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Research Article

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A two-level approach to geospatial identification of optimal pitaya cultivation sites using multi-criteria decision analysis

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Abstract

BACKGROUND: Pitaya, also known as dragon fruit, is one of the most popular and expensive fruits in the world. It has been commercially produced since the early 20th century. This plant requires a specific growing environment and ecological conditions, so it is typically cultivated under greenhouse conditions in Türkiye. However, there is a clear need for a comprehensive assessment of outdoor adaptation and/or outdoor growing areas for sustainable yield at the regional scale.

RESULTS: This study presents a multi-criteria decision-making analysis-based geographical information system (GIS) study to identify and evaluate the suitability of outdoor growing areas for pitaya. In this study, eight crucial factors were identified for outdoor pitaya cultivation: temperature, rainfall, soil pH, soil depth, land use capability, altitude, slope and aspect. An analytical hierarchy process was conducted to determine the weights for each parameter, followed by a weighted overlay analysis using GIS tools. The range of weight values was obtained between 0.2748 and 0.0319. The area of the best places for pitaya cultivation was calculated to be 9245.7 ha (11.7%). It was determined that 32.63%, 37.57% and 18.1% of the locations were moderately suitable, less appropriate and unsuitable, respectively.

CONCLUSION: The selection of comparable production sites will be guided by the study. Such suitable site selection studies are extremely significant since the cultivation of the pitaya plant, which has a high commercial value for economically developing countries, will be crucial to the growth of agricultural employment in these nations. Future research will be guided by this study's methodology and analysis strategies.
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Keywords: site selection; multi-criteria decision analysis; pitaya fruit; GIS; land use planning

INTRODUCTION

Tropical fruit cultivation plays an important role in generating income for producers and creating job opportunities in the market, as with other crops, since the 1970s. Although the prices of tropical fruit are higher than those of most traditional fruit types, their richness in vitamin C and antioxidants and having different flavors increase the demand for these fruit species day by day.[1] Tropical fruits account for 3% of world agricultural food product exports and a value above USD1000 per ton places them as the third most valuable fruit group globally.[2] Developing countries account for about 98% of total tropical fruit production, while developed countries account for 80% of world import trade.[3] Pitaya, one of the tropical fruits and known as dragon fruit, is a member of the cactus family (Cactaceae), specifically the *Selenicereus* genus (formerly *Hylocereus*), and is an exotic fruit, naturally grown in tropical and subtropical regions of Mexico, Central America and South America. Southeast Asia is the second most likely center of origin. These fruits are appropriate for tropical and subtropical areas because they flourish in warm, humid temperatures with nutrient-rich soil.[4-7] Pitaya is a climate-smart crop due to its low water requirements, high water use efficiency, drought resistance and ability to adapt easily to high temperatures and light intensity. The fruit can tolerate a wide range of challenging soil conditions, including those with high salinity. These attributes have facilitated the large-scale commercial cultivation of pitaya fruit in over 30 tropical and subtropical countries worldwide.[6] Today, the regions where commercially produced and cultivated species are grown are Indonesia, Taiwan, Vietnam, Thailand, Philippines, Sri Lanka, Malaysia, Bangladesh, Bahamas, Bermuda, Colombia, Israel, Philippines, Myanmar, Nicaragua, northern Australia, Okinawa (Japan), Hawaii and the West Indies.[5,8] Pitaya, which is of great importance for human

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health due to its high fiber content, antioxidant properties and richness in vitamins and minerals, is also considered to be very valuable economically.[9-14] Although the average productivity of pitaya varies according to the physical and ecological characteristics of the growing environment, the average annual production of a four-year-old plant is 25 kg. It is also known that it provides a yield of approximately 10 to 30 tons/da per year, depending on the planting density.[10] The period from planting to harvest is 12 to 18 months and it is a perennial crop with a lifespan of 20–30 years.[15] Therefore, this plant has a high potential to provide regular financial income in suitable growing environments. The dragon fruit market is growing at a strong rate due to the increasing demand for fresh dragon fruit. Although dragon fruit is relatively new and not widely advertised, especially in Europe, research shows that Europe is the fastest growing market for demand for dragon fruit.[16] Vietnam, the world's leading exporter of dragon fruit, accounts for more than half of the world's production, with a value of approximately USD900 million.[17,18] In Türkiye, pitaya cultivation started in 2012 with varieties brought from the USA and spread rapidly in a short time, especially in the Mediterranean region. Türkiye's first pitaya registration was made on behalf of BATEM in 2018.[19] Bloody Mary and Cosmic Charlie pitaya cultivars are Türkiye's first registered tropical plants. Cosmic Charlie is a hybrid variety from *Hylocereus guatemalensis* and *Hylocereus undatus*. Bloody Mary is a common variety from the genus *Hylocereus* and the species *polyrhizus*.[18] These two varieties have been adapted and started to be grown commercially in the Mediterranean region. However, the current production in Türkiye is far below the marketable volume today. The low cost of cultivation, the absence of any diseases and pests that require intensive control and the low need for irrigation and fertilization reduce operating costs, and the 20- to 30-year lifespan of the plant increases economic efficiency. Therefore, it seems to be a very profitable investment for Türkiye.[20,21] In this context, due to its high efficiency, low production cost and economic value, its popularity has increased considerably among agricultural producers in Türkiye's suitable climatic regions.

Pitaya, which adapts quickly to tropical regions and can grow well in terms of ecological conditions, can be grown outdoors in these tropical climate regions,[22,23] but it is mostly grown in greenhouse conditions in subtropical regions.[24,25] Although it is mostly grown in greenhouse conditions in Türkiye, it is also grown outdoors. Due to the high greenhouse installation costs and the availability of outdoor cultivation opportunities, the study reported here focused on identifying the most suitable areas where pitaya can be grown commercially outdoors.

The ecological and climatic conditions required for pitaya cultivation in Türkiye are available in the Mediterranean region. Current pitaya cultivation is mostly carried out in the provinces of Hatay, Adana, Osmaniye, Mersin, Antalya and Mugla, where the Mediterranean climate prevails.[21,25] Antalya province ranks first in Türkiye's tropical fruit production. Antalya is the source of 81% of Türkiye's commercial avocado production and 33% of banana production. Accordingly, Antalya province was chosen as the study area due to its climate and ecological characteristics, considering pitaya's growing environmental factors.

Many studies have been conducted on pitaya in the literature, and most of these studies focus on the effects of pitaya on health,[26] its chemical content,[27] diseases and pests,[28,29] market research,[14,30] production conditions,[31,32] storage conditions,[33,34] harvest and production period.[5,35] The lack of studies on determining the most suitable areas for outdoor cultivation of the pitaya plant based on the relevant cultivation criteria and the fact that they have not been conducted specifically in Türkiye constitute the motivation for this study.

Remote sensing and geographic information systems (GIS) technologies have been frequently preferred in many disciplines, especially in recent years, due to their fast and accurate results in appropriate site selection studies such as site selection of solid waste disposal,[36,37] selection of optimum location of astronomical observatories,[38] solar farm site selection[39] and site selection of wind farms.[40] Similarly, with the advancement in GIS technologies, multi-criteria decision-making analyses (MCDA) in recