licensed growers (closed source with patent) and by Embrapa (the public Brazilian Agricultural Research Corporation) through its grape breeding program «Grapes of Brazil» (*Uvas do Brasil*) (open source) (Leão, Nascimento, Moraes & de Souza, 2020).

The decision-making process in agriculture requires methods that assist the Decision Maker (DM) to evaluate these alternatives, considering multiple criteria and preferences (Leyva, Álvarez & Ahumada, 2017; Tascioglu, Akpinar & Bozkurt, 2020; Hassan *et al*., 2020). Given this importance, the selection of commercial grape cultivars must be performed in a way that meets a series of criteria, such as preference of the consumer market, yield, susceptibility to pests, post-harvest, ease of transport, cost, payment of royalties, etc. (Leão, 2021).

Thus, it is necessary to use methods that support the rural producer in making structured decisions that maximize the probability of choosing grape cultivars that ensure greater profitability. Traditional methods of feasibility analysis involve only cost or productivity analyses and the Multi-Criteria Decision Analysis (MCDA) methods are an alternative for this type of evaluation, since recurring mistakes in the process of choosing grape cultivars can affect yield, grape quality, cost of production, and profitability and even lead to lack of acceptance by the consumer market (Wang *et al*., 2017).

Thus, the new Flexible and Interactive Tradeoff (FITradeoff) multi-criteria method may be a solution, since applying it makes the decision-making process simpler and more accurate. In addition, through it, the alternatives considered can be ranked, with tools that offer better visualization of the problem, of the criteria, and of the possible solution to be considered (de Almeida, de Almeida, Costa & de Almeida-Filho, 2016).

Studies based on more recent and sophisticated methods like FITradeoff with the support of the Multi-Attribute Value Theory (MAVT) have been applied in an increasing way in recent years for the purpose of assisting decision making in the most diverse sectors (Camilo, de Souza, Frazão & da Costa Junior, 2020; Rodrigues, Casado, Carvalho, Silva & Silva, 2020; de Almeida, Frej & Roselli, 2021). In the agriculture sector, studies applied to viticulture can be obtained through statistical analyses and/or with multi-criteria selection software, such as ELECTRE GD, Selegen, ANOVA, R, among others (Aznar & Caballer, 2005; Marques-Perez, Segura & Maroto, 2014; Vera-Montenegro, Baviera-Puig & Garcia-Alvarez-Coque, 2014; Mir & Padma, 2016; Leyva *et al.,* 2018; Crnèan, 2018; Vianna, Massignan & Dortzbach, 2019).

Nevertheless, the approaches cited above lack solutions for the challenges faced by rural producers related to cultivar selection. That requires effective structuring of the alternatives considering qualitative and quantitative criteria specific to grape, as, for example, the choice of open or closed technological standards (the latter requiring payment of royalties) or subjective evaluations of the shape or flavor of the grape, which is what makes this an original study. Consequently, in the approach of Kang, Frej & de Almeida (2020), the use of FITradeoff deals with the problem of eliciting processes. However, investigation of such a method in the agricultural sector, as explored by Carrillo, Roselli, Frej & de Almeida (2018), is still quite limited.

Linked to the above, even with the progressive adoption of FITradeoff, the method has not been used for selection of the best table grape cultivars for commercial purposes under the multi-criteria perspective. Thus, a pertinent question arises: How can a rural producer choose the best table grape cultivars to begin a commercial field in the Submédio São Francisco Valley considering multiple criteria? Therefore, the aim of this study is to select table grape cultivars under different criteria through the FITradeoff method for a rural producer who intends to begin or expand production, since it provides a potential solution in the multi-criteria choice process.

2. MATERIALS AND METHODS

2.1. PHASES OF THE STUDY

This research uses a case study, since it was performed on a farm that produces only table grapes from open-source cultivars (developed by Embrapa) and that needed to evaluate new closed-source cultivars (that is, developed by private international companies in which royalties are charged) to expand its growing area.

