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Selection of the optimal lettuce cultivar to agronomic traits in summer production using multicriteria decision-making MABAC method

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Abstract

Five lettuce cultivars ('Kiribati', 'Tourbillon', 'Carmesi', 'Lianabel', and 'Biondonna') were grown in the open-field experiment during the summer of 2018. The aim was to find the optimal summer lettuce cultivar according to morphological and production parameters, suitable for the fresh market and food industry processing by applying the MABAC (Multi-Attributive Border Approximation Area Comparison) method. The correlation analysis was carried out to reduce the number of criteria that have high coefficient values and a double influence on the ranking results. The study involved five alternatives (cultivars) and five different criteria regarding morphological parameters (rosette height, rosette diameter, rosette fresh weight, number of leaves, and stem height). Weight coefficients were determined using the AHP (Analytic Hierarchy Process) method while the stability of the obtained ranking list was determined by applying sensitive analysis through six scenarios. According to the selected criteria, the obtained results showed that the green cultivar 'Tourbillon' has the best results, while the least favorable results were obtained by the red cultivar 'Carmesi'. Furthermore, this study tends to facilitate cultivar selection by farmers to avoid economic losses and sustain the required quantity and quality standard demands for the fresh product and food industry market.

***Key words*:** lettuce, summer, MABAC, morphology, biomass

INTRODUCTION

Lettuce (*Lactuca sativa*, L.) is a leafy vegetable salad crop from the Asteraceae family. Annual production of lettuce and chicory in the European Union was 3.525.660 tons, with leading countries Spain, Italy, Belgium, and France (FAOSTAT, 2022). Health benefits originate from being low-calorie, low-fat, and enriched in minerals, vitamins, fiber, phenolics, and other health-promoting compounds (Mampholo et al., 2016; Iqbal et al., 2022). Lettuce groups such as butterhead, iceberg, leaf, romaine, Batavia, and stem include different cultivars. Cultivars are recognised in different leaf colours, shapes, sizes, textures, tastes, quality parameters influencing market price, and consumer choice (Mampholo et al., 2016).

Lettuce can be cultivated throughout the whole year in different production systems (open field, covered systems or hydroponics) with multiple growing cycles. It stands for a cool season vegetable with optimal temperature during the vegetation period 21-23 ˚C (day) and 15-18 ˚C (night). In continental climate, especially when during summer daily temperatures exceed 30 ˚C which can increase the risk of bolting (Ilić et al., 2017), leading to a shortened vegetation period and reduced fresh mass. Also, a long photoperiod can cause premature stem elongation and initiate the flowering phase (Al-Harbi, 2001). Consequently, plants lose marketable value and quality for processing, resulting in a poor head density, and bitter taste (Lafta et al., 2021).

The market of fresh lettuce and ready-to-eat products demands a continuous supply of raw materials. Quality demands are decreased in situations of supply shortage, usually during unfavorable environmental conditions. Reduction of the stem height and the number of dark green and yellowish leaves increases the proportion of edible fresh mass used in processing (Simko et al., 2014). Sudden high temperatures in the open field can trigger an early transformation from the vegetative to the generative stage, before the expected finishing of the vegetation period, and contribute to a higher percentage of unusable plant parts for processing.

For the reasons mentioned above, the summer production of lettuce in the open field demands slight modifications compared to spring and autumn production (planning of seedling production, resistant cultivars, white mulch film, micro-sprinklers or drip irrigation, shading nets) (Bernardoni et al., 2004; Ilić et al., 2017). The great benefit of different multi-criteria decision-making methods (MCDM) is to empower the decision-making process to be more precise, rational, and efficient (Zavadskas and Turskis, 2010). These methods operate with the existence of several different alternatives, several criteria that should be considered for each alternative, making a decision, and choosing the final optimal solution. Their advantage is to exclude contradictory conclusions by taking a multiple number of criteria into account. Recent research showed the lowest number of applied MCDM methods in agricultural and biological sciences compared to other disciplines (Taherdoost and Madanchian, 2023). Nevertheless, these methods were used to solve different problems in agriculture areas like the selection of sustainable suppliers (Puška et al., 2023), assessment of the supply chain of fresh vegetables (Guritno et al., 2015), implementation of integrated methods in the orchard (Maksimović et al., 2017). The MABAC method was used to evaluate rapeseed and pear cultivars (Nedeljković et al., 2021; Nedeljković et al., 2022).

