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Use of some multicriteria decision-making methods such as grey relational analysis (GRA), the complex proportional assessment (COPRAS), and weighted aggregated sum product assessment (WASPAS) in selection of some Anatolian pine (*Pinus nigra* Arnold.) origins in semi-arid forestation works in Denizli Region

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Abstract

Aiming to determine the quantitative sapling characteristics that are important for sapling nursing methods, the present study was carried out on 2-year-old naked root Anatolian Black Pine (Pinus nigra Arnold. subsp. pallasiana (Lamb.) Holmboe) saplings obtained from four different seed origins from Denizli Forest Sapling Nursery Directorate. In this study, the selection of these four seed origins was examined using multicriteria decision-making methods (MCDM) by the determination of quantitative differences between origins and the use of suitable origins in practice. Within the context of the present study, the weight coefficients (significance degrees) of saplings such as height, root neck diameter, and last-year shoot length, and root length were measured using the Criteria Importance Through Intercritera Correlation (CRITIC) method. Secondly, the development performances of these four black pine origins were examined using Grey Relation Analysis (GRA), The Complex Proportional Assessment (COPRAS) and Weighted Aggregated Sum Product Assessment (WASPAS) methods. Besides that, since CRITIC-based GRA, COPRAS, and WASPAS methods showed complete consistency in terms of performance ranking, proportional values were very close to each other, and these methods have positive and very high levels of relationships with each other, it was considered that these methods can be alternative to each other in any measurement ranking or performance measurement. Accordingly, all these multicriteria decision-making methods (GRA, COPRAS, and WASPA) were successfully implemented in origin selection. Given the results obtained, it was determined that, in all three methods, İnceler origin ranked first and Çatak origin ranked last.

Keywords: Black pine; COPRAS; GRA; Multicriteria decision-making; Semi-arid area; Methods; WASPAS

1. Introduction

Türkiye has different ecological conditions that can be partially or completely distinguished from others by different geomorphological characteristics. These different ecological regions create a significant diversity in terms of plants, as with all organic species, in Türkiye [1, 2]. It puts the natural resources in Türkiye to a different point from the aspects of biological diversity and benefits they offer. One part of this important richness is Black Pine (*Pinus nigra* Arnold.). The general and common name of the black pine variety, which naturally distributes in Türkiye, is "Anatolian Black Pine" (*Pinus nigra* Arnold. subsp. *pallasiana* (Lamb.) Holmboe). Black pine is an important species that is naturally distributed as the main and marginal population in Thrace, Marmara, Central and Eastern Black Sea, Central Anatolia, Mediterranean, and Eastern Anatolia regions. Black pine is a very important species, which has a very wide geographical

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variation and is included in many forest zones. For this reason, seed stands were selected among the mature stands, which are widely available in almost any region in our country, and also clonal seed nurseries were established. As a half-light tree, it has a high tolerance to extreme habitat conditions thanks to its taproot system and abstinent characteristics. Moreover, the forests of this species are generally same-aged ones and they might establish one-layered and also multilayered stands during density and pole stages during the youth [3-5].

Quantitative characteristics of organisms are formed and shaped by the joint effects of morphological and environmental conditions [6,7]. These quantitative characteristics always provide important data about the growth and genetic diversity [8, 9]. For this reason, these parameters that are generally determined during youth and maturity periods offer significant information in determining the genetic quality level and sapling quality classes. In the present study carried out with 4 different black pine origins (Denizli-İnceler, Denizli-Elmaözü, Denizli-Buldan, and Uşak-Çatak) in Denizli Forest Nursery Directorate, it was aimed by making use of MCDM methods to measure the accuracy of selection for the use of these origins in establishing semi-arid region forestation from the aspect of some important quantitative characteristics of 2+0-year-old naked root black pine saplings. As MCDM methods, CRITIC-based GRA, WASPAS, and COPRAS methods were used.

