Erwerbs-Obstbau
https://doi.org/10.1007/s10341-022-00797-1

ORIGINAL ARTICLE / ORIGINALBEITRAG

Selection of the Optimal Apple Variety for Raising Orchards Using the Methods of Multi-criteria Analysis

Miroslav Nedeljković[1] · Adis Puška[2] · Aleksandar Maksimović[3] · Radmila Suzić[4]

Received: 15 February 2021 / Accepted: 5 November 2022

Abstract
Raising an orchard is a long-term investment and it is necessary to plan for all possibilities. The choice of the system of planting, tree distance, selection of varieties and planting materials must be carefully considered to ensure maximum production. Selection of the appropriate varieties of fruit is the most important problem fruit growers are faced with. Planting the wrong varieties entails long-term negative consequences. This paper deals with the way in which the model of decision-making can be used to facilitate decision-making. A hybrid decision-making model based on the method of multi-criteria analysis and group decision-making was created. By using a fuzzy approach and expert evaluation on the apples, the ranking of individual apple varieties was performed. Out of the total number of apple varieties, six varieties that are the most famous in the world were selected for this paper. These are also the varieties that are the most planted ones. The results of this study showed that the 'Jonagold' variety has the best results, while the 'Gala' variety showed the worst results. The application of the decision-making model provides guidelines for improving the decision-making process in orchards. The model can be used with the necessary corrections in other branches of orchards and serve orchardists to improve production.

Keywords Apple · Multi-criteria analysis · Orchards · Apple varieties · FUCOM · WASPAS

Introduction

Apples that belong to the rose family (Rosaceae) are the most produced in the world (Ntakyo et al. 2013). There are more than 7500 varieties of apples in the world, such as: 'Red Delicious', 'Golden Delicious', 'Fuji' and 'Jonagold', which are the most famous among them (Wu et al. 2016). Apple is a fruit from which, with various technological processes, one can get a wide variety of products such as jam, sweets, alcoholic drinks, vinegar and others. When selecting varieties of apples for raising orchards, it is necessary to examine all the aspects of investment and make decision to select a variety that best meets the goals of set investment (Maksimović et al. 2017). According to the same authors (2017), it is necessary to respect all the criteria of modern orchards such as economic, technological, and ecological criteria. Rozman et al. (2017) considered that the choice of varieties as one of the most important decisions when investing in new orchards. Considering a number of different criteria (economic, technical, and ecological), the decision-maker applies the appropriate method on the choice of varieties and eventually decides on several different alternatives (varieties). It is necessary to emphasize that each decision is based on a compromise solution, and that no solution satisfies all the goals set in the model. In the situation where a decision is made between several set alternatives and where they are evaluated by different criteria, multi-criteria analysis (MCDA) methods are used. The MCDA methods need to be adapted to the qualitative nature of the data.

In previous studies related to agriculture and agribusiness, the Analytical Hierarchical Process (AHP) method was used. Agha et al. (2012) used the AHP method when

✉ Adis Puška
adispuska@yahoo.com

1 Institute of Agricultural Economics, Volgina 15, 11060 Belgrade, Serbia

2 Department of Public Safety, Government of Brčko District of Bosnia and Herzegovina, Bulevara mira 1, 76100 Brčko, Bosnia and Herzegovina

3 Faculty of Ecology, Independent university of Banja Luka, Braće Podgornika 8, 78000 Banja Luka, Bosnia and Herzegovina

4 Faculty of Business in Belgrade, Singidunum University, Danijelova 32, 160622 Belgrade, Serbia

Published online: 29 December 2022

selecting crops required for planting, while Montazar and Gaffari (2011) used this method to select crops for irrigation systems. Rozman et al. (2015) used the AHP method to evaluate 13 apple varieties for new orchard. In addition, apart from using the AHP method, some authors used other methods or combinations of several methods. Zengeneh et al. (2015) used the Delphi, TOPSIS, and Fuzzy AHP method to make a choice of locating agricultural service centers. Using the fuzzy TOPSIS method and entropy, Sudha and Jeba (2015) have evaluated five different crops aiming at obtaining better and more accurate results that would be used by the decision-maker. The DEX method of multi-criteria decision-making has also found its application in the fruit varieties selection when raising new orchards (Rozman et al. 2017; Maksimović et al. 2017).

The aim of this paper is to choose the most suitable apple variety and also to decide which is the first choice for raising new orchards in Bosnia and Herzegovina (BiH) by applying the MCDA method. The climatic specifics prevailing in BiH were considered, and the expert assessment of individual varieties was used. People familiar with apple variety usage and with decades of experience in apple production in BiH were taken as experts.

Using expert decision-making, each apple variety had to be evaluated according to five main criteria that were previously set. In addition to the practical importance that model brings form of guidelines for building a new orchard according to modern market requirements. The importance is reflected in the possibilities of applying the new decision-making model based on the methods of MCDA. The model application is based on three methods of multi-criteria analysis: FUCOM (Full Consistency Method), a method used to find the importance of main criteria, CRITIC (Criteria Importance Through Intercriteria Correlation), a method used to find importance of sub-criteria and fuzzy WASPAS method (Weighted Aggregated Sum Product Assessment), used to rank the selected fruit varieties and find the ranking using expert ratings. These methods form a hybrid decision model which was used in this paper.

Research Methodology

The methodology used in this paper consisted of three phases, which are presented in Table 1:

- Phase 1. Initial phases and data collection
- Phase 2. Determining the weight criteria through FUCOM and CRITIC methods
- Phase 3. Calculation of ranking results and conducting sensitivity analysis using the fuzzy WASPAS method

The first phase and data collection consisted of seven steps. The first one was the definition of decision-making problem, in this case selection of the apple variety for a new orchard. Based on the decision problem, the research aim was formed. The problem of decision-making required subjective evaluation by experts, thus it was necessary to form a group of them. The selected experts are seven professors from the Department of Fruit Growing at the Universities of Novi Sad (Serbia), Niš (Serbia), and Bijeljina (BiH). The experts have years of experience and extensive knowledge of the fruit and apple varieties used in areas of BiH, Croatia and Serbia. After the experts had been selected, they chose the apple varieties that are mostly grown in these areas, to represent alternatives in this paper. Then, in cooperation with experts, the criteria were selected according to which these alternatives were ranked. Based on the selected criteria and alternatives, a decision-making model was formed (Fig. 1).