Climate change and global warming are becoming a threat to global vegetable production, especially when plants are grown in open fields and protected environments depending on outdoor temperature (Kumsong et al., 2023). In these conditions, choosing an adequate cultivar for summer production is the first step in planning production to avoid losses in quantity and quality parameters, and sustain economic income. Therefore, the objective of this study was to determine the most favorable cultivar, according to the morphological and production parameters, for summer open-field production for the fresh market and food industry by applying the MABAC method.

MATERIAL AND METHODS

Five lettuce cultivars were examined 'Kiribati', 'Tourbillon', 'Carmesi' (Rijk Zwaan, the Netherlands), 'Lianabel', and 'Biondonna' (Bejo Zaden, the Netherlands) during the summer open field trial. 'Kiribati' belongs to an oak-leaf type, a cultivar with compact, large, round rosette, with green, wavy leaves, suitable for growing in an open field and greenhouses from spring to autumn, with a long harvest period. 'Carmesi' also known as a “triple” red lollo rosso type with a rosette consisted of intensely shiny and curly red leaves with a strong tolerance to bolting, suitable from spring to autumn cultivation. 'Tourbillon' is a green Batavia type with an open head formed from light green leaves suitable for production during spring, summer and autumn, with good resistance to flowering and tipburn. 'Biondonna' is a green lollo bionda type, having medium green, curly, vigorous rosette with tipburn tolerance. 'Lianabel' is a green Batavia type with a compact head and strong resistance to bolting and tipburn.

Lettuce seedlings were grown in peat cubes size of 4 cm and formulated from the substrate Potgrond H (Klasmann-Deilmann, Germany) in a glasshouse condition in the company Grow Rasad (Irig, Serbia). Seeds were mechanically sown on June 04 and the seedlings production lasted for 16 days. An open field experiment was conducted during June-July 2018 in the company Iceberg Salat Centar (Surčin, Serbia). Before starting the experiment, randomised soil samples were collected at 0-30 cm depth. The soil was enriched with sufficient levels of macronutrients and humus (total nitrogen-0.15%, readily available phosphorus-83.5 mg/100 g, readily available potassium-25.4 mg/100 g, and humus-4.2%), with neutral to slightly alkaline reaction (pH- 7.3).

Plants were mechanically transplanted on June 21, in black marsh soil and the whole experiment lasted for 32 days. Regular farming practices were applied during the growing period (irrigation, foliar fertilisation, hoeing, protection against diseases and pests). The experiment was organised in a complete block design. The dimension of the main plots was 1 × 3 m, in three replications. The distance between plants was 27 × 27 cm. During the vegetation, period air temperature, air relative humidity, and precipitation were collected using RC-4HC Data Logger (Elitech Technology Inc., USA) and rain gauge (TFA Dostmann GmbH & Co. KG, Germany**)**. Climatic parameters were measured for 24 hours during the vegetation period (Table 1). Plants were exposed to different day lengths - photoperiods from 15 h 59 min to 14 h 15 min obtained for the Surčin location (WU, 2018).

Table 1. Climate conditions during the lettuce growing cycle

	Average air temperature (˚C)	Maximum air temperature (˚C)	Minimum air temperature (˚C)	Average air humidity (%)	Total precipitation (mm)
June 2018	18.3	31.5	10.9	73.2	15.1
July 2018	21.5	32.8	10.3	71.8	40.8

All cultivars were harvested by hand on the same day, when they reached commercial size and technological maturity. Rosette fresh weight, leaf and stem fresh weight were measured using a scale, and the results are presented in grams (g). Rosette and stem height and diameter were measured using a digital caliper and expressed in centimeters (cm).