The study was designed in three steps. The first consisted of definition of the theme and objectives, in which an extensive bibliographical review was carried out regarding the method and the characteristics of the grape cultivars, given the need to analyze different characteristics of tradeoff involved in the research problem. In the second step, the decision matrix was characterized, with the criteria and alternatives defined by the DM, as well as by the data he provided, acquired through interviews and through collection from data banks, articles, and studies regarding the grape genotypes. In the last phase of the study, the method was applied with participation of the DM, in which his preferences were elicited in the FITradeoff, and finally, the results were analyzed and discussed. The flowchart with the phases of the study is shown in Figure Nº 1.

2.2. FITRADEOFF

The Flexible and Interactive Tradeoff (FITradeoff) is a flexible preference eliciting method for determination of the scale constants, denominated as weights, based on preferences coming from a decision maker from partial information in the tradeoff procedure (de Almeida *et al*., 2016). It

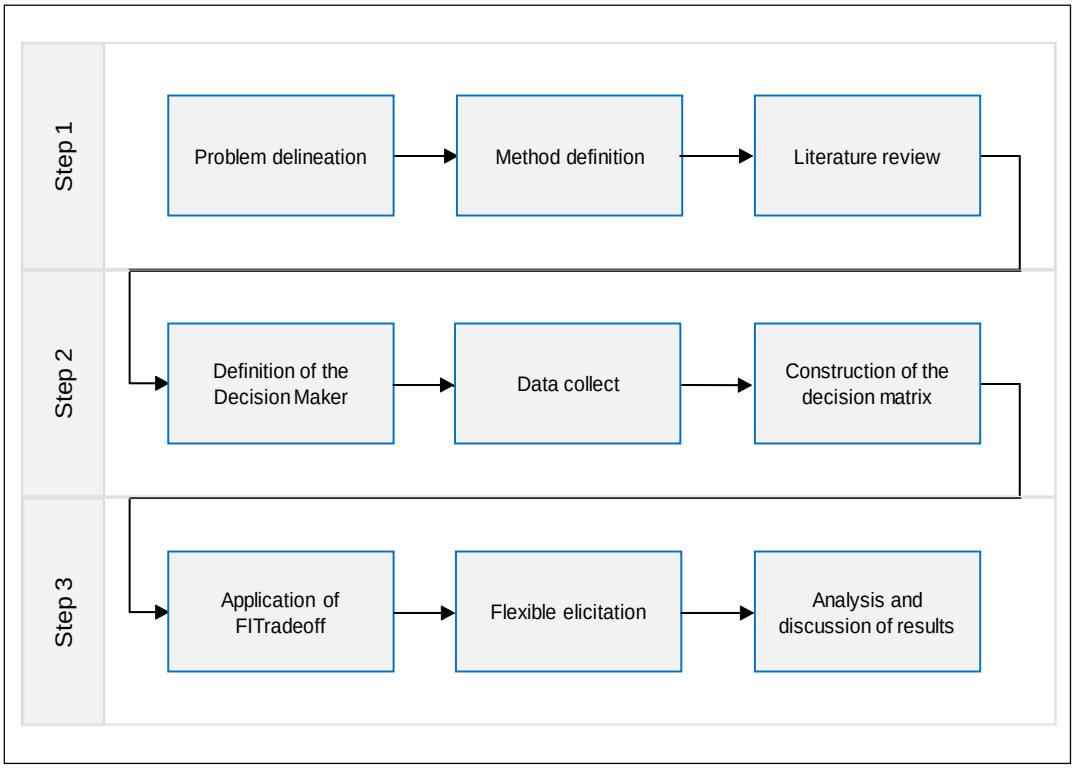

Figure 1. Research phases

overcomes the difficulties found in the traditional Tradeoff procedure (Keeny & Raiffa, 1979), improving its applicability by being adaptable to different scenarios, as well as by having an interactive characteristic, since its steps involve interaction with the DM and contain an evaluation of the alternatives present (Frej, de Almeida & Costa, 2019).