Based on the created model, a questionnaire consisting of two parts was formed. The first part of the questionnaire consisted of sub-criteria on which experts had to evaluate apple varieties through linguistic values. The second part of the questionnaire consisted of determining the importance

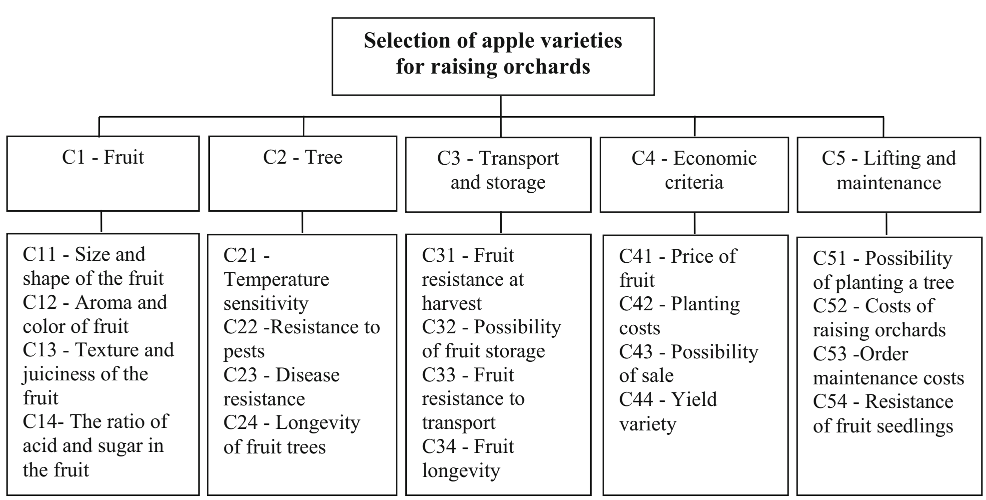


Fig. 1 Decision model

Table 1 Research methodology

Phase 1. The initial phase and data collection	Defining the problem and the aim of the research
	Forming an expert group
	Defining alternatives and criteria
	Forming models and questionnaires
	Data collection from experts
	Evaluation and input of the collected data
	Forming an initial decision matrix
Phase 2. Determining the weight of the criteria using the FUCOM and CRITIC methods	Ranking and comparison of criteria in a pair of main criteria
	Defining the constraints of a nonlinear model
	Calculating the values of the main criteria
	Dephasing and normalization of the initial decision matrix
	Calculating the values of standard deviation and correlation
	Implementation of the CRITIC method procedure
	Calculating the weight of sub-criteria
Phase 3. Calculating the results and conducting sensitivity analysis using the fuzzy WASPAS method	Normalization of the initial decision matrix
	Complicating the normalized decision matrix
	Determination of total relative significance by WSM and WPM methods
	Determining the cumulative criterion of optimality and ranking alternatives
	Scenario formation and sub-criteria weight
	Calculate the ranking order alternative for each scenario
	Discussion on the obtained results

of the main criteria. Based on the completed questionnaires, the data were evaluated and imported into the decision-making model. Then, the initial decision matrix was formed as the first step in the implementation of MCDA methods. Ranking alternatives in this decision-making model is prior to the determination of criteria weights.

Determining the weight of the criteria is the second phase of the research consisting of seven steps. The first three steps are related to the FUCOM method and the calculation of the weight of the main criteria, the other four steps are related to the CRITIC method and the calculation of the weight of the sub-criteria. In order to determine the main weight of the criteria, the experts filled in the second part of the questionnaire. First, they determined the rank of the main criteria according to the importance they have for each expert. They then compared these criteria in pairs and determined the value of the significance of the criteria in relation to the most important criterion. After that, the constraints of the nonlinear model were calculated, and the weights of the main criteria were formed. The weights of the sub-criteria were calculated based on the initial decision matrix. First, the initial decision matrix was defuzzified and normalized. Then the values of standard deviation and correlation were calculated, steps of the CRITIC method were used and the value of the weights of the sub-criteria was formed. Since the weights for the main criteria and sub-criteria have been calculated, it was necessary to rank the model alternatives.

Calculating the results and conducting sensitivity analyses consisted of seven steps. The first step was the normalization of the initial decision matrix, which was followed by the aggravation of the decision matrix. Then, relative significance according to the WSM and WPM methods was used, as well as determining the cumulative optimality criterion and determining the ranking of alternatives. Once the ranking order of alternatives was formed, it was necessary to determine the scenarios and the weights of their sub-criteria. Then, the ranking of alternatives for each scenario was calculated and the obtained results were discussed.

FUCOM Method

The FUCOM method represents a new model for determining the criteria weight in the MCDM environment. It is based on comparing the criteria in pairs and confirming the results by deviating from the maximum consistency, developed by Pamučar et al. (2018). The FUCOM method validates the model by calculating the error size for the obtained weight vectors and determining the degree of consistency (Ibrahimović et al. 2019). There are some advantages to the FUCOM method compared to other methods such as: fewer comparisons in a pair of criteria, the ability to evaluate the results by defining deviations from the maximum consistency and respect for consistency when comparing criteria in a pair. FUCOM provides the ability to perform model validation by calculating the error size for the obtained weight vectors and by determining the degree of consistency. The application of this method reduces subjectivity in the decision-making process, since in some methods the weight coefficients influence the final solutions.

The implementation of the FUCOM method was performed using the following steps (Pamučar et al. 2018):

- Step 1. Ranking of criteria/sub-criteria using expert evaluation
- Step 2. Determining the vector of comparative significance of the evaluation criteria
- Step 3. Defining the constraints of a nonlinear optimization model. The values of weight coefficients should satisfy two conditions:
  - Condition 1. The ratio of weight coefficients is equal to the comparative significance between the observed, i.e. the condition is met when: $w_k / w_{k+1} = \varphi_{k/(k+1)}$
  - Condition 2. The final values of the weighting coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$
- Step 4. Defining the model for determining the final values of the weighting coefficients of the evaluation criteria respecting the following conditions:

$$\begin{aligned} &\min \chi \\ &s.t. \\ &\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \le \chi, \forall j \\ &\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \chi, \forall j \\ &\sum_{j=1}^{n} w_j = 1, \\ &w_j \ge 0, \forall j \end{aligned} \tag{1}$$

- Step 5. Solving the model and obtaining the final values of the evaluation of the criteria/sub-criteria $(w_1, w_2, ..., w_n)^T$

CRITIC Method

In decision-making problems, criteria as a source of information have weight that reflects the amount of information contained in each one of them (Zavadskas et al. 2019). To determine the weight of the criteria, different methods, divided into subjective and objective, were used. The CRITIC method is one of the objective methods for determining the criteria weight. It was developed by Diakoulaki et al. (1995) and was used to determine objective values of criterion weights that include the intensity of contrast and the conflict contained in the structure of the decision problem (Puška et al. 2018a). To determine the contrast of the criteria, the standard deviations of the standardized criterion values of the variants per column were used, as well as the correlation coefficients of all pairs of columns. The steps in implementing the CRITIC method are as follows:

- Step 1. Defuzzification of initial decision matrix. Before the other steps of the CRITIC method are performed, *fuzzy* numbers should be converted to numerical values (Kiani Mavi et al. 2016). Defuzzification is performed using the following expression:

$$P(\widetilde{m}) = \frac{1}{6}(m_1 + 4xm_2 + m_3) \tag{2}$$

where m_1 is the first value of *fuzzy* number, m_2 the second value of *fuzzy* number and m_3 the third value of *fuzzy* number.