In literature, [10], used the CRITIC method in determining the most important criteria in Web service selection. [11] Used the CRITIC method in determining the significance degrees of criteria in establishing mini network projects in renewable energy production. Using the CRITIC method, [12], revealed the most important criteria influencing the functional performance of open-degree friction structures reinforced with nylon and polypropylene fibers. [13] used the GRA method in analyzing the performances of old asphalt renewal methods. Using the GRA method, [14] calculated the performances of agricultural machinery of a company producing agricultural equipment in İzmir province. Using Fuzzy WASPAS and AHP methods, [15] determined the best worksite location based on the relevant data for Vilnius province. Within the context of Türkiye's technical, economic, environmental, and social criteria, [16] measured the performances of wind, solar, hydro, biomass, and geothermal energies of Türkiye in providing the energy by making use of Entrophy-based WASPAS method. Within the context of an experimental design, [12] used CRITIC-based WASPAS method in analyzing the performances of materials determining the water flow quality and water noise reduction from the water canals. [17] Investigated the optimal energy source of Türkiye by using the COPRAS method.

CRITIC method offers advantages such as determining the relative importance of criteria, reducing the subjectivity, and not considering the non-significant characteristics of criterion weights [18]. The most important distinguishing characteristic of the CRITIC method is that this method uses an objective weighting process, in which standard deviations and inter-criteria correlation are used together, rather than subjective weighting based on expert opinions [19]. When compared to other MCDM methods and statistical methods, the GRA method offers important advantages in terms of deviations and degradations in some assumptions [20]. Since it provides an effective and understandable procedure in cases where the objectives determined for separate alternatives cannot be analyzed using a single characteristic, the COPRAS method is the leading one among the methods used in MCDM techniques [21, 22]. Using the criterion weights in solving the MCDM problems, the WASPAS method yields the performance results of options by the criteria. In the end, the options are ranked from best to worst. Moreover, this method aims to achieve the highest consistency in estimation by optimizing the weighted integrated function [23].

2. Material and methods

2.1. Material

Examining the climatic characteristics of the study area, it was determined that the mean temperature was 16.2°C; the highest temperature was observed in July and August, whereas the lowest temperatures were observed in January, February, and December. The average precipitation was found to be 563.9 mm. Besides that, the vegetation period in the region ranges between 5 and 6 months [24]. The descriptive information about the origins is presented in Table 1.

In the present study, the measurements were carried out with three repeats without including the array of saplings in the pillow line and those in the adjacent lines besides the pillow line. Thus, for each quantitative characteristic, the measurements were carried out on 300 saplings (3 repeats, 100 saplings in each repeat) for each origin. For this reason, 1200 saplings were used in total for 4 origins. During the measurements, sapling height (SH) and last-year shoot length (SL) were measured using a ruler with "cm" increments. The measurements of root neck diameter (RND), which is one of the most important parameters of nutrition and growth in black pine saplings, by the origins were carried out using a diameter gauge having "mm" increments. Within the scope of this study, "the root length (RL) that was reported to be important for nutrition and catch is another parameter examined on 2+0-year-old naked root saplings by origins. The average changes in quantitative characteristics of 2-year-old naked root black pine saplings by origins are presented in Table 2.

Table 1 Information about black pine origins

Origin Name	Altitude (m)	Exposure
Denizli-İnceler	1230	South
Denizli-Elmaözü	1275	South
Denizli-Buldan	1243	South
Uşak-Çatak	1032	Southeast

Table 2 Mean results for quantitative characteristics of black pine origins

Origins	SH	RND	SL	RL
İnceler	38.7	7.8	3.5	25.6
Elmaözü	24.3	6.4	2.3	23.9
Buldan	21.6	6.1	1.8	21.7
Çatak	15.2	5.3	1.2	15.3

2.2. Method

Application steps of the CRITIC method used for the weight coefficients of origins' quantitative characteristics and the steps of GRA, COPRAS, and WASPAS methods used during the ranking process are presented below.

CRITIC method consists of 5 steps [20, 25-26].

Ai: i[th] decision alternative $(i = 1,2, \ldots, m)$
Cj: j[th] assessment criterion $(j = 1,2, \ldots, n)$
x_{ij}: value of i[th] alternative by j[th] assessment criterion
x_j^{max}: maximum value of decision alternatives by j[th] criterion
x_j^{min}: minimum value of decision alternatives by j[th] criterion
r_{ij}: value of i[th] alternative by j[th] assessment criterion
ρ_{jk}: relationship coefficient between any j criterion and k criterion
σ_j: standard deviation of j[th] criterion $(j = 1,2, \ldots, n)$
w_j: weight of j[th] assessment criterion $(j = 1,2, \ldots, n)$

Step 1. Establishing the decision matrix

$$X = \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2. Normalization of decision matrix

For the utility-oriented (maximization) criteria

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \quad (2)$$

Step 3. Establishing relationship coefficient matrix

$$\rho_{ij} = \frac{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})(r_{ik}-\overline{r_k})}{\sqrt{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})^2(r_{ik}-\overline{r_k})^2}} \quad (3)$$

Step 4. Calculating the Cj values

$$Cj = \sigma_j \sum_{k=1}^{n}(1-\rho_{jk}) \quad (4)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})^2}{m-1}} \quad (5)$$

Step 5. Calculating weight coefficients

$$w_j = \frac{c_j}{\sum_{k=1}^{n} c_j} \quad (6)$$

Application of the GRA method consists of 6 steps [27-29].