As defined by Mendes, Frej, de Almeida & de Almeida (2020), one of the main benefits noted upon comparing the FITradeoff method to the traditional Tradeoff model is considerable reduction in the demand for information required for decision making, with less cognitive effort. The Tradeoff method requires complete information on the part of the decision maker, whereas for FITradeoff, only partial information is necessary, maintaining its axiomatic structure. Thus, according to de Almeida *et al*. (2016), the previous recurrent inconsistency of 67% is significantly mitigated, since the DM provides reports of strict preferences and not of indifferences, providing for a process that is more reliable and applicable to different areas.

Carrillo *et al*. (2018) and Frej *et al*. (2019) highlight the steps to follow in development of the FITradeoff method, where, first of all, an inter-criteria evaluation should be performed in order to determine the importance, in decreasing order, of the weights of the criteria adopted (k_i) belonging to a k-weight set given by the scale of constants to be ranked (1).

$$k_1 > k_2 > k_3 > \ldots k_n \quad (1)$$

Following that, determination is made, through a value function $v(a_j)$, of the value of an alternative (a_j) in relation to a criterion i, from the sum of the scale constants, which are normalized in a linear scale from 0 to 1, expressed in Equation (2).

$$v\left(a_j\right) = \sum_{j=1}^{n} k_i v_i\left(a_j\right) \quad (2)$$

Based on that, considering γ alternatives through maximization of the Linear Programming Problem (LPP), an alternative will be denominated potentially optimal if the value (a_j), resulting in (2), is greater or similar to those of the alternatives in one or more scale constants present in the k-weight set, obtained in Equation (3).

$$\sum_{j=1}^{n} k_i v_i\left(x_{ij}\right) \geq \sum_{j=1}^{n} k_i v_i\left(x_{iz}\right) \forall z = 1,\ldots,r, z \neq j \quad (3)$$

If an optimal alternative potential is not identified, in contrast with the traditional Tradeoff method, the DM will respond to elicitations regarding the consequences without needing to specify an exact value of indifference (x_{ij}), but rather between points (x_i') and ('') provided from strict preferences defined by the decision makers. Then, a new weight area (1) with restrictions is obtained in the form of inequalities denoted in equations (4) and (5), to once more apply the LPP, until a new potentially optimal alternative is identified.

$$k_i v_i\left(x_i{}'\right) \geq k_{i+1} \quad (4)$$

$$k_i v_i\left(x_i{}''\right) \leq k_{i+1} \quad (5)$$

Even though FITradeoff is a recent method, it has already been applied in the most diverse manners, solving problematic aspects of choosing (de Almeida *et al*., 2016), in which it is possible to perform sensitivity analysis, ranking problematics (Frej *et al*., 2019), as well as classification problems (Kang *et al*., 2020) and portfolio selection (Frej, Ekel & de Almeida, 2021), which has not yet been greatly exploited. The methods listed deal with different sectors in their applications, according to each specificity, which meet the requirements of each case, such as water supply (Monte & Morais, 2019), textile industry (Rodrigues *et al*., 2020), medicine (Camilo *et al*., 2020), information technology (Poleto, Clemente, de Gusmão, Silva & Costa, 2020), renewable energy sources (Fossile, Frej, da Costa, de Lima & de Almeida, 2020) etc. For more in-depth discussion of the operation of the method, reading the studies of Frej *et al*. (2019), Mendes *et al*. (2020), de Almeida *et al*. (2016, 2017), and Almeida-Filho, de Almeida & Costa (2021) is recommended.

2.3. CHOICE OF CRITERIA AND ALTERNATIVES

The case study was applied on a farm for production of table grapes in the municipality of Petrolina, PE, in the Northeast region of Brazil, in which there are 8 ha planted of two open-source table grape cultivars: 6 ha occupied by 'BRS Vitória' and 2 ha by 'BRS Ísis'. The Decision Maker (DM) is the farm owner. A limitation of this work was that it considered only a single DM, instead of multiple DMs. For the study, the DM indicated three real closed-source grape cultivars called Sugar Crisp (IFG11), Timpson (SNFL), Autumn Crisp (Sun World) denominated respectively as U1, U2, U3–which were selected in a deterministic way by the DM since he would like to expand his agricultural production considering their values in the market, productivity, tendencies for costumers' preferences, among other features. The three cultivars mentioned have white grape color in common, as well as other important agronomic traits, such as high yield, desirable berry size, and pleasant flavor. It is important to emphasize that, in other case studies, these varieties could be previously chosen differently and the three varieties cannot serve as a bias.

Coelho, Araújo & Lima (2022) have emphasized that since 2008, the grapevine varieties traditionally cultivated in the São Francisco Valley have experienced a decline in profitability. In 2010, the region witnessed the inception of trials involving patented grape varieties. Presently, these trials have burgeoned to encompass an expansive repertoire of over 130 cultivars, which have been genetically engineered and developed by six international corporations (Grapa, Ifg, Snfl, Ana, Stargrown, and Hoerkstra), in conjunction with domestic varieties painstakingly evolved by Embrapa without incurring any royalty-related expenses (Eijsink, 2019). In a broader context, these grapevine varieties have exhibited remarkable adaptability to the climatic conditions of the São Francisco Valley region. This adaptability

has enabled year-round production, rendering the region capable of catering to both national and international markets, thereby yielding two to three harvests annually. Furthermore, Coelho, Araújo, and Lima (2022) have conducted deterministic analyses, probing the behavior of economic efficiency and economic-financial viability indicators. These analyses have ascertained that the cultivation of seedless grapes stands as a fiscally sound agricultural pursuit, contingent upon an assumed return on invested capital ranging between 12% and 35%. Consequently, the selection between domestically developed grape varieties by Embrapa (2021), and those necessitating the payment of licensing fees and royalties demands meticulous examination due to the potential impact on overall profitability positively or negatively. In the specific case under scrutiny within this study, the DM endeavors to expand production towards grape varieties experiencing heightened market demand. The criteria to evaluate these three cultivars were listed according to the preference and experience of the DM in order to select which grape cultivars have greatest potential of being produced on his property.

For the small producer of the Submédio of the São Francisco Valley, there is the difficulty of access to closed-source grape cultivars since there is restriction in making new cultivars available on the part of each genetics and breeding company. For example, even if the grower has interest and is able to invest in production of a certain cultivar, if that cultivar has already reached the limit foreseen for growing it and the production volume in the country, there is no possibility of it being grown by this new producer; even when the grower is licensed for growing the cultivar, the areas dedicated to it will be limited. Despite all that, the decision maker has the desire of acquiring a closed-source cultivar from the perspective of increasing profitability and competitiveness not only in the Brazilian market, but especially in the foreign market. In addition, he may enhance his production chain by the quality and diversification of the grape cultivars acquired.

The descriptions of each one of the criteria are shown in Table Nº 1, along with specification of the units of measurement and scales used, also the respective classifications regarding the type of variable and if the decision maker aims to minimize or maximize them. Maximization of berry shape, for example, refers to the fact that an elliptical shape is preferred by the consumer market.

From the data provided by the decision maker, as well as research on the remaining information carried out in data banks, publications, articles, and platforms regarding grape genotypes, the Decision Matrix was filled out on Microsoft Excel®. In a preliminary manner in the criteria selection process, two of the 13 previously listed criteria were eliminated: Color and the presence of seeds. These criteria were eliminated because the three varieties had the same color (all white) and none of them had seeds (seedless grapes), making it unnecessary to include the criteria in the matrix. Thus, 11 criteria remained: (C1) access to the cultivar, (C2) sales value, (C3) yield, (C4) cost of production, (C5) resistance to rain, (C6) royalties charged, (C7) flavor, (C8) SS (°Brix), (C9) berry firmness, (C10) berry size, and (C11) berry shape. Based on these criteria, the consequence table was set up, where the performance of each one of the grapes is represented in relation to the criteria listed, as represented in Table Nº 2.