- Step 2. Normalize the defuzzified initial decision matrix by using the following expressions:

  For criteria that need to be maximized:

$$r_{ij} = \frac{x_{ij} - x_r^{**}}{x_j^{*} - x_j^{**}} \tag{3}$$

  For criteria that need to be minimized:

$$r_{ij} = 1 - \frac{x_{ij} - x_r^{**}}{x_j^{*} - x_j^{**}} \tag{4}$$

where x^*_j—the maximum value of the feature for a given criterion, x^{**}_j—the minimum value of the feature for a given criterion.

- Step 3. Calculate the values of the standard deviation and the symmetric linear correlation matrix of all pairs per column.
- Step 4. Determine the amount of information using the following expression:

$$C_j = \sigma_j \sum_{k=1}^{m} \left(1 - r_{jk}\right) j = \overline{1, m} \tag{5}$$

where σ_j is a standard deviation criterion and r_{jk} correlation coefficient for the criteria.

- Step 5. Calculation of the final value using the following expression:

$$w_j = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{6}$$

The CRITIC method assigns more weight to a criterion that has a higher standard deviation value and that has little to do with other criteria (Zavadskas et al. 2019). Based on this, it can be said that in order for the value of the criteria weight to be higher, it is necessary that the values of alternatives by criteria are different and deviate from the values of other criteria.

Fuzzy WASPAS Method

The WASPAS method was developed by Zavadskas et al. (2012). This method is derived from two methods: the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). The result of the alternative by this method is the sum of the attribute values. The WPM method is designed to avoid alternatives with poor values. The result for each alternative was obtained as a product of the scale assessment of each attribute to strength equal to the importance of the weight of the attribute (Turskis et al. 2015). The application of the fuzzy WASPAS method is done by following these steps.

- Step 1. Forming an initial fuzzy decision matrix
- Step 2. Normalization of the initial decision matrix. It is performed using the following expressions. For criteria to be maximized:

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{7}$$

For criteria that need to be minimized:

$$r_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{8}$$

- Step 3. Complicating the normalized decision matrix. The aggravation is done using the following expression:

$$vij = wjxrij \tag{9}$$

- Step 4. Calculating the value of the optimality function:
- a) Calculating the value of the WSM method for each alternative using the following expression:

$$Q_i = \sum_{j=1}^{n} x_{ij} \tag{10}$$

- b) Calculating the value of the WPM method for each alternative using the following expression:

$$P_i = \prod_{j=1}^{n} x_{ij} \tag{11}$$

- Step 5. Defuzzification of WSM and WPM method values. Dephasing of values is performed using the following expressions:

$$Q\left(\widetilde{m}\right) = \frac{1}{3}\left(Q_1 + Q_2 + Q_3\right) \tag{12}$$

$$P\left(\widetilde{m}\right) = \frac{1}{3}\left(P_1 + P_2 + P_3\right) \tag{13}$$

where Q1 is the first value of the fuzzy number, Q2 is the second value of the fuzzy number, and Q3 is the third value of the fuzzy number. The same applies for P values.

- Step 6. Determining the final values of the alternatives using the following expression:

$$K_i = \lambda \sum_{j=1}^{m} Q_i + (1\text{–}\lambda) \sum_{j=1}^{m} P_i \tag{14}$$

The highest value of alternatives indicates the best ranked alternative, while the lowest value reflects the worst ranked alternative.

Case Study

This research shows the way in which the selection of apple varieties for raising a new orchard can be made. In addition, this research offers the integration of FUCOM, CRITIC and WASPAS methods in a fuzzy environment. During the research, professors from Fruit-growing department from the Universities of Novi Sad, Niš and Bijeljina were contacted. Seven professors completed a two-part questionnaire. Based on the defined criteria, the experts were to evaluate the apple varieties: 'Golden Delicious' (A1), 'Jonagold' (A2), 'Gala' (A3), 'Idared' (A4), 'Granny Smith' (A5) and 'Top Red' (A6). The reason why these varieties were chosen should

Table 2 Defining the main criteria of research

Criteria	Definition
Fruit	Fruit is the seed-bearing structure formed from the ovary after flowering
Tree	Tree is a perennial plant with an elongated stem, or trunk, supporting branches and leaves
Transport and storage	The process of fruit transport from producer to customer including the processes of sorting, packaging, and storage of fruit
Economic criteria	It represents an overview of the market and the possibility of selling certain apple varieties
Raising and maintaining orchards	It includes activities related to planting fruit, development, and maintenance of orchards

Table 3 Fuzzy number membership function (Shen et al. 2013)

Linguistic values	Fuzzy numbers
Very bad (VB)	(0,0,1)
Bad (B)	(0,1,3)
Medium bad (MB)	(1,3,5)
Medium (M)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very good (VG)	(9,10,10)

be sought in the fact that these varieties are mostly grown in these areas, and in the world (Wu et al. 2017). The following studies were used to form the criteria for the model: Farag, et al. (2012), Rozman et al. (2015), Milovanović and Stojanović (2016), Maksimović et al. (2017), Rozman et al. (2017), Paunović et al. (2018), Maksimović et al. (2017), Nedeljković, et al. (2021), Puška et al. (2022) and Nedeljković, et al. (2022). A preliminary list of criteria was established based on these studies. Later the experts selected the criteria that, according to them, would best solve this decision-making problem. The model used to evaluate apple varieties for orchard uplift consisted of 25 hierarchical structured criteria (Fig. 1). Five of them represent the main criteria that are further divided into four secondary criteria (Table 2).

An equal number of sub-criteria were selected so that a particular criterion would not be preferred. These criteria are presented as follows:

1. The criterion "Fruit" (C1) aims to examine the size and shape of the fruit, the aroma and color of the fruit, the texture and juiciness of the fruit, and also the ratio of acid and sugar in the certain varieties of apples.
2. The criterion "Tree" (C2) aims to examine the susceptibility to low temperatures, pests, disease resistance and longevity of the tree of certain varieties of apples.
3. The criterion "Transport and storage" (C3) aims to examine the resistance of the fruit at harvest, the possibility of fruit storage, the resistance of the fruit to transport and the longevity of the fruit of certain varieties of apples.
4. The "Economic Criterion" (C4) aims to examine the price of certain varieties per kilogram, planting costs, the possibility of sale and the yield of certain varieties of apples.
5. The criterion "Raising and maintaining orchards" (C5) aims to examine the possibility of planting a tree, the cost of raising and maintaining orchards, and the resistance of fruit seedlings by individual apple varieties when raising orchards.