Step 1. Establishing the decision matrix

$$x_i = \left(x_i(j), \ldots x_i(n)\right)\ i = 1,2,\ldots,m\ ;\ j = 1,2,\ldots,n \quad (7)$$

x_i refers to decision alternatives, whereas $x_i(j)$ refers to the value of that decision alternative for j[th] criterion.

$$X = \begin{bmatrix} x_1(1) & \cdots & x_1(n) \\ \vdots & \ddots & \vdots \\ x_m(1) & \cdots & x_m(n) \end{bmatrix} \quad (8)$$

Step 2. Establishing the reference series and comparison matrix

$$x_0 = x_0(j)\ \ j = 1,2,\ldots,n \quad (9)$$

In order to meet the criteria in the decision problem, $x_0(j)$ value in Equation 9 refers to the best value of j[th] criterion among the normalized values to be obtained in the next step. Within this context, by adding the first row, the decision matrix shown in Equation 7 is converted to the comparison matrix.

Step 3. Establishing the comparison matrix

Equation 10 is used in cases that criteria are utility-oriented (maximization).

$$x_i^* = \frac{x_i(j)-\min_j x_j(j)}{\max_j x_j\,(j) - \min_j xj\,(j)} \quad (10)$$

In cases of criteria, for which the optimal condition is important, Equation 11 is used. Optimal values range between $\min_j x_j(j) \le x_{0b}(j) \le \max_j x_j\,(j)$.

$$x_i^* = \frac{x_i(j)-x_{0b}(j)}{\max_j x_j\,(j) - x_{0b}(j)} \quad (11)$$

In this case, the decision matrix is converted to Equation 12 matrix.

$$X^* = \begin{bmatrix} x_1^*(1) & \cdots & x_1^*(n) \\ \vdots & \ddots & \vdots \\ x_m^*(1) & \cdots & x_m^*(n) \end{bmatrix} \quad (12)$$

Step 4. Establishing the absolute matrix

The absolute difference between normalized components of comparison matrix and components of normalized decision matrix is calculated using Equation 13. The values calculated using Equation 13 are used in establishing absolute value matrix with Equation 14.

$$\Delta_{0i} = x_0^*(j) - x_i^*(j) \quad (13)$$

$$\Delta_{0i} = \begin{bmatrix} \Delta_{01}(1) & \cdots & \Delta_{01}(n) \\ \vdots & \ddots & \vdots \\ \Delta_{0m}(1) & \cdots & \Delta_{0m}(n) \end{bmatrix} \quad (14)$$

Step 5. Establishing the gray relational coefficient matrix

The components of this matrix, $\zeta \in [0,1]$, are calculated using Equations 15, 16, and 17.

$$\gamma_{0i}(j) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(j) + \zeta\Delta_{max}} \quad (15)$$

$$\Delta_{max} = \max_i \max_j \Delta_{0j}(j) \quad (16)$$

$$\Delta_{min} = \min_i \min_j \Delta_{0j}(j) \quad (17)$$

Where, ζ refers to the contrast control coefficient.

Step 6. Determining the grey relational degrees

In cases with criteria having the same significant levels, the grey relational degree is calculated using Equation 18, whereas Equation 19 is used in other cases. Where, $\sum w_i = 1$.

$$\Gamma_{0i} = \frac{1}{n}\sum_{j=1}^{n} \gamma_{0i}(j) \quad (18)$$

$$\Gamma_{0i} = \frac{1}{n}\sum_{j=1}^{n} [w_i(j)\, \gamma_{0i}(j)] \quad (19)$$

COPRAS method consists of 6 steps [30-34].