Given this importance of the problematic of ranking, FITradeoff was applied to the data for the purpose of placing the alternatives in increasing order based on a preference structure. For construction of the ranking to be possible, the pair-by-pair dominance relationships present among the alternatives are evaluated from information provided by the DM subjectively according his preferences (once again, it should be noted that the opinions of other specialists or decision-makers were not used).

Finally, with the participation of the decision maker, the method was applied in FITradeoff to the problematic of ordering, following two steps. In the first, pair-by-pair comparison was taken into account–the choice of this type of analysis was made considering the small group of alternatives available, as well as the fact that many of the criteria had shown a very similar degree of importance to the DM.

Table 1
Description of criteria

Criteria	Description	Measurement	Classification
Access to the cultivar	The producer's level of difficulty in gaining access to the vine genotype	1 - Very difficult 2 - Difficult 3- Median 4 - Easy 5 - Very easy	Discreet Maximize
Royalties charged	Percentage of royalties charged on sales volume	Percentage	Continuous Minimize
Cost of production	Degree of cost in grape production	1 - Low 2 - Medium 3 - High	Discreet Minimize
Sales value	The selling price of grapes on the market	Reais (R$)	Continuous Maximize
Yield	Grape variety productivity scale	1 - High 2 - Average 3 - Low	Discreet Maximize
Resistance to rain	Degree of resistance of the variety to rain	1 - Low 2 - Medium 3 - High	Discreet Maximize
Flavor	Grape flavor	1 - Neutral 2 - Foxed 3 - Muscat 4 - Special	Discreet Maximize
Berry's Firmness	Berry´s firmness	1 - Nothing firm 2 - Not firm 3 - Median 4 - Firm 5 - Very firm	Discreet Maximize
SS (°Brix)	Grape sugar level	Degree (°)	Continuous Minimize
Berry's shape	Berry's shape	1 - Globose 2 - Oval 3 - Elliptical	Discreet Maximize
Berry's size	Berry's size	Millimeter (mm)	Discreet Maximize

Table 2
Consequence matrix of the performance of grape varieties

Genotype	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
U1 (Sugar Crisp (IFG11))	1	9.5	2	5	3	0.05	1	17	3	20	3
U2 (TIMPSON (SNFL)	4	10	3	3	1	0.03	3	18.2	4	22	2
U3 (AUTUMN CRISP (Sun World	3	4	2	4	1	0.05	3	19.3	5	30	3

After initial selection of the criteria, it is necessary to determine the degree of preference among the alternatives, based on their importance to the DM, which may vary according to the criteria and to the scenario proposed by the method. For example, the DM must choose the best scenario for the yield and cost criteria in relation to others. That way, pair-by-pair comparison proved to be simpler in the process of choosing, by providing better understanding of the dominance relationships in each one of the interactions since the DM chose between two consequences that represented the best case possible for a certain criterion and the worst for all the rest. Thus, the FITradeoff method was applied, where from extraction of the dominance relationship found among the alternatives, obtained through pair-by-pair comparison, the following ranking was the result:

$$k_{Access\ to\ the\ cultivar} > k_{Sales\ value} > k_{Yield} > k_{Cost\ of\ production} > k_{Resistance\ to\ rain} > k_{Royalties\ charged} > k_{Flavor} > k_{SS} > k_{Berry\ firmness} > k_{Berry\ size} > k_{Berry\ shape}$$

Such a sequence exactly portrays the desire of the decision maker, who has the priority of maximizing ease of access to the cultivar, since if he is unable to obtain a certain grape genotype, there is no use in highlighting the other criteria. In addition, the subsequent preferences of the decision maker are aspects related to maximization of profit and reduction of costs (sales value, yield, cost of production). The criteria referring to the properties of the grape, especially those in respect to the berry, had less relevance in the choice of the decision maker.