Statistical analysis was performed using a one-way ANOVA with a Tukey's test for post hoc comparison. All results were calculated at a significance level α of 0.05. Pearson's correlation was used to test the possible correlation between observed parameters. The statistical analysis was performed using the software SPSS Statistics (Version 25.0.; Armonk, NY, USA: IBM Corp) and Microsoft Office Excel 2019 (Microsoft Corp., USA).

For the evaluation and selection of the cultivar with the most favorable morphological and production parameters during the summer, we used the multi-criteria decision-making method - MABAC (Multi-Attributive Border Approximation Area Comparison), developed by Pamučar and Ćirović (2015). The main goal of this approach is to determine the distance of the criterion function of each observed alternative from the limit approximate value through 6 steps. A sensitive analysis was carried out through 6 different scenarios to determine the impact of the changes in the value of the weighting coefficients on the alternatives ranking list.

RESULTS AND DISCUSSION

Using one-way ANOVA different morphological parameters (rosette height, diameter, fresh weight, number of leaves, leaf fresh weight, stem height, diameter and stem fresh weight) were tested using Tukey's test for post hoc comparison, and results are presented in Table 2.

Table 2. Effect of different lettuce cultivars on morphological and production parameters

	Rosette height (cm)	Rosette diameter (cm)	Rosette fresh weight (g)	Number of leaves	Fresh leaf weight (g)	Stem height (cm)	Stem diameter (cm)	Stem fresh weight (g)
Cultivar								
Kiribati	20.39±0.3 c	31.72±0.5 c	334.11±11.1 c	41.44±1.0 d	293.33±9.3 c	6.86±0.2 c	2.26±0.1 c	33.67±2.1 c
Tourbillon	19.50±0.2 bc	30.26±0.8 abc	348.11±5.3 c	35.56±0.4 c	326.11±4.6 d	4.30±0.1 a	1.81±0.0 b	16.56±0.8 b
Lianabel	21.61±0.2 d	30.72±0.4 bc	330.44±7.1 c	39.78±0.8 d	308.11±6.8 cd	5.03±0.2 ab	1.69±0.0 b	16.44±0.6 b
Biondonna	17.72±0.2 a	28.08±0.5 a	268.11±7.4 b	26.11±0.9 b	240.44±7.3 b	5.31±0.3 b	1.75±0.1 b	20.33±1.2 b
Carmesi	18.81±0.4 ab	28.54±0.5 ab	155.11±5.1 a	20.44±0.4 a	144.44±4.5 a	5.09±0.3 ab	1.36±0.1 a	7.67±0.6 a
Significance								
Cultivar	***	***	***	***	***	***	***	***

The data show the means (n = 9) ± SE. Values followed by the same letter are not significantly different at the 0.05% level of probability according to Tukey's test. Asterisks indicate significant differences at * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns, non-significant.

Cultivar showed a significant influence on all tested morphological traits (Table 2). The green Batavia cultivar 'Lianabel' showed the highest value of rosette height (21.61 cm), cultivar 'Kiribati' the highest value for rosette diameter (31.72 cm), compared to 'Biondonna' that showed the lowest value for both traits (17.72 cm; 28.08 cm, respectively) (Table 2). Rosette diameter is a parameter that can reflect the ecological adaptation of the genotype, strongly related to photosynthetic rate and water retention capacity (Porto et al., 2014). Our results showed a higher rosette diameter compared to Pereira et al. (2023) in a summer experiment with six lettuce cultivars ranging from 19.43-23.39 cm. The explanation for wider rosettes obtained in our experiment could be due to wider plant spacing in our experiment 25 × 25 cm, compared to 20 × 20 cm. An increase in plant height, width, number of leaves, and fresh mass in different plant spacing is probably the result of less competition between plants for nutrients, moisture and light (Moniruzzaman, 2006). Also, rosette diameter visually can affect consumer choice of selecting the wider and heavier ones.