When evaluating the sub-criteria, the experts had to choose a certain linguistic value that corresponds to a particular apple variety. Linguistic values consisted of seven degrees of agreement ranging from "very bad" to "very good". All linguistic values are presented in Table 3 with the corresponding fuzzy number membership function. Affiliation functions were determined based on previous research conducted by Shen et al. (2013).

Results

When evaluating individual apple varieties, it is necessary to determine the weights of the main criteria first. Accordingly, the experts completed the second part of the questionnaire, which related to determining the importance of the main criteria. They determined which one is the most important criterion. Then it was assigned a value of one (1). Furthermore, other criteria were compared with it with reference to determine their importance. In this way, the order of the criteria according to the importance was established and assigned up to the value nine (9). The higher the value of the criterion, the less important it is. Based on the ob-

Table 4 Criteria evaluation by experts

Expert 1	C4	C1	C3	C5	C2
C4 (the best criterion)	1	2.5	3	6	8
Expert 2	C1	C5	C4	C3	C2
C1 (the best criterion)	1	3	3.5	4	8
Expert 3	C4	C5	C1	C3	C2
C4 (the best criterion)	1	2	4	4.5	7
Expert 4	C4	C5	C3	C1	C2
C4 (the best criterion)	1	3	4.5	5	7.5
Expert 5	C1	C4	C5	C3	C2
C1 (the best criterion)	1	3	4	5.5	8
Expert 6	C1	C4	C3	C5	C2
C1 (the best criterion)	1	2	4	5	7
Expert 7	C5	C4	C1	C3	C2
C5 (the best criterion)	1	3.5	5	6	8

Table 5 Value of weights for each criterion based on expert evaluation

Expert 1	C1	C2	C3	C4	C5
	0.2138	0.1298	0.2020	0.3029	0.1515
Expert 2	C1	C2	C3	C4	C5
	0.3006	0.1288	0.1804	0.1898	0.2004
Expert 3	C1	C2	C3	C4	C5
	0.1774	0.1364	0.1689	0.2956	0.2217
Expert 4	C1	C2	C3	C4	C5
	0.169	0.1377	0.1770	0.3098	0.2065
Expert 5	C1	C2	C3	C4	C5
	0.3109	0.1332	0.1622	0.2072	0.1865
Expert 6	C1	C2	C3	C4	C5
	0.2979	0.1375	0.1787	0.2234	0.1625
Expert 7	C1	C2	C3	C4	C5
	0.1756	0.1380	0.1610	0.2034	0.3220

tained expert evaluations, it can be seen that three experts believe that C1 and C4 are the best criteria, while the seventh expert believes that C5 is the most important criterion when choosing a variety for raising orchards (Table 4). Having performed the steps of the FUCOM method, the values of the criteria weights were obtained according to the evaluation of each expert (Table 5).

A geometric mean is used to match the weight values given by the experts on the criteria. By conducting a geometric mean, each expert is equally valued, and the opinions of all experts are equally respected. The results obtained of the weight of the criteria show that according to the expert, the most important criterion is C4, while criterion C2 is the least important criterion in evaluating apple varieties for raising a new orchard (Table 6).

Once the weights of the main criteria have been determined, the weights of the sub-criteria requested to be determined. The CRITIC method was used to determine the weights of the sub-criteria. The first step in determining weights was to form an initial decision matrix. Since the fuzzy approach was used in this study, the experts evaluated apple varieties according to the individual sub-criteria in the form of linguistic values. The experts evaluated individual varieties with grades from "very bad" (VB) to "very good" (VG) and in this way the initial decision-making matrix with linguistic values was formed (Table 7). In order to do the calculation, it was mandatory to transform the linguistic values into fuzzy numbers using the defined membership functions (Table 3). In this a way, a fuzzy initial decision matrix was formed. Since seven experts gave their grades, it was essential to sublimate those grades and make one decision matrix. In that case, the geometric mean was used, and a common fuzzy decision matrix was formed (Table 8). It represents the initial decision matrix for the CRITIC and WASPAS methods.

When implementing the CRITIC method, the first stage of the common fuzzy decision matrix is required (expression 2). The value of the standard deviation is then calculated for each sub-criterion. The correlation between the pairs of sub-criteria within the individual main criteria is calculated by applying a symmetric linear correlation matrix. Subsequently, a sum of values is formed by the individual sub-criteria which is multiplied by the standard deviation (expression 5). Afterwards, the value of the weights of the individual criteria is formed (expression 6). By multiplying the weights of the main criteria with the weights of the sub-criteria the final values of the weights of all sub-criteria are obtained. Table 9 shows all the steps for determining the final weights of the sub-criteria.

After the calculation of the sub-criteria weights was done, the alternatives were ranked according to the experts' evaluations. The fuzzy WASPAS method was used in this study. The calculation of values for alternatives be-

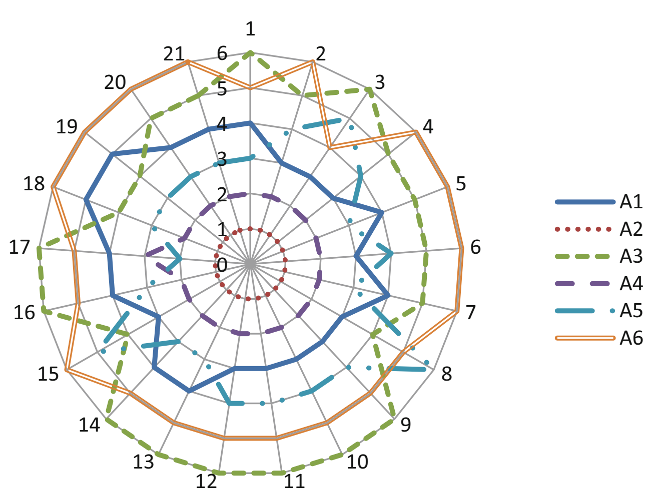
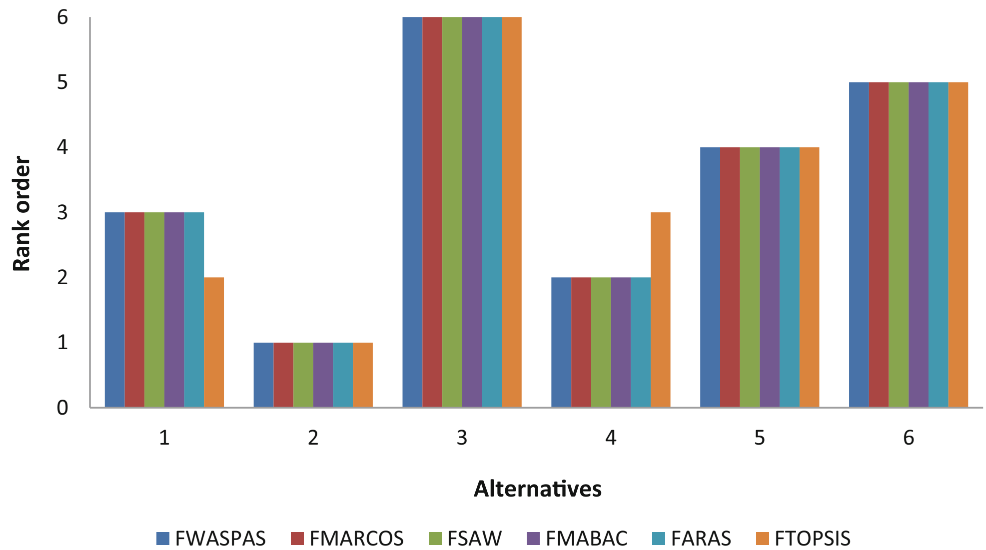