It should be emphasized that the royalties present in the closed-source cultivars are of great importance to the decision maker, but as the mean percentage is around 5% in most grapes sold, the decision maker decided to place greater emphasis on other criteria, due to the restriction in the variation of the values of this criterion.

After obtaining the ranking of the criteria, the second part of the application of FITradeoff consisted of carrying out flexible elicitation, which proved to be easily understood by the decision maker. Under the premise that those alternatives that are dominant will potentially be optimal, those under domination will not be. In addition, it is necessary to take into consideration that an alternative not being under domination does not necessarily imply that it is potentially optimal.

3. RESULTS

Flexible elicitation was then used to obtain the pair-by-pair dominance matrix, generated in each one of the steps. Table Nº 3 synthesizes the application of this step, in which the first column portrays the numbering of the interactions, and the second and third columns indicate the consequences presented for the choice of the decision maker. In Table Nº 3, A simulates an intermediate result for one of the criteria indicated, and the worst for the others, whereas B indicates the best result possible for a determined criterion, as well as the worst for the rest. The consequence that was selected by the DM is indicated in the third column, and the last column presents the levels of ranking obtained from application of the Linear Programming Problem (LPP) in the FITradeoff.

That way, FITradeoff achieved the best alternative after only 6 interactions. Two of the cultivars–Timpson (SNFL) (U2) and Autumn

Table 3
Flexible elicitation steps

Steps	Consequence A	Consequence B	Answer	Ranking levels
1	3 - Access to the cultivar	Berry's firmness	A	2
2	3 - Access to the cultivar	Sales Value	B	2
3	11.75 - Sales Value	Yield	B	2
4	2.5 - Yield	Cost of production	I	2
5	4 - Cost of production	Resistance to rain	A	2
6	2 - Resistance to rain	Royalties charged	A	3

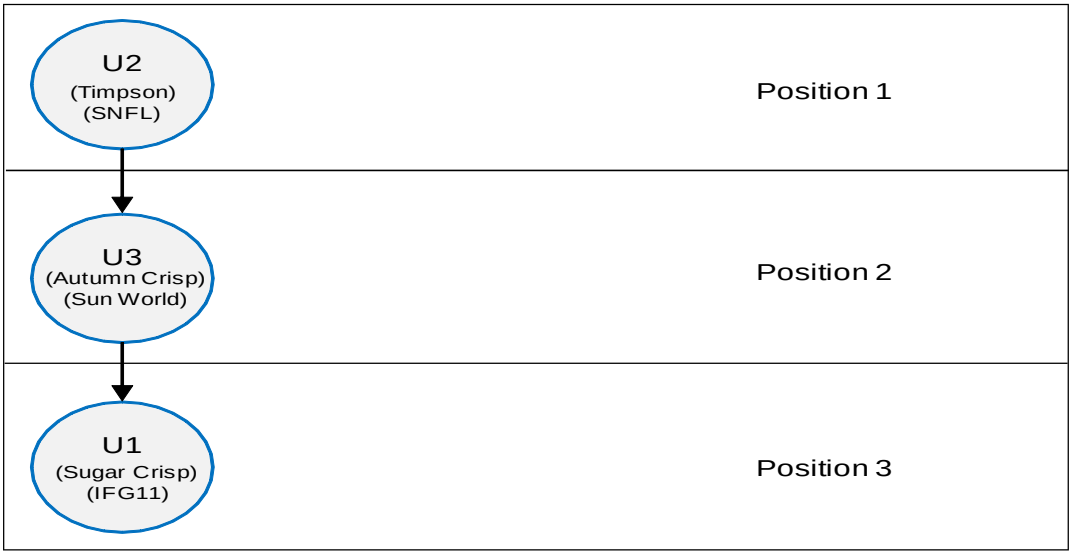

Figure 2. Hasse diagram of grape varieties

Crisp (Sun World) (U3), persisted as potentially optimal throughout the process. Following from the response of the sixth interactions, the result of the procedure indicated 'U2' as the best alternative. Access to the cultivar and Sales value were important criteria to ranking U2 at the top of the ranking.

