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DETERMINING CRITERIA WEIGHTS IN FRUIT PRODUCTION USING FUZZY MCDM METHOD

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Abstract

This research focused on the use of multi-criteria decision-making (MCDM) methods in fruit production, which requires the evaluation of numerous economic, biological, and technological factors. The complexity of decision-making in fruit production stems from the need to assess both quantitative and qualitative criteria. To address this, we applied the IMF SWARA method and the Fuzzy Bonferroni operator to determine the weight coefficients of key criteria. The research was conducted in multiple stages, utilizing a combination of different methods. In the first stage, the research team identified 11 criteria to be evaluated by various experts. In the second stage, a survey was developed, and 17 experts in the field of fruit production assessed the weight of the parameters. Finally, the determination of the criteria weights, using the IMF SWARA method and the Fuzzy Bonferroni operator, was based on the previous evaluation provided by four experts who identified themselves as belonging to the group of "University Professors". Out of a total of eleven criteria, two (C4 and C7) were identified as the most important.

Key words: *cultivars/rootstocks, ranking, fruit experts, evaluation, agriculture*

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1. Introduction

Competitiveness in fruit production depends on a range of factors, including economic, biological, technological, meteorological, and others. Achieving favourable economic results requires management and decision-making processes that acknowledge the existence of multiple factors and criteria, as well as the use of generally accepted methods of multi-criteria decision-making. On the other hand, research activities in fruit production and breeding involve the use of a larger number of criteria (attributes), some of which are quantitative while others are qualitative in nature. The existence of numerous criteria (attributes) and goals, both in production practice and in research activities, necessitates their systematization and the use of appropriate methods of multi-criteria analysis. This approach contributes to reducing subjectivity during decision-making (ranking), ultimately having a positive effect on the objectivity of the outcome of the given process. In recent years, a number of publications have been released in the scientific literature that deal with the practical application of multi-criteria decision-making methods in various fields of agriculture, including fruit production (Rozman et al., 2017; Vico et al., 2017; Bodiroga et al., 2022).

The wide range of application areas for multi-criteria analysis models has led to the rapid development of methods in this field. Consequently, we now have at our disposal a powerful set of methods capable of successfully solving most real-world MCDM problems. A review of numerous literature sources (Polatidis et al., 2006; Velasquez & Hester, 2013) has established that multi-criteria analysis methods can be divided into:

Multiple Attribute Decision Making (MADM) is characterized by the need to select the most acceptable alternative from a set of alternatives presented based on defined criteria. The common way of representing MADM problems is in matrix form (performance matrix or decision matrix).

Multiple Objective Decision Making (MODM) is explicitly defined by the analytical form of each criterion individually. A characteristic of MODM is that, through certain mathematical analyses, a set of multiple objective functions is transformed into a single-criterion decision-making problem. This is then solved using the standard method of single-criterion linear programming, most commonly the simplex procedure.

Regardless of the applied technique, the procedure will consist of the following phases: Defining the problem and certain key parameters; Determining the decision criteria – the model creation phase; Formulating functional relationships between the established criteria; Generating alternatives – the model solving phase, and Selecting an action in accordance with the established criteria – the solution implementation phase.

The aim of this research is to show the method of determining the weighting coefficients of criteria using the IMF SWARA method and Fuzzy Bonferroni operator.

2. Methods

The research was conducted in multiple stages, utilizing a combination of different methods. In the first stage, the research team identified 11 criteria to be evaluated by various experts. In the second stage, a survey was developed, and 17 experts in the field of fruit production assessed the weight of the parameters. Finally, in the third stage, the individual criterion weights were determined based on the evaluations of four experts from the group categorized as "University Professors."

2.1. IMF SWARA method

The IMF SWARA method was proposed by Vrtagić et al. (2021) and it contains the steps given below (Moslem et al. 2023):

Step 1: Put the criteria in descending order according to their expected importance.

Step 2: Identify a relatively lower importance of the criterion (criterion *Cj*) in relation to the previous one (*Cj−1*), and repeat it for each subsequent criterion. $\overline{\wp_j}$ represents the comparative importance of an average value.

Step 3: Define the fuzzy coefficient $\overline{\Im_j}$:

$$\overline{\Im_j} = \begin{cases} \bar{1} & j = 1 \\ \overline{\wp_j} \oplus \bar{1} & j > 1 \end{cases}$$

Step 4: Define the obtained weights $\overline{\aleph_j}$:

$$\overline{\aleph_j} = \begin{cases} \bar{1} & j = 1 \\ \dfrac{\overline{\aleph_{j-1}}}{\overline{\Im_j}} & j > 1 \end{cases}$$

$\overline{\Im_j}$ represents the fuzzy coefficient given in the previous step.