Rosette fresh weight is one of the most important parameters contributing to the lettuce yield. Genotype has a great influence on lettuce fresh mass (Govedarica-Lučić et al., 2014). The green Batavia cultivar 'Tourbillon' showed the highest rosette fresh weight (348.11 g) compared to the red lollo cultivar 'Carmesi' which showed the lowest (155.11 g). Apart from 'Tourbillon' having the highest fresh mass, cultivars 'Kiribati' and 'Lianabel' stood out as having no statistical difference between these three cultivars. Our findings are supported by previous research data that confirmed rosette fresh weight in green lettuce cultivars being higher than red (Koudela and Petríkova, 2008; Barickman et al., 2018). Average rosette fresh weight was in line with summer leaf lettuce obtained by Kopta et al. (2018).

Similarly, the same tendency was observed for the leaf fresh weight parameter. Cultivar 'Tourbillon' obtained the highest leaf fresh weight (326.11 g) compared to the red lollo cultivar 'Carmesi' (144.44 g). The findings of Sublett et al. (2018) also showed the same pattern in green lettuce cultivar having higher leaf mass compared to red counterpart. A very strong positive correlation was found between rosette and leaf fresh weight (0.99^{**}, Table 3) pointing out the importance of the leaf fresh weight in total mass. Our results were in line with the fresh leaf weight of four lettuce cultivars grown in a summer open-field experiment obtained by Carini et al. (2020).

Table 3. Correlation analysis of different lettuce agronomic criteria

Criteria	Rosette height	Rosette height	Rosette fresh weight	Number of leaves	Fresh leaf weight	Stem height	Stem diameter	Stem freh weight
Rosette height	1							
Rosette diameter	0.63^{**}	1						
Rosette fresh weight	0.47^{**}	0.53^{**}	1					
Number of leaves	0.66^{**}	0.64^{**}	0.89^{**}	1				
Fresh leaf weight	0.47^{**}	0.52^{**}	0.99^{**}	0.87^{**}	1			
Stem height	0.28	0.42^{**}	0.16	0.32^{*}	0.06	1		
Stem diameter	0.24	0.47^{**}	0.69^{**}	0.68^{**}	0.62^{**}	0.56^{**}	1	
Stem fresh weight	0.25	0.49^{**}	0.63^{**}	0.66^{**}	0.54^{**}	0.73^{**}	0.88^{**}	1

Asterisks indicate significant differences at * $p \leq 0.05$; ** $p \leq 0.01$.

Leaf number is one of the most important production parameters which depends on cultivar, agricultural practice, and environmental factors, where high temperatures, can accelerate vegetative growth, which leads to earlier flowering, and a reduction in the number of leaves (Sediyama et al., 2009). The red-coloured cultivar 'Carmesi' showed the lowest number of leaves (20.44) compared to all green cultivars with the highest number in the cultivar 'Kiribati' (41.44) (Table 2). Cultivars with a larger number of leaves are preferred by farmers and consumers (dos Santos et al., 2021). By increasing the number of leaves, it is expected to achieve better absorption of the light, which affects photosynthesis, faster growth and fresh mass. This parameter is also in a very strong positive correlation with rosette fresh weight (0.89^{**}, Table 3). Our results are in line with the number of leaves obtained in different experiments with lettuce in summer (Ilić et al., 2017; Carini et al., 2020).