Thus, the ranking of the table grape cultivars is illustrated in Figure Nº 2, where the diagram presents the dominance relationship among the 3 cultivars: 'U2' dominates 'U1' and 'U3', and 'U3' dominates 'U1'.

Consequently, the DM has an indication of the best option of grape cultivar in an understandable way. In addition, FITradeoff calculates the largest possible amount of information provided by the decision maker in order to determine the inequalities among the criteria, and from that, construct what is known as the weight area. It expresses a clear relationship of dominances of alternatives; that is, the selected value of the alternative that makes it dominate the others is presented.

1. DISCUSSION

For the scenario discovered, with Timpson (SNFL) (U2) being the best alternative, Figure Nº 3 shows the analysis of sensitivity provided through the resulting weight area containing the upper and lower limit of the scale constants of each one of the eleven criteria–in decreasing order. In Figure Nº 3, the reference of intervals of each constant are provided, showing the largest and smallest value that each one can express, as well as the value of the scale constant that maximizes the overall value of the alternative (denoted by X).

According to Carrilo *et al*. (2018), the larger the amplitude of the intervals of the values, the more robust the result will be; that is, the recommendation of the best decision for the DM will be made in a more assertive manner. That way, analysis of the diagrams shows that as of alternative C5 (resistance to rain), the distance between the upper and lower limits begins to become more restricted, to the point that a linear constant is established from C6 (royalties charged) on. This is due to the fact of several of these underlying criteria not having exhibited a totally established preference for the decision maker himself, since for him, the last four had less preference according to DM. In addition, some of these criteria (flavor, berry shape, royalties charged, and resistance to rain) had very similar or even equal data, which may lead to the proximity of the values of the constants.