A_i: i[th] decision alternative
C_j: j[th] assessment criterion
w_j: weight of j[th] assessment criterion ($j = 1,2,\ldots,n$)
x_{ij}: value of i[th] alternative by j[th] assessment criterion ($j = 1,2,\ldots,n$)
d_{ij}: normalized value of i[th] alternative by j[th] assessment criterion ($j = 1,2,\ldots,n$)

Step 1. Establishing the decision matrix

$$D = \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (20)$$

Step 2. Normalization and weighting the decision matrix

$$x_{ij}^* = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad \forall j = 1,2,\ldots,n \quad (21)$$

Step 3. Weighting the normalized decision matrix

$$d_{ij} = x_{ij}^*\, w_j \quad (22)$$

$$D' = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \quad (23)$$

Step 4. Summing the normalized indices of weights

For the maximization-oriented criteria,

$$s_{+i} = \sum_{j=1}^{k} d_{+ij} \quad j = 1,2,..,k \tag{24}$$

Step 5. Determining the significance levels of decision matrices

$$Q_i = s_{+i} + \frac{s_{-min} \sum_{i=1}^{m} s_{-i}}{s_{-i} \sum_{i=1}^{m} \frac{s_{-min}}{s_i}} \tag{25}$$

Step 6. Performance indices of a decision alternative

$$P_i = \frac{Q_i}{Q_{max}} \cdot 100 \tag{26}$$

Similar to the COPRAS method, WASPAS method is implemented in 6 steps [20, 35-38, 39].

m: number of decision alternatives $(i = 1,2, \dots, m)$
n: number of assessment criteria $(j = 1,2, \dots, n)$
x_{ij}: value of i[th] alternative by j[th] assessment criterion $(j = 1,2, \dots, n)$
x_{ij}^*: normalized value of i[th] alternative by j[th] assessment criterion $(j = 1,2, \dots, n)$
w_j: weight of j[th] assessment criterion $(j = 1,2, \dots, n)$

Step 1. Establishing the decision matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{27}$$

Step 2. Normalization of decision matrix

Equation 3 is used for utility-oriented criteria.

$$x_{ij}^* = \frac{x_{ij}}{\max_i (x_{ij})} \quad i = 1,2, \dots, m; j = 1,2, \dots, n \tag{28}$$

Step 3. Measuring the total relative significance of i[th] alternative in WSM (Weighted Sum Method)

$$Q_i^{(1)} = \sum_{j=1}^{n} x_{ij}^* \; w_j \tag{29}$$

Step 4. Measuring the total relative significance of i[th] alternative in WPM (Weighted Product Method)

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(x_{ij}^*\right)^{w_i} \tag{30}$$

Step 5. Calculation of Weighted Joint General Criteria Value for WSM and WPM Models

$$Q_i = \frac{1}{2}\left[Q_i^{(1)} + Q_i^{(2)}\right] = \frac{1}{2}\left[\sum_{j=1}^{n} x_{ij}^* \; w_j + \prod_{j=1}^{n} \left(x_{ij}^*\right)^{w_i}\right] \tag{31}$$

Step 6. Determining the Relative Significance Value of Decision Alternatives

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)} = \lambda \sum_{j=1}^{n} x_{ij}^* \; w_j + (1-\lambda) \prod_{j=1}^{n} \left(x_{ij}^*\right)^{w_i} \tag{32}$$

Used in Equation 32, λ parameter ranges between 0 and 1. If $\lambda = 0$, then it turns into WPM method, whereas it turns into WSM method when $\lambda = 1$. Zavadskas et al. suggested Equation 33 for λ.

$$\lambda = \frac{\sigma^2\left(Q_i^{(2)}\right)}{\sigma^2\left(Q_i^{(1)}\right) + \sigma^2\left(Q_i^{(2)}\right)} \dots\dots\dots\dots \tag{33}$$

3. Results

Given the results obtained in the present study, weight coefficients of quantitative characteristics were calculated using the CRITIC method. Within this context, the decision matrix was established using Equation 1 specified in the first step of the CRITIC method. In the second step, since the criteria (components) were utility-oriented (maximization), the normalization values of the decision matrix were calculated using Equation 2. Accordingly, within the context of the CRITIC method, the decision matrix and normalized decision matrix values are presented in Table 3.