Stem height for all cultivars was up to 7 cm (Table 2). The oak cultivar 'Kiribati' showed the highest stem height (6.86 cm), compared to the Batavia cultivar 'Tourbillon' which showed the lowest value (4.30 cm). According to Santana et al. (2012) stem height of up to 7 cm is favorable for the food industry, while a height of 7-9 cm indicates the starting of stem elongation. Apart from temperature, stem elongation also depends on the photoperiod, where lettuce plants tend to elongate in photoperiods longer than 13 h. In our experiment, the maximal temperature during the day exceeded 30 °C, as well as the photoperiod, which was higher than 14 h, but with no signs of flowering. Stem height is an important trait for lettuce breeding programs because it is directly related to flowering. From this aspect, the shorter the stem, the greater the resistance to flowering. Results of Sediyama et al. (2009) showed longer stems in six lettuce cultivars in summer, compared to the winter trial, which indicates a connection between temperature and flowering.

Stem diameter and weight are also traits of interest for both breeders and farmers as they affect quality attributes and resistance to adverse environmental conditions (Pereira et al., 2023). Having smaller and lighter stems facilitates work in the food industry during processing, having less waste and a higher percentage of lettuce edible parts. Green cultivar 'Kiribati' showed the highest stem diameter (2.26 cm) and stem fresh weight (33.67 g), compared to red cultivar 'Carmesi' which showed the lowest value for both parameters (1.36 cm and 7.67 cm, respectively) (Table 2). Research by Sublett et al. (2018) showed a similar tendency to obtain the lowest stem diameter in red compared to green-leaf lettuce cultivar. Our results for stem diameter and weight were in line with different lettuce cultivars grown in the summer experiments (Carini et al., 2020; Pereira et al., 2023).

Choosing the most favorable lettuce cultivar, by taking into account each of the analysed criteria, is a complex decision because the different criteria can indicate conflicting conclusions when deciding on the cultivar. For this reason, the ranking was performed using the MABAC method. The correlation analysis was carried out to reduce those criteria that have high coefficient values and that have a double influence on the ranking results (Table 3).

Based on the correlation coefficient results presented in Table 3, a reduction was made, by excluding criteria of leaf fresh weight, stem diameter, and fresh weight. The mentioned criteria had correlation coefficient values > 0.8 with some of the other analysed criteria, which indicates a strong linear relationship. Therefore, five remaining criteria were selected for ranking purposes: rosette height (C1), rosette diameter (C2), rosette fresh weight (C3), number of leaves (C4), and stem height (C5). In the first step, the initial matrix of order $m \times n$ (5 × 5) was formed, and then in the next step, the normalisation procedure was carried out using the equation for the beneficial criteria:

$$n_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-}$$ where it:

$x_i^+ = max(x_1, x_2, \ldots, x_m)$ the maximum values of the observed criterion

$x_i^- = min(x_1, x_2, \ldots, x_m)$ the minimum values of the observed criterion

The remaining criteria where the lower value is also more favorable (cost-type criteria) are normalised by the following equation:

$$n_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+}$$

The normalised matrix with the elements is given in Table 4.

Table 4. The normalised matrix

A	C1	C2	C3	C4	C5
A1	0.31	1.00	0.93	1.00	0.00
A2	0.54	0.60	1.00	0.72	1.00
A3	0.00	0.73	0.91	0.92	0.71
A4	0.72	0.13	0.00	0.00	0.69
A5	1.00	0.00	0.59	0.27	0.60

Alternatives: A1- 'Kiribati'; A2- 'Tourbillon'; A3- 'Lianabel'; A4- 'Carmesi'; A5- 'Biondonna'; Criteria: C1- rosette height; C2- rosette diameter; C3- rosette fresh weight; C4- number of leaves; C5- stem height.

In the third step, the elements of the weight matrix were calculated based on the equation:

$$v_{ij} = w_i t_{ij} + w_i$$

Where it:

t_{ij}- elements of the normalised matrix

w_i- weighting coefficients of the criteria

Weight coefficients were determined using the AHP method (Analytical Hierarchy Process, Al-Harbi, 2001) using experts' opinions when comparing selected criteria, and results are given in Table 5.