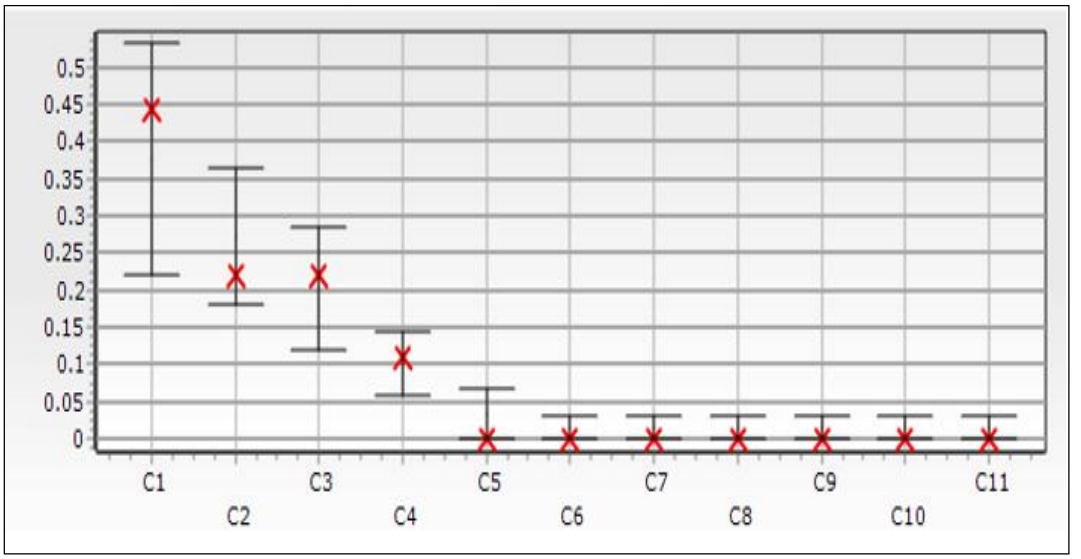

Figure 3. Weight Area–Software FITradeoff

Although the amplitude between the weight limits proved to be quite closed for most of the alternatives, for those considered most important to the DM, a more considerable opening was expressed. This is due to the fact of 'U2' standing out within the preferences of the decision maker, as well as of 'U1' having an inferior result in many of them. The 'U2' cultivar proves to have the easiest access, the lowest royalties charged and cost of production, median sales value, and highest yield, among other criteria.

Thus, taking this justification into consideration, FITradeoff achieved a final solution which was taken as recommendable and adequate for the decision maker. With little time and effort required and with only 6 questions, the flexible elicitation process was able to provide for grounded and satisfactory decision making, achieving its purpose. Thus, FITradeoff provided a full ordering of the alternatives to this problem described by Frej *et al*. (2019). It is important to emphasize that the MCDA has the subjectivity of a rural producer and this characterize varies among rural producers and according to the data of each grape. The MCDA does not allow generalization of results, because they are specific to each decision maker.

4. CONCLUSION

The present study applied the Flexible and Interactive Tradeoff to the problematic of feasibility study considering multi-criteria in reference to table grape cultivars for commercial sale in the *Submédio* of the *São Francisco* Valley. Thus, based on data collection regarding 11 criteria referring to three closed-source grape cultivars, the study achieved its goal of selecting the best from the perspective and preferences of a rural producer.

The application of FITradeoff proved to be practical, with few inconsistencies, and it was easily understood by the DM. It provided a satisfactory result with little time and effort spent, leading to a final suggestion for the decision maker. In addition, at the end of the process, it provided graphical visualization of the performance and dominance of each criterion selected, as well as a ranking of the grape cultivars through the Hasse Diagram, with the order of the best alternatives. The Timpson (SNFL) (U2) cultivar was the optimal solution, followed by Autumn Crisp (Sun World) – (U3), which was potentially optimal through most of the process, and the Sugar Crisp (IFG11) (U1) cultivar was last. The access to the cultivar and sales values were the most important criteria, while berry shape and berry firmness were the least important for the DM.

Therefore, FITradeoff for the problematic of ranking (Frej *et al.*, 2019), through the concept of pair-by-pair dominance relationships, provided a complete ordering of the alternatives. It was possible to acquire not only a satisfactory result from it, but also vast knowledge regarding the method and the grape genotypes studied, generating interest in deepening these topics. The method showed how to use other criteria, beyond the costs, to analyze the feasibility of choosing new grape cultivars. A limitation of this work was that it considered only a single decision maker considering his experience and, consequently, its subjectivity. The evaluation could be conducted with a larger number of farmers who are willing to assess the same grape varieties to give more robustness to the results. It is expected in the future to replicate this work with other decision makers and/or more specialists in grape production, in order to elicit the preferences of rural producers in the São Francisco Valley for the choice of new grape varieties. A second limitation is that this research does not compare grapes with and without royalties, which could be interesting to carry out in future studies. In the future, the authors hope to expand the variety of grape cultivars so that decision-makers can make choices based on quali-quantitative criteria. There is also an expectation to conduct assessments with rural producers with expertise in grape production, aiming to establish a panel comprising a minimum of 10 producers and specialists. This panel will include individuals who have previously tested the varieties reported in this case, as well as those cultivating different varieties, contributing to the enhanced accuracy of the multi-criteria evaluation. It is important to emphasize that the varieties presented at the end of the ranking in this study may appear at the top of the ranking for other rural producers intending to replicate the work. This, of course, depends on a subjective assessment by the decision-maker.

Based on these results, the authors suggest applying this method to other segments of agriculture that require multi-criteria evaluations to resolve problems involving selection and ranking of cultivars, as well as to problems involving feasibility analysis.

5. CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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