Fig. 2 The results of the sensitivity analysis when changing sub-criterion weights

Fig. 3 Results of sensitivity analysis when performing different methods



gan with the formation of a common fuzzy decision matrix. After that, the data was normalized (expression 7). The reason why expression (8) was not used in the normalization should be found in the fact that it was desirable that all grades, according to individual sub-criteria, were as high as possible, so normalization was performed for maximization. This was followed by the difficulty of normalizing the fuzzy decision matrix. The process was done by multiplying the individual values by the corresponding weights for these criteria. The WSM and WPM values were then calculated (expressions 10 and 11), defuzzified (expressions 12 and 13) and the final value for individual alternatives was formed (expression 14). In this case, the same importance was assigned to the WSM and WPM values to avoid alternatives with bad values, while at the same time obtaining the result of ranking the alternatives in a simple way (Table 10).

Based on the obtained results, it can be concluded that the best alternative is A2—'Jonagold', followed by alternative A4—'Idared', while the lowest scores on the expert's evaluation received alternative A3—'Gala'. When looking at the individual values of WSM and WPM, it can be seen that the cumulative ranking is the same as when applying these individual methods. In this way, the final ranking of the apple varieties used can be further confirmed. In order to obtain more complete results, it is necessary to conduct a sensitivity analysis that will examine how stable each alternative is when changing the weights of the individual sub-criteria.

Sensitivity Analysis

The sensitivity analysis was performed in two ways. The first way was to change the weight of the criteria and observe how this affected the ranking of alternatives (Puška et al. 2018b). Another way to conduct sensitivity analysis was to compare the ranking of alternatives obtained by the fuzzy WASPAS method with the ranking orders obtained using other fuzzy methods (Pamučar and Božanić 2019).

In this research, 20 sub-criteria and 21 scenarios based on them were used. According to the scenario, it was assumed that an individual sub-criterion had six times higher value than other sub-criteria and the value of that sub-criterion was 0.24, while the value of other sub-criteria was 0.04 (Table 11). Scenario 21 was set up so that all sub-criteria were given the same importance and the same weight value (0.05) was assigned. In this way, a certain sub-criterion was more important than the other sub-criteria. By using these scenarios, it was observed how each individual criterion had an impact on the ranking of alternatives in the evaluation of apple varieties when raising a new orchard.

The performed sensitivity analysis showed that alternative A2 was insensitive to changes in the value of the weights of the sub-criteria and that it took the first place in all scenarios. Alternative A4 showed sensitivity to scenario 17 when this alternative took the third place. On the other hand, in all other scenarios it took the second place in the ranking. Alternative A1 took the third place in 10 scenarios, the fourth place in 8 scenarios and the fifth place in two scenarios. The worst results were taken by this alterna-

Table 6 Final weight value for criteria

Final	C1	C2	C3	C4	C5
Value	0.2316	0.1370	0.1786	0.2473	0.2055

Table 7 Linguistic evaluations of sub-criteria by experts

Expert 1	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	G	G	G	MG	M	M	M	MG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	G	G	MG	G	G	MG	MG	G	MG	G	G	G	MG	M	MG	MG	MG	M	M	M
A3	M	MG	MG	MG	MB	M	M	MG	MB	MB	MB	M	MG	M	MG	MG	M	M	MG	MB
A4	VG	VG	G	G	G	MG	M	G	MG	M	MG	M	M	M	M	MG	MB	M	MG	M
A5	VG	MG	MB	M	MG	M	M	MB	M	M	MG	M	MG	MG	MB	MG	G	MG	M	MG
A6	G	MG	MG	M	MB	MB	M	MG	M	MG	M	MG	MG	MG	M	MG	MG	MB	MB	MB
Expert 2	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	MG	M	MG	MG	MB	MG	M	MG	G	MG	G	M	M	M	MG	MG	MG	MG	MB	MG
A2	MG	M	G	MG	MG	M	G	MG	G	G	MG	G	MG	M	MG	MG	MG	M	M	M
A3	MB	MG	MB	MG	M	MB	MG	MG	MB	MG	MB	M	MG	MB	G	MG	M	M	MG	MB
A4	G	VG	MG	MG	VG	M	M	G	G	M	MB	MB	MG	M	M	G	MB	MG	MG	MG
A5	VG	MG	MG	MB	M	M	MB	M	MB	MG	MG	M	G	MB	MB	MG	G	MG	MG	MG
A6	MG	MG	MG	M	MB	MG	M	MG	M	MG	M	MG	MG	MG	M	G	MG	MB	MB	MB
Expert 3	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	G	G	M	G	M	M	M	MG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	VG	G	MG	G	MG	MG	MG	G	MG	G	G	G	MG	M	MG	MG	MG	M	M	M
A3	M	MG	M	MG	MB	MG	M	MG	M	MB	M	MG	M	MB	M	M	M	M	MG	MG
A4	G	VG	G	G	MG	MG	MG	G	MG	M	MG	MG	M	M	M	MG	M	MG	M	MG
A5	VG	MG	M	M	MG	M	M	MG	M	M	MG	M	MG	MG	MB	M	G	MG	M	MG
A6	G	MG	MG	M	MB	MB	M	MG	M	MG	M	MG	MG	MG	M	MG	MG	MB	MB	MB
Expert 4	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	VG	G	G	MG	M	M	M	MG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	VG	G	G	G	G	MG	M	G	MG	VG	G	G	MG	M	G	MG	MG	M	MG	MG
A3	MB	G	G	G	MB	M	MG	G	MB	M	MB	M	MG	MG	G	MG	M	MG	MG	MG