Table 5. Weight coefficients (w_i) according to the AHP method

C	C1	C2	C3	C4	C5
w_i	0.04	0.04	0.51	0.27	0.15

The degree of consistency for the observed coefficients is satisfactory because it is lower than the threshold value of 0.1 (consistency ratio (CR)=0.05). The results of the weight matrix are presented in Table 6.

Table 6. Weighted decision-making matrix

A	C1	C2	C3	C4	C5
A1	0.05	0.08	0.98	0.53	0.15
A2	0.06	0.06	1.01	0.46	0.29
A3	0.04	0.07	0.97	0.51	0.25
A4	0.07	0.05	0.51	0.27	0.25
A5	0.08	0.04	0.80	0.34	0.23

Alternatives: A1- 'Kiribati'; A2- 'Tourbillon'; A3- 'Lianabel'; A4- 'Carmesi'; A5- 'Biondonna'; Criteria: C1- rosette height; C2- rosette diameter; C3- rosette fresh weight; C4- number of leaves; C5- stem height.

In the next step, a matrix of boundary approximate areas is determined by the following equation:

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m}$$

Where it:

v_{ij}– elements of the weight matrix

m –total number of alternatives

The values of the border approximate area for each of the observed criteria are given in Table 7.

Table 7. Border approximate area (g_i)

Criteria	C1	C2	C3	C4	C5
g_i	0.06	0.06	0.83	0.41	0.23

In the fifth step, the distance matrix of the alternatives from the border approximate areas is determined. Alternatives can belong to the borderline, upper or lower approximation area. An alternative that is considered as the best, must belong to the above approximate area with as many criteria as possible. In the last step, the alternatives are ranked by determining the values of the criterion functions by alternatives (Si) by summing the distance of the alternatives from the border approximate areas. The distance matrix, criterion functions and ranking list are presented in Table 8.

Table 8. Distance matrix and the ranking list of alternatives

Alternatives	Criteria					S_i	Rank
	C1	C2	C3	C4	C5		
A1	-0.01	0.02	0.15	0.13	-0.08	0.21	**3**
A2	0.00	0.01	0.19	0.05	0.06	0.31	**1**
A3	-0.02	0.01	0.14	0.10	0.02	0.26	**2**
A4	0.01	-0.01	-0.32	-0.14	0.02	-0.45	**5**
A5	0.02	-0.02	-0.02	-0.07	0.01	-0.08	**4**

Alternatives: A1- 'Kiribati'; A2- 'Tourbillon'; A3- 'Lianabel'; A4- 'Carmesi'; A5- 'Biondonna'; Criteria: C1- rosette height; C2- rosette diameter; C3- rosette fresh weight; C4- number of leaves; C5- stem height; Si- sum of the distance of the alternatives from the border approximate areas.

Results given in Table 8 confirmed that the application of the MABAC method can provide a more precise answer instead of using just one-way ANOVA results to select adequate lettuce cultivar for summer open-field production. Cultivar 'Tourbillon' was ranked as the best alternative among other cultivars regarding all important parameters contributing to yield and quality for fresh market selling and food processing. This experiment showed that cultivar 'Kiribati', besides being in a group of cultivars with the highest rosette fresh weight, also had the tallest and heaviest stem, which can lead to premature bolting and the possible deterioration of the taste and quality after processing with possible tipburn, pinking, browning and decreased shelf life of the final product. Considering the height and diameter of the stem 'Kiribati' should be harvested before others in the summer, to avoid possible early flowering. The lowest ranked cultivar 'Carmesi' showed 2.24 times lower fresh mass and 2.03 times lower number of leaves compared to the highest rated, and also exhibited the lowest measurements of the stem, and these results make this cultivar the least suitable for food processing in the summer.