Step 5: Compute the fuzzy weight coefficients:

$$\overline{w_j} = \frac{\overline{\aleph_j}}{\sum_{j=1}^{n} \overline{\aleph_j}}$$

where the fuzzy relative weight of the criteria *j* is denoted by $\overline{w_j}$, and the number of criteria is denoted by *n.*

2.2 Fuzzy Bonferroni operator

For averaging criteria weighs obtained by four decision-makers, a fuzzy Bonferroni aggregator was used (Ashraf et al. 2022; Nedeljković et al. 2021).

$$a_{ij} = (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}) = \begin{cases} a_{ij}^{l} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{l\,p} \otimes a_j^{l\,q} \right)^{\frac{1}{p+q}} \\ a_{ij}^{m} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{m\,p} \otimes a_j^{mq} \right)^{\frac{1}{p+q}} \\ a_{ij}^{u} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{u\,p} \otimes a_j^{uq} \right)^{\frac{1}{p+q}} \end{cases}$$

where e is the number of experts participating in the research, and p, $q \geq 0$ are a set of non-negative numbers.

3. Results and discussion

3.1 Expert evaluation of criteria

The implementation of methods for determining weight coefficients was carried out on 11 selected criteria for ranking combinations of plum cultivars/rootstocks that are important in biotechnical research processes. Given that the selection of a combination of cultivars/rootstocks in fruit production is an extremely demanding process that includes various aspects, the following criteria are included: C1 - the number of flower buds per 1 m of fruiting twig (number/m); C2 - the number of flower buds per 1 m of 2-year old twig (number/m); C3 - germination of pollen (%); C4 final fruit set (%); C5 - trunk cross-sectional area (tree vigor, cm^2); C6 – Cumulative yield efficiency (kg/cm^2); C7 - Fruit weight (g); C8 – Flesh ratio (%); C9 Soluble solids (%); C10 - Total phenolic content in skin of fruit (mg GAE g^{-1} FW); C11 - radical-scavenging activity (μmol TE g^{-1} FW).

According to many authors (*Nenadović-Mratinić et al*., 2007; *Thurzó et al*., 2008; *Milatović et al*., 2014), the density of flower buds is an important parameter which indicates the potential yield of cultivars. The density of flower buds is important for determination of the intensity of pruning, because the cultivars with higher number of flower buds require heavy pruning, while the cultivars with less number of flower buds require light pruning (Milatović & Đurović, 2010).

The correct choice of the appropriate main cultivar in the orchard, as well as the selection of the appropriate pollinator, is one of the basic conditions for successful and profitable production of fruit trees. Pollination and fertilization are essential for adequate fruit set in plums. The functional ability of pollen, i.e. its germination and the growth of the pollen tube condition the processes of fertilization and fruit set.

Fruit set is one of the most significant indicators of fruit trees productivity (Glišić et al., 2012; Nikolić et al., 2012). Trunk cross-sectional area (TCSA) is considered as the most important indicator of tree vigor. Using of dwarf or semidwarf rootstocks enables an increase of the number of trees and higher yield per unit area (Kosina et al., 2000). One of the most important pomological properties of cultivar is fruit weight. Fruit weight is a characteristic that is inherited quantitatively and which determines yield, fruit quality and consumer acceptability (Crisosto et al., 2004).

According to many authors, the key parameters that determine the quality and the acceptance of the fruit by consumers are the content of soluble solids and total acids, as well as ration between them. (Crisosto et al., 2004). Phenolic compounds are biologically active substances having antioxidant properties and positive effects on human health (Walkowiak-Tomczak, 2008). The skin contains about five times more phenolic substances than the flesh (Stacewicz-Sapuntzakis et al., 2001). Antioxidant activity of plum fruits is higher in comparison to other pome and stone fruits, with the exception of sour cherries. In relation to the apple it is two to four times higher (Kim et al., 2003; Cho et al., 2007). The antioxidant activity values are significantly higher in the skin than in the flesh of the fruits, which can be explained by the higher content of total phenolic compounds and anthocyanins (Stacewicz-Sapuntzakis et al., 2001). Preliminary results are related to four of 17 experts involved in project research who are university professors. Their assessment of the criteria is shown in Table 1.