Table 7 (Continued)

A4	VG	VG	G	G	MG	MG	MG	G	MG	MG	MG	MG	MG	M	M	G	MB	M	MG	M
A5	VG	MG	M	M	M	M	M	MB	M	M	MG	M	MG	MG	MB	MG	VG	G	M	MG
A6	G	MG	MG	MG	MB	MB	M	MG	M	MG	M	MG	MG	MG	M	VG	MG	MB	MB	MB
Expert 5	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	VG	G	VG	MG	M	M	M	MG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	VG	VG	MG	G	VG	MG	G	G	MG	G	G	G	MG	G	G	MG	MG	M	G	G
A3	M	MG	MG	G	MB	M	MG	MG	MG	MB	MB	M	MG	G	MG	MG	M	M	G	MB
A4	VG	VG	VG	G	G	MG	M	G	MG	M	G	G	MG	M	M	MG	G	G	MG	M
A5	VG	MG	MB	G	VG	M	G	G	M	M	MG	G	MG	MG	MB	MG	G	MG	M	G
A6	G	MG	MG	M	MB	MB	M	MG	M	MG	M	MG	MG	MG	M	MG	MG	MB	MB	MB
Expert 6	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	VG	VG	MG	M	M	M	M	VG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	G	G	MG	M	G	MG	MG	G	MG	G	G	G	MG	M	VG	MG	MG	M	M	M
A3	M	MG	MG	M	MB	G	M	G	MG	MB	MG	G	MG	M	VG	MG	M	M	MG	G
A4	VG	MG	M	G	VG	MG	M	G	MG	M	MG	G	M	M	M	G	MB	M	MG	G
A5	VG	MG	MG	M	G	M	M	MG	M	M	MG	M	MG	MG	MG	VG	G	MG	MG	G
A6	G	MG	MG	G	MB	MB	M	G	M	MG	M	MG	MG	MG	M	MG	MG	MB	MB	MB
Expert 7	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
A1	MG	MG	G	MG	M	M	M	MG	MG	MG	G	MG	M	M	MG	MG	M	MB	MB	M
A2	G	G	MG	G	G	MG	MG	G	MG	G	G	G	MG	M	MG	MG	MG	MG	M	M
A3	M	M	MG	MG	MB	M	MG	G	MB	MG	MB	MG	MG	M	MG	MG	M	MG	MG	MB
A4	VG	VG	MG	G	G	M	M	VG	MG	M	MG	MG	MG	M	MG	MG	MB	MG	MG	M
A5	VG	MG	MB	MG	MG	M	M	MB	MG	M	MG	M	MG	MG	MB	MG	G	MG	M	MG
A6	G	MG	MG	M	MB	MB	M	G	MG	MG	M	MG	MG	MG	M	MG	MG	MB	MB	MB

Table 8 Fuzzy decision matrix

Criteria	C_{11}			C_{12}			C_{13}			C_{14}		
	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3
A1	7.08	8.76	9.70	6.13	8.10	9.36	5.84	7.82	9.22	4.88	6.92	8.81
A2	7.43	9.08	9.85	6.43	8.40	9.50	5.50	7.52	9.28	5.91	7.98	9.36
A3	2.19	4.32	6.36	4.88	6.92	8.81	3.88	6.13	8.10	5.12	7.17	8.95
A4	8.38	9.70	10.00	8.28	9.50	9.85	5.84	7.82	9.22	6.67	8.68	9.85
A5	9.00	10.00	10.00	5.00	7.00	9.00	2.17	4.42	6.51	3.11	5.30	7.28
A6	6.67	8.68	9.85	5.00	7.00	9.00	5.00	7.00	9.00	3.64	5.71	7.64
Criteria	C_{21}			C_{22}			C_{23}			C_{24}		
	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3
A1	2.56	4.65	6.67	3.23	5.25	7.26	3.00	5.00	7.00	5.44	7.37	9.14
A2	6.59	8.50	9.70	4.65	6.67	8.68	5.12	7.17	8.95	6.67	8.68	9.85
A3	1.17	3.23	5.25	3.11	5.30	7.28	4.02	6.06	8.08	5.78	7.80	9.42
A4	6.83	8.63	9.70	4.32	6.36	8.38	3.47	5.50	7.52	7.26	9.14	10.00
A5	4.93	6.94	8.63	3.00	5.00	7.00	2.89	5.06	7.02	2.45	4.81	6.85
A6	1.00	3.00	5.00	1.26	3.39	5.44	3.00	5.00	7.00	5.50	7.52	9.28
Criteria	C_{31}			C_{32}			C_{33}			C_{34}		
	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3
A1	5.25	7.26	9.14	5.00	7.00	9.00	7.00	9.00	10.00	4.65	6.67	8.68
A2	5.25	7.26	9.14	7.26	9.14	10.00	6.67	8.68	9.85	7.00	9.00	10.00
A3	1.85	4.11	6.21	1.85	4.11	6.21	1.47	3.64	5.71	3.92	5.99	7.91
A4	5.25	7.26	9.14	3.23	5.25	7.26	4.17	6.43	8.40	4.07	6.35	8.23
A5	2.76	4.88	6.92	3.23	5.25	7.26	5.00	7.00	9.00	3.39	5.44	7.37
A6	3.23	5.25	7.26	5.00	7.00	9.00	3.00	5.00	7.00	5.00	7.00	9.00
Criteria	C_{41}			C_{42}			C_{43}			C_{44}		
	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3
A1	3.00	5.00	7.00	3.00	5.00	7.00	5.00	7.00	9.00	5.00	7.00	9.00
A2	5.00	7.00	9.00	3.39	5.44	7.37	5.99	7.91	9.42	5.00	7.00	9.00
A3	4.65	6.67	8.68	2.66	4.93	6.94	5.57	7.54	9.08	4.65	6.67	8.68
A4	4.02	6.06	8.08	3.00	5.00	7.00	3.23	5.25	7.26	5.78	7.80	9.42
A5	5.25	7.26	9.14	3.97	6.20	8.28	1.26	3.39	5.44	5.06	7.02	8.81
A6	5.00	7.00	9.00	5.00	7.00	9.00	3.00	5.00	7.00	5.71	7.64	9.28
Criteria	C_{51}			C_{52}			C_{53}			C_{54}		
	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3	m_1	m_2	m_3
A1	3.23	5.25	7.26	1.26	3.39	5.44	1.00	3.00	5.00	3.23	5.25	7.26
A2	5.00	7.00	9.00	3.23	5.25	7.26	3.64	5.71	7.64	3.64	5.71	7.64
A3	3.00	5.00	7.00	3.47	5.50	7.52	5.25	7.26	9.14	2.09	4.47	6.53
A4	1.54	3.78	5.79	4.21	6.28	8.20	4.65	6.67	8.68	3.92	5.99	7.91
A5	7.26	9.14	10.00	5.25	7.26	9.14	3.47	5.50	7.52	5.50	7.52	9.28
A6	5.00	7.00	9.00	1.00	3.00	5.00	1.00	3.00	5.00	1.00	3.00	5.00

tive in scenarios 18 and 19 where this alternative showed the highest sensitivity to weight changes in these sub-criteria. Alternative A3 showed the worst results of all alternatives in 10 scenarios, while alternative A6 showed the worst results in the other 10 scenarios.