After ranking the alternatives, a sensitive analysis procedure was carried out, to determine the impact of changes in the value of the weighting coefficients on the ranking list of the alternatives (Božanić et al., 2019). The sensitive analysis was performed through 6 scenarios. In the first scenario, all criteria are given the same importance. Through the other 5 scenarios, in each of them, the criteria were individually given 2 times greater importance compared to the other criteria that had equal importance. The results are given in Figure 1.

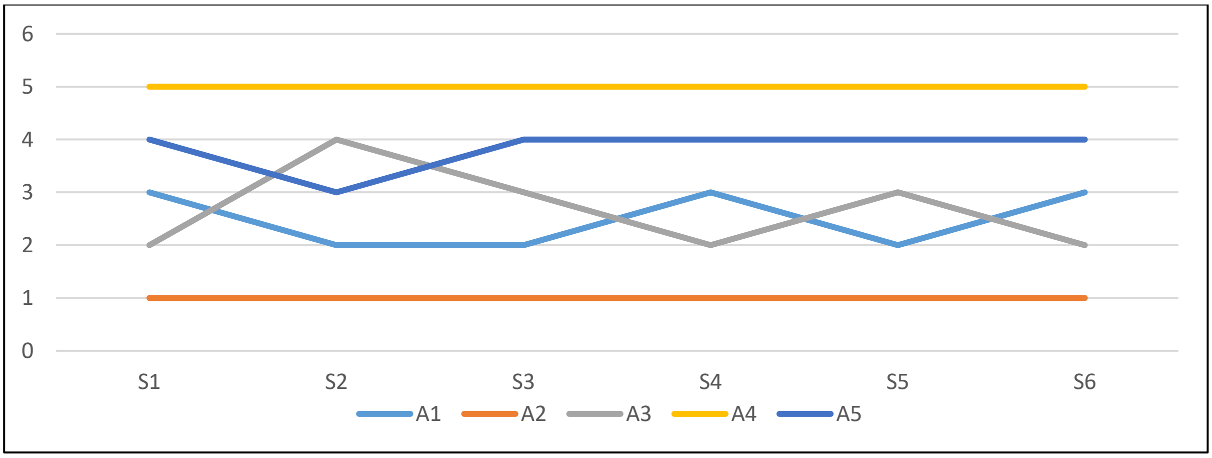

Figure 1. Sensitive analysis through 6 scenarios. Alternatives: A1- 'Kiribati'; A2- 'Tourbillon'; A3- 'Lianabel'; A4- 'Carmesi'; A5- 'Biondonna'

Based on the data from Figure 1, it can be concluded that there are no changes in the ranking list by scenario when it comes to the best and worst-ranked alternatives. Also, alternative A5 is ranked 4th in 5 out of a total of 6 scenarios. Alternative A1 was ranked second in 50% of the scenarios, while alternative A3 ranked second in the other scenarios.

CONCLUSIONS

Selection of the most optimal cultivar for the summer production included several criteria (rosette height, rosette diameter, rosette fresh weight, number of leaves, and stem height) for five cultivars using multi-criteria decision-making MABAC method. The obtained results showed that the green Batavia cultivar 'Tourbillon' has the best results and it can be recommended to farmers for summer open-field production. Even though the cultivar 'Kiribati', was in the group with the highest rosette fresh mass, this cultivar obtained the tallest and heaviest stem, which is not a suitable trait for the fresh market and processing. Summer lettuce production in the open field can be challenging due to outdoor temperatures that usually exceed 30 °C during the day. High temperatures can cause stem elongation, activate the flowering phase, decrease fresh mass, and deteriorate the taste. The lowest-ranked cultivar 'Carmesi' showed a lower fresh mass and a number of leaves compared to the highest-rated, which makes this cultivar the least suitable for food processing in the summer. The sensitive analysis confirmed no changes in the ranking list by all six scenarios regarding the best and worst-ranked alternatives. Therefore, choosing an adequate cultivar for summer production is the basic step to avoid economic losses, quantity and quality attributes.

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