Table 1. Evaluation of criteria by four experts

E1	$\overline{\wp_j}$	E2	$\overline{\wp_j}$	E3	$\overline{\wp_j}$	E4	$\overline{\wp_j}$
C3		C4		C7		C3	
C4	(0,0,0)	C5	(0,0,0)	C8	(0,0,0)	C4	(0,0,0)
C7	(0,0,0)	C6	(0,0,0)	C9	(0.222,0.25,0.286)	C2	(0.222,0.25,0.286)
C1	(0.222,0.25,0.286)	C7	(0,0,0)	C10	(0,0,0)	C1	(0.222,0.25,0.286)
C2	(0,0,0)	C9	(0,0,0)	C11	(0,0,0)	C6	(0,0,0)
C6	(0,0,0)	C1	(0.222,0.25,0.286)	C1	(0.222,0.25,0.286)	C5	(0.222,0.25,0.286)
C8	(0,0,0)	C2	(0,0,0)	C2	(0,0,0)	C7	(0,0,0)
C5	(0.25,0.286,0.333)	C8	(0.222,0.25,0.286)	C4	(0,0,0)	C8	(0,0,0)
C9	(0,0,0)	C3	(0.222,0.25,0.286)	C3	(0.222,0.25,0.286)	C9	(0,0,0)
C10	(0,0,0)	C10	(0.25,0.286,0.333)	C5	(0,0,0)	C10	(0,0,0)
C11	(0,0,0)	C11	(0,0,0)	C6	(0,0,0)	C11	(0,0,0)

3.2 Determining Criteria Weights

After applying all steps of IMF SWARA method and fuzzy Bonferroni operator preliminary weights have been obtained as follows:

$$\overline{w_1} = (0.083, 0.089, 0.095), \quad \overline{w_2} = (0.089, 0.095, 0.101)$$
$$\underline{w_3} = (0.087, 0.093, 0.099), \quad \underline{w_4} = (0.108, 0.113, 0.118)$$
$$\underline{w_5} = (0.074, 0.080, 0.087), \quad \underline{w_6} = (0.085, 0.090, 0.096)$$
$$\underline{w_7} = (0.103, 0.107, 0.112), \quad \underline{w_8} = (0.085, 0.091, 0.097)$$
$$\underline{w_9} = (0.084, 0.090, 0.096), \quad w_{10} = (0.065, 0.072, 0.079)$$
$$w_{11} = (0.065, 0.072, 0.079)$$

Obtained results show that criteria C4 and C7 represent the most important criteria with crisp values of 0.113, and 0.107 respectively, while C10 and C11 represent criteria that have less significance with equal value of 0.072.

4. Conclusions

This paper presents the results of research that are part of the project Multi-Criteria Decision-Making in Fruit Production. Preliminary findings indicate that MCDM methods can be used to address various problems in agriculture and fruit production. Based on the previous survey and independent evaluation of criteria by experts, combined with different mathematical methods, it is possible to obtain the weighting coefficients for selected criteria. In our research, out of a total of eleven criteria, two (C4 and C7) were identified as the most important. After determining the criteria weights, an MCDM method is applied in the next phase, leading to the final ranking of alternatives—in this specific case, combinations of cultivar/rootstock.

For broader application of MCDM methods in solving multi-criteria problems in agriculture, it is necessary to inform researchers and practitioners about the potential of these methods. Since MCDM methods are not well-known among experts in agriculture, there is a need to develop a more "user-friendly" approach. A potential solution could be the creation of specific applications with a simple interface designed for a wider range of users.

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REFERENCES

[1] Ashraf, A., Ullah, K., Hussain, A., & Bari, M. (2022). Interval-valued picture fuzzy Maclaurin symmetric mean operator with application in multiple attribute decision-making. *Reports in Mechanical Engineering*, *3*(1), 210–226. https://doi.org/10.31181/rme20020042022a

[2] Bodiroga, R., Sredojević, Z., Vico, G., Govedarica-Lučić, A. (2022). Influence of different production methods on economic results of greenhouse vegetable production. *Custos e @gronegócio on line*, *18*(2), 44–62.

[3] Cho, Y. S., Yeum, K. J., Chen, C. Y., Beretta, G., Tang, G., Krinsky, N. I., Yoon, S., Lee-Kim, Y. C., Blumberg, J. B., Russell, R. M. (2007). Phytonutrients affecting hydrophilic and lipophilic antioxidant activities in fruits, vegetable and legumes. *Journal of the Science of Food and Agriculture*, *87(6)*, 1096–1107. https://doi.org/10.1002/jsfa.2817

[4] Crisosto, C. H., Garner, D., Crisosto, G. M., & Bowerman, E. (2004). Increasing 'Blackamber' plum (Prunus salicina Lindley) consumer acceptance. *Postharvest Biology and Technology*, *34(3)*, 237–244. https://doi.org/10.1016/j.postharvbio.2004.06.003

[5] Glišić, I., Cerović, R., Milošević, N., Đorđević, M., & Radičević, S. (2012). Initial and final fruit set in some plum (Prunus domestica L.) hybrids under different pollination types. *Genetika*, *44*(3), 583–593. https://doi.org/10.2298/GENSR1203583G