Based on the obtained results and the conducted sensitivity analysis, it can be concluded that alternative A2 is the best of all alternatives, while alternatives A3 and A6 showed the worst results (Fig. 2).

Another way to perform sensitivity analysis is to test the rankings obtained by fuzzy WASPAS with the rankings obtained by implementing the methods: fuzzy MARCOS (Measurement Alternatives and Ranking according to the Compromise Solution), fuzzy SAW (Simple Additive Weighting technique), fuzzy MABAC (Multi-Attributive Border Approximation area Comparison), fuzzy ARAS (Additive Ratio Assessment), fuzzy TOPSIS (Technique for Order Performance by Similarity to Ideal Solution). By performing these methods, results were obtained which

Table 9 Implementation of the CRITIC method

Standard deviation																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
0.37	0.40	0.39	0.38	0.45	0.35	0.40	0.35	0.45	0.36	0.39	0.35	0.38	0.40	0.39	0.38	0.36	0.39	0.43	0.34
Correlation																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
1.00	0.45	0.08	–0.08	1.00	0.80	0.40	0.18	1.00	0.63	0.79	0.56	1.00	0.59	–0.33	–0.05	1.00	0.17	–0.27	0.28
0.45	1.00	0.68	0.83	0.80	1.00	0.67	0.45	0.63	1.00	0.68	0.90	0.59	1.00	–0.61	0.37	0.17	1.00	0.79	0.81
0.08	0.68	1.00	0.70	0.40	0.67	1.00	0.52	0.79	0.68	1.00	0.45	–0.33	–0.61	1.00	–0.45	–0.27	0.79	1.00	0.38
–0.08	0.83	0.70	1.00	0.18	0.45	0.52	1.00	0.56	0.90	0.45	1.00	–0.05	0.37	–0.45	1.00	0.28	0.81	0.38	1.00
$\sum_{k=1}^{m}(1-r_{jk})$																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
0.00	0.55	0.92	1.08	0.00	0.20	0.60	0.82	0.00	0.37	0.21	0.44	0.00	0.41	1.33	1.05	0.00	0.83	1.27	0.72
0.55	0.00	0.32	0.17	0.20	0.00	0.33	0.55	0.37	0.00	0.32	0.10	0.41	0.00	1.61	0.63	0.83	0.00	0.21	0.19
0.92	0.32	0.00	0.30	0.60	0.33	0.00	0.48	0.21	0.32	0.00	0.55	1.33	1.61	0.00	1.45	1.27	0.21	0.00	0.62
1.08	0.17	0.30	0.00	0.82	0.55	0.48	0.00	0.44	0.10	0.55	0.00	1.05	0.63	1.45	0.00	0.72	0.19	0.62	0.00
$C_j = \sigma_j \sum_{k=1}^{m}(1-r_{jk})$																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
0.93	0.41	0.60	0.59	0.73	0.38	0.56	0.65	0.46	0.28	0.42	0.38	1.05	1.06	1.70	1.20	1.00	0.48	0.90	0.51
w																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
0.37	0.16	0.24	0.23	0.32	0.16	0.24	0.28	0.30	0.18	0.27	0.25	0.21	0.21	0.34	0.24	0.35	0.16	0.31	0.18
The final weight criteria																			
C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
0.08	0.04	0.05	0.05	0.04	0.02	0.03	0.04	0.05	0.03	0.05	0.04	0.05	0.05	0.08	0.05	0.07	0.03	0.06	0.04

Table 10 Calculating the ranking of alternatives using the fuzzy WASPAS method

Alternative	WSM			$Q\ (\widetilde{m})$	WPM			$P\ (\widetilde{m})$	K_i	Rang
A1	0.68	0.77	0.86	0.7688	0.63	0.75	0.84	0.7392	0.7540	3
A2	0.87	0.91	0.95	0.9136	0.86	0.91	0.95	0.9077	0.9106	1
A3	0.58	0.69	0.79	0.6882	0.50	0.66	0.78	0.6458	0.6670	6
A4	0.75	0.82	0.88	0.8202	0.70	0.80	0.87	0.7921	0.8062	2
A5	0.66	0.75	0.83	0.7479	0.58	0.72	0.82	0.7095	0.7287	4
A6	0.58	0.69	0.80	0.6906	0.50	0.66	0.78	0.6501	0.6704	5

Table 11 Scenarios used in sensitivity analysis

Scenarios	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{53}	C_{54}
Scenario 1	**0.24**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Scenario 2	0.04	**0.24**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Scenario 3	0.04	0.04	**0.24**	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Scenario 18	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**0.24**	0.04	0.04
Scenario 19	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**0.24**	0.04
Scenario 20	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**0.24**
Scenario 21	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

showed that only with the fuzzy method TOPSIS there was a different ranking order. There was a change in the ranking order for alternatives A1 and A3 in the results. Alternative A1 took the second place using the fuzzy TOPSIS method, and alternative A3 took the third place. The ranking order of other alternatives was the same as with other methods which led to the confirmation of the results obtained using the fuzzy WASPAS method (Fig. 3).

Conclusion

Nowadays, orchardists are faced with a big dilemma when choosing an assortment for planting. Traditional individual parameters prove to be unsuccessful. The decision on which variety to plant can no longer be made based on one criterion, but it is necessary to apply a multi-criteria approach. In this paper, a multi-criteria model based on group decision-making was created, where among the proposed six apple varieties, the best variety for raising a new apple orchard was selected. An expert system based on expert evaluations and group decision-making was applied. Each apple variety was evaluated according to the five main criteria by the model applied in the paper.