Table 3 Decision and Normalized Decision Matrices

Decision Matrix				
Criterion Orientations	**Max**	**Max**	**Max**	**Max**
Origins	SH	RND	SL	RL
İnceler	38.7	7.8	3.5	25.6
Elmaözü	24.3	6.4	2.3	23.9
Buldan	21.6	6.1	1.8	21.7
Çatak	15.2	5.3	1.2	15.3
Normalized Decision Matrix				
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	1	1	1	1
Elmaözü	0.387234	0.44	0.478261	0.834951
Buldan	0.27234	0.32	0.26087	0.621359
Çatak	0	0	0	0

In the CRITIC method, the relational coefficient matrix was established using Equation 3. Then, standard deviation values (σ) and C_j values were calculated using Equations 4 and 5. In the final step, Equation 6 was used in measuring the weight coefficients of components (w_j). The relational coefficient matrix, $1-p$ matrix, C_j, σ, and (w_j) are presented in Tablo 4.

Table 4 Relational matrix ($\boldsymbol{p}$), $\boldsymbol{1-p}$, $\boldsymbol{\sigma}$, $\boldsymbol{C_j}$, and $\boldsymbol{w_j}$ values

Relational Decision Matrix				
	SH	**RND**	**SL**	**RL**
SH	1	0.99769	0.99366	0.853234
RND	0.99769	1	0.995593	0.886504
SL	0.99366	0.995593	1	0.885138
RL	0.853234	0.886504	0.885138	1
$(1-p)$ values				
	SH	**RND**	**SL**	**RL**
SH	1	0.00231	0.00634	0.146766
RND	0.00231	1	0.004407	0.113496
SL	0.00634	0.004407	1	0.114862
RL	0.146766	0.113496	0.114862	1
$\boldsymbol{\sigma}$	0.178524	0.173867	0.180214	0.191622
$\boldsymbol{c_j}$	0.20627	0.194768	0.202851	0.263504
$\boldsymbol{w_j}$	0.237805	0.224544	0.233863	0.303789

Given Table 4, the weight coefficients of components were found to be root length (w_{RL} = 0.303789), sapling height (w_{SH} = 0.237805), shoot length (w_{SL} = 0.233863), and root neck diameter (w_{RND} = 0.224544). Examining Table 4, no significant difference was found between sapling height, shoot length, and root neck diameter.

The decision matrix established at the beginning of the GRA method is presented in Table 3. In the second step, maximum values were obtained from the values of components in the decision matrix in Table 3 and a comparison matrix was achieved. Within this context, the values of the normalized decision matrix and absolute value matrix in the GRA method are presented in Table 5.

Table 5 Normalized Values and Absolute Values within the context of GRA

Normalized Decision Matrix				
	Max	**Max**	**Max**	**Max**
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	1	1	1	1
Elmaözü	0.387234	0.44	0.478261	0.834951
Buldan	0.27234	0.32	0.26087	0.621359
Çatak	0	0	0	0
Absolute Value Matrix				
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	0	0	0	0
Elmaözü	0.612766	0.56	0.521739	0.165049
Buldan	0.72766	0.68	0.73913	0.378641
Çatak	1	1	1	1

Table 6 Performance Levels of Black Pine Origins by Criteria

Δ_max	1					
Δ_min	0					
ζ	0.5					
Grey Relational Coefficient Matrix					**Equal Significance Level**	
Origins	**SH**	**RND**	**SL**	**RL**	Γ_{0i}	**Rank**
İnceler	1	1	1	1	1	1
Elmaözü	0.449331	0.471698	0.489362	0.751825	0.540554	2
Buldan	0.407279	0.423729	0.403509	0.569061	0.450894	3
Çatak	0.333333	0.333333	0.333333	0.333333	0.333333	4
Grey Relational Coefficient Matrix					**Different Significance Level**	
Origins	**SH**	**RND**	**SL**	**RL**	Γ_{0i}	**Rank**
İnceler	1	1	1	1	1	1
Elmaözü	0.449331	0.471698	0.489362	0.751825	0.555609	2
Buldan	0.407279	0.423729	0.403509	0.569061	0.459238	3
Çatak	0.333333	0.333333	0.333333	0.333333	0.333333	4
w	0.237805	0.224544	0.233863	0.303789		

Before calculating the grey relational coefficient matrix values, the minimum and maximum values are determined among the absolute values matrix in Table 5, together with the distinguishing coefficient value (ζ). The results are presented in Table 6.

Given Table 6, the distinguishing coefficient value (ζ) was found to be 0.5. In the final step, the grey relational coefficient matrix was established based on the equalities and differences of significance levels.

Given Table 6, it was determined that the ranking of origins didn't change by equal and different weight coefficients. Accordingly, the origins ranked as İnceler, Elmaözü, Buldan, and Çatak.

Performances of application areas were determined using the COPRAS method. The decision matrix established in Table 3 and the normalized and weighted decision matrix obtained using the CRITIC method are presented in Table 7.

Table 7 Normalized and Weighted Normalized Decision Matrices within the context of COPRAS

Normalized Decision Matrix				
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	0.387776	0.304688	0.397727	0.295954
Elmaözü	0.243487	0.25	0.261364	0.276301
Buldan	0.216433	0.238281	0.204545	0.250867
Çatak	0.152305	0.207031	0.136364	0.176879
w	0.237805	0.224544	0.233863	0.303789
Weighted Normalized Decision Matrix				
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	0.092215	0.068416	0.093014	0.089907
Elmaözü	0.057902	0.056136	0.061123	0.083937
Buldan	0.051469	0.053505	0.047836	0.076211
Çatak	0.036219	0.046488	0.03189	0.053734

Since all the criteria were utility-oriented structures, criterion orientations were considered as maximization. The sum of weighted normalized decision indices (S_{+i}) was considered as sole maximization. This value is calculated by summing the weighted normalized decision matrix (Table 7) by the decision alternatives. Finally, the performances of origins by the COPRAS method are calculated overS_{+i}. Calculated accordingly, performance values (P_i) are presented in Table 8.

Given Table 8, selection performances of origins by the COPRAS method were found to rank as İnceler (100), Elmaözü (75.41765), Buldan (66.66233), and Çatak (48.99714). There were significant differences between İnceler and Çatak in terms of performance.

Table 8 $\boldsymbol{S_{+i}}$ **and** $\boldsymbol{P_i}$ values of origins

Origins	$\boldsymbol{S_{+i}}$	$\boldsymbol{P_i}$	**Rank**
İnceler	0.343552	100	1
Elmaözü	0.259099	75.41765	2
Buldan	0.229019	66.66233	3
Çatak	0.16833	48.99714	4

In the WASPAS method, the decision matrix values presented in Table 3 should be normalized first. Criterion orientations and normalized values calculated are presented in Table 9.

Table 9 Normalized Decision Matrix by WASPAS

Normalized Decision Matrix				
Origins	**SH**	**RND**	**SL**	**RL**
İnceler	1	1	1	1
Elmaözü	0.627907	0.820513	0.657143	0.933594
Buldan	0.55814	0.782051	0.514286	0.847656
Çatak	0.392765	0.679487	0.342857	0.597656
$\boldsymbol{w}$	0.237805	0.224544	0.233863	0.303789

Using the values presented in Table 9 and the weight coefficients, criteria of which were specified within the context of the CRITIC method, total relative significance levels of countries are determined by making use of WSM (Q_1) and WPM (Q_2) methods. Accordingly, the values calculated are presented in Table 10.

Table 10 Total relative significance levels of black pine origins by weighted sum ($\boldsymbol{Q_1}$) and weighted product ($\boldsymbol{Q_2}$) methods

WSM-based relative significance values					
Origins	**SH**	**RND**	**SL**	**RL**	$\boldsymbol{Q_1}$
İnceler	0.237805	0.224544	0.233863	0.303789	1
Elmaözü	0.149319	0.184241	0.153681	0.283615	0.770857
Buldan	0.132728	0.175605	0.120272	0.257508	0.686114
Çatak	0.093401	0.152575	0.080182	0.181561	0.507719
WPM-based relative significance values					
Origins	**SH**	**RND**	**SL**	**RL**	$\boldsymbol{Q_2}$
İnceler	1	1	1	1	1
Elmaözü	0.895238	0.956552	0.906478	0.979342	0.760219
Buldan	0.870511	0.946295	0.855976	0.951029	0.670589
Çatak	0.800724	0.91689	0.778539	0.855241	0.488842
$\boldsymbol{Q_i}$ **values**					
İnceler	1	1			
Elmaözü	0.765538	2			
Buldan	0.678351	3			
Çatak	0.498281	4			

In accordance with the weighted sum method for each black pine origin in the WASPAS method, total relative significance levels (Q_1) of each decision alternative (country) are summed based on the weighted product method and the result is divided by total relative significance level (Q_1) of each black pine origin according to weighted sum method in order to determine the selection performance values (Q_i). The values found are presented in Table 6. Moreover, the rankings for different λ values are shown in Table 11.

Table 11 Performance ranking of black pine origins by different λ values

Different λ values and rankings								
	λ=0		λ=0.25		λ=0.75		λ=1	
Origins	0	Rank	0.25	Rank	0.75	Rank	1	Rank
İnceler	1	1	1	1	1	1	1	1
Elmaözü	0.760219	2	0.762878	2	0.768197	2	0.770857	2
Buldan	0.670589	3	0.67447	3	0.682232	3	0.686114	3
Çatak	0.488842	4	0.493562	4	0.503	4	0.507719	4

As seen in Table 11, the performance rankings of origins by the WASPAS method were found to be the same as presented in Table 10. Accordingly, the ranking of origins in all λ values was found to be İnceler, Elmaözü, Buldan, and Çatak.

4. Discussion

In the present study carried out on 2-year-old naked root black pine saplings obtained from four different seed origins (Denizli-İnceler, Denizli-Elmaözü, Denizli-Buldan, and Uşak-Çatak) from Denizli Forest Sapling Nursery Directorate, it was aimed to reveal the difference between origins by saplings' quantitative characteristics, which are important for the quality and adaptation capacity of saplings, such as sapling height, root neck diameter, last-year shoot length, and root length. Within this context, as a result of the statistical analyses conducted on the raw data obtained from the measurements carried out in the nursery, important and practical scientific data that will contribute to black pine farmers were obtained.

The first objective of this study was to determine the significance levels within the scope of the CRITIC method for origins. The second objective is to measure the development performances of origins by using MCDM methods such as CRITIC-based GRA, WASPAS, and COPRAS methods, as well as ranking the origins accordingly. Examining the weight coefficients of criteria, it was determined that there was no significant difference between the weight coefficients of sapling height, last-year shoot length, and root neck diameter. Ranking the origins by these methods, Çatak origin ranked the last, while the most successful origin was found to be İnceler. The reason for Çatak origin ranking the last might be because it is an origin from outside the Denizli region, it took some time for this origin to adapt to the ecological conditions of the study area, and decreases might have occurred in its growth parameters for this reason.

Al the phenotypical characteristics of plants are shaped by the mutual interactions between their genetic structures and environmental conditions [40, 41]. One of the leading environmental factors influencing the plant development is the climate [42-44]. Among the climatic parameters, drought is the factor limiting the plant growth the most [45, 46]. In recent studies, it was determined that the level of drought will gradually increase due to the global climate change [47-50]. Thus, the studies carried out on species, which can grow in arid areas in particular, gain a specific importance because the studies showed that the organisms that will be affected by the drought arising from the global climate change the most would be the plants and those studies underline the importance of drought-resistant species and origins [51, 52].

5. Conclusion

Having a wide geographic variation, black pine is commonly used in landscaping projects, as well as forestation, erosion control, and rehabilitation efforts in semi-arid and arid regions [5, 53-55]. Drought tolerance of this species allows for further expansion of the areas of use due to the increase in drought because of global climate change. Thus, it is very important to determine the quality levels of saplings obtained from different origins of this species and use them in forestation projects.

Recommendations

In the light of scientific results obtained in the present study, it can be stated that mass production of high-quality saplings and using them in forestation projects in areas, where the extreme habitat conditions are dominant, as soon as possible are important for the performance and productivity of these remarkable investments. On the other hand, by carrying out similar studies on saplings produced from the seeds obtained from marginal populations of black pine, conducting an accurate sampling in all the distribution areas, especially for micro-ecological conditions, would offer significant advantages in developing and implementing species-specific improvement strategies and preparing effective sapling production and use programs.

The present study was carried out in Denizli Forest Nursery Directorate by using local and non-local origins. It is a preliminary and pioneering research. It is recommended to use systematic sampling method under different ecological conditions for the future studies on this subject. Use of seeds from much higher number of origin and implementation of different genetic tests would contribute to obtaining better results. Future studies to be carried out accordingly would contribute to increasing the value of this species, which is very important and common in our country, from genetic, improvement, silvicultural, ecological, and economic aspects. In particular, by emphasizing the changes in geographical variations, involvement of this species in studies on climate change and establishing new seed improvement zones are very important for practitioners. Thanks to those studies, production quality of this species in nursery gardens can be significantly improved.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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