[6] Kim, D. O., Jeong, S. W., & Lee, C. Y. (2003). Antioxidant capacity of phenolic phytochemicals from various cultivars of plums. *Food Chemistry*, *81*, 321-326. https://doi.org/10.1016/S0308-8146(02)00423-5

[7] Kosina, J., Geibel, M., Fischer, M., & Fischer, C. (2000). Evaluation of some new plum rootstocks in the orchard. *Acta Hortic. 538*, 757–760. https://doi.org/10.17660/ActaHortic.2000.538.137

[8] Milatović, D., & Đurović, D. (2010). Characteristics of one-year old shoots of peach and nectarine cultivars. *Journal of Pomology*, *44*(169–170), 27–34. https://hdl.handle.net/21.15107/rcub_agrospace_2342

[9] Milatović, D., Đurović, D., & Zec, G. (2014). Morphological properties of fruit bearing shoots of apricot cultivars. *Journal of Agricultural Sciences* (Belgrade), *59*(3), 265-274. http://dx.doi.org/10.2298/jas1403265m

[10] Moslem, S., Stević, Ž., Tanackov, I., & Pilla, F. (2023). Sustainable development solutions of public transportation: An integrated IMF SWARA and Fuzzy Bonferroni operator. *Sustainable cities and society*, *93*, 104530. https://doi.org/10.1016/j.scs.2023.104530

[11] Nedeljković, M., Puška, A., Doljanica, S., Virijević Jovanović, S., Brzaković, P., Stević, Ž., & Marinkovic, D. (2021). Evaluation of rapeseed varieties using novel integrated fuzzy PIPRECIA–Fuzzy MABAC model. *Plos one*, *16*(2), e0246857. https://doi.org/10.1371/journal.pone.0246857

[12] Nenadović-Mratinić, E., Milatović, D., Đurović, D., & Jovičić, Z. (2007). Morphological characteristics of fruiting twigs in plum cultivars (Prunus domestica L.). *Journal of Pomology*, *41*, 51–56.

[13] Nikolić, D., Rakonjac, V., & Fotirić-Akšić, M. (2012). The effect of pollenizer on the fruit set of plum cultivar Čačanska Najbolja. *Journal of Agricultural Sciences (Belgrade)*, 57(1), 9–18. http://dx.doi.org/10.2298/JAS1201009N

[14] Polatidis, H., Haralambopoulos, D. A., Munda, G., & Vreeker, R. (2006). Selecting an appropriate multicriteria decision analysis technique for renewable energy planning. *Energy Sources, Part B: Economics, Planning, and Policy*, *1(2)*, 181–193. https://doi.org/10.1080/009083190881607

[15] Rozman, Č., Maksimović, A., Puška, A., Grgić, Z., Pažek, K., Prevolšek, B., & Ćejvanović, F. (2017). The use of multi criteria models for decision support system in fruit production. *Erwerbs-Obstbau*, *59*(3), 235–243. https://doi.org/10.1007/s10341-017-0320-3

[16] Stacewicz-Sapuntzakis, M., Bowen, P. E., Hussain, E. A., Damayanti-Wood, B. I., & Farnsworth, N. R. (2001). Chemical composition and potential health effects of prunes: A functional food. *Critical Reviews in Food Science and Nutrition, 41*, 251–286. https://doi.org/10.1080/20014091091814

[17] Thurzó, S., Szabó, Z., Nyéki, J., Racskó, J., Drén, G., Szabó, T., Nagy, J., Holb, I. J., & Veres, Z. S. (2008). Some fruit-bearing shoot characteristics of nine sweet cherry cultivars in Hungary. *Acta Horticulturae*, *795*, 673–676. https://doi.org/10.17660/ActaHortic.2008.795.106

[18] Velasquez, M., & Hester, T.P. (2013). An Analysis of Multi-Criteria Decision-Making Methods. *International Journal of Operations Research*, *10*(2), 56–66.

[19] Vico G., Govedarica-Lucic A., Rajic Z., Bodiroga R., Mičić I., Zec-Sambol S., & Micic M. (2017). Multi Attribute Assessment Approach in Vegetable *Production. Economics of Agriculture*, *64*(4), 1355–1365.

[20] Vrtagić, S., Softić, E., Subotić, M., Stević, Ž., Dordevic, M., & Ponjavic, M. (2021). Ranking road sections based on MCDM model: New improved fuzzy SWARA (IMF SWARA). *Axioms*, *10*(2), 92. https://doi.org/10.3390/axioms10020092

[21] Walkowiak-Tomczak, D. (2008). Characteristics of plums as a raw material with valuable nutritive and dietary properties-a review. *Polish Journal of Food and Nutrition Sciences*, *58(4)*, 401–405.