During the evaluation of individual varieties, the integration of FUCOM, CRITIC and WASPAS methods was used, and a hybrid decision-making model based on group decision-making and fuzzy approach was formed. The weights of the main criteria were determined by the FUCOM method, the weights of the sub-criteria were determined by the CRITIC method, while the fuzzy WASPAS method was used to rank the alternatives. Using the decision-making model, results were obtained and showed that the best alternative was A2—'Jonagold', followed by the alternative A4—'Idared', while the worst results, according to experts, were the alternative A3—'Gala'. To obtain more complete results, a sensitivity analysis was conducted to examine how stable each alternative is when changing the weights of individual sub-criteria. The conducted sensitivity analysis confirmed the results of the research.

The model presented through testing has shown a high degree of flexibility, so it can be used in other branches of the economy and in other decision-making problems. When using the model, special attention should be paid to the selection of experts, since the model is based on expert knowledge. The biggest advantage of this model is its multiple application. The recommendation for future researchers in this field is to systematize a "package" of alternatives depending on the field of research and the methods that can be used.

Conflict of interest M. Nedeljković, A. Puška, A. Maksimović and R. Suzić declare that they have no competing interests.

References

Agha SR, Latifa GN, Nassar HA, Shehada RY (2012) Multi criteria governmental crop planning problem: an analytic hierarchy approach. Management 2(4):96–105. https://doi.org/10.5923/j.mm.20120204.03

Diakoulaki D, Mavrotas G, Papayannakis L (1995) Determining objective weights in multiple criteria problems: the critic method. Comput Oper Res 22(7):763–770. https://doi.org/10.1016/0305-0548(94)00059-h

Farag KM, Elsabagh AS, ElAshry HA (2012) Fruit characteristics of "Zaghloul" date palm in relation to metaxenic influences of used

pollinator. Am J Agric Environ Sci 12(7):842–855. https://doi.org/10.5829/idosi.aejaes.2012.12.07.1803
Ibrahimović FI, Kojić SL, Stević ŽR, Erceg ŽJ (2019) Donošenje investicione odluke u transportnoj kompaniji primenom integrisanog FUCOM-MABAC modela. Tehnika 74(4):577–584. https://doi.org/10.5937/tehnika1904577I
Kiani Mavi R, Goh M, Kiani Mavi N (2016) Supplier selection with Shannon entropy and fuzzy TOPSIS in the context of supply chain risk management. Procedia—social Behav Sci 235:216–225. https://doi.org/10.1016/j.sbspro.2016.11.017
Maksimović A, Grgić Z, Ćejvanović F (2017) Multi-attribute analysis of orchard according to the integrated production concept. Econ Agric 64(1):69–79. https://doi.org/10.5937/ekoPolj1701069M
Milovanović Ž, Stojanović M (2016) Izbor sorti višnje za sadnju primenom AHP metodologije. Agroekonomika 45(72):11–19
Montazar A, Gaffari A (2011) An Ahp model for crop planning within irrigation command areas. Irrigation Drainage 61(2):168–177. https://doi.org/10.1002/ird.645
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):e246857. https://doi.org/10.1371/journal.pone.0246857
Nedeljković M, Puška A, Suzić R, Maksimović A (2022) Multicriteria model of support for the selection of pear varieties in raising orchards in the Semberija region (Bosnia and Herzegovina). Sustainability 14(3):1584. https://doi.org/10.3390/su14031584
Ntakyo PR, Mugisha J, Elepu G (2013) Socio-economic factors affecting apple production in southwestern Uganda. African Crop Sci J 21(4):311–321
Pamučar D, Božanić D (2019) Selection of a location for the development of multimodal logistics center: application of single-valued neutrosophic MABAC model. Oper Res Eng Sci Theory Appl 2(2):55–71. https://doi.org/10.31181/oresta1902039p
Pamučar D, Stević Ž, Sremac S (2018) A new model for determining weight coefficients of criteria in MCDM models: full consistency method (FUCOM). Symmetry 10(9):393. https://doi.org/10.3390/sym10090393
Paunović M, Milutinović O, Puzić G (2018) Personal subjectivity impact reduction in choice of sour cherry varieties for orchard establishment using fuzzy system. Econ Agric 65(2):545–554. https://doi.org/10.5937/ekoPolj1802545P
Puška A, Beganović A, Šadić S (2018a) Model for investment decision making by applying the multi-criteria analysis method. Serbian J Manag 13(1):7–28. https://doi.org/10.5937/sjm13-12436
Puška A, Kozarević S, Stević Ž, Stovrag J (2018b) A new way of applying interval fuzzy logic in group decision making for supplier selection. Econ Comput Econ Cybern Stud Res 52(2):217–234. https://doi.org/10.24818/18423264/52.2.18.13
Puška A, Nedeljković M, Prodanović R, Vladisavljević R, Suzić R (2022) Market assessment of pear varieties in Serbia using fuzzy CRADIS and CRITIC methods. Agriculture 12(2):139. https://doi.org/10.3390/agriculture12020139
Rozman Č, Hühner M, Kolenko M, Tojnko S, Unuk T, Pažek K (2015) Apple variety assessment with analytical hierarchy process. Erwerbs-Obstbau 57(2):97–104. https://doi.org/10.1007/s10341-015-0236-8
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
Shen L, Olfat L, Govindan K, Khodaverdi R, Diabat A (2013) A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. Resour Conserv Recycl 74:170–179. https://doi.org/10.1016/j.resconrec.2012.09.006
Sudha AS, Jeba JRI (2015) Crop selection based on fuzzy TOPSIS using entropy weights. IJCA 124(14):16–20. https://doi.org/10.5120/ijca2015905782
Turskis Z, Zavadskas E, Antucheviciene J, Kosareva N (2015) A hybrid model based on fuzzy AHP and fuzzy WASPAS for construction site selection. Int J Comput Commun Control 10(6):113–128. https://doi.org/10.15837/ijccc.2015.6.2078
Wu X, Wu B, Sun J, Ya N (2017) Classification of apple varieties using near infrared reflectance spectroscopy and fuzzy discriminant C-means clustering model. J Food Process Eng. https://doi.org/10.1111/jfpe.12355
Zangeneh M, Akram A, Nielsen P, Keyhani A (2015) Developing location indicators for agricultural service center: a Delphi-TOPSIS-FAHP approach. Prod Manuf Res 3(1):124–148. https://doi.org/10.1080/21693277.2015.1013582
Zavadskas EK, Turskis Z, Antucheviciene J, Zakarevicius A (2012) Optimization of weighted aggregated sum product assessment. Elektronika Ir Elektrotechnika 122(6):3–6. https://doi.org/10.5755/j01.eee.122.6.1810
Zavadskas EK, Stević Ž, Turskis Z, Tomašević M (2019) A novel extended EDAS in Minkowski space (EDAS-M) method for evaluating autonomous vehicles. Stud Informatics Control 28(3):255–264. https://doi.org/10.24846/v28i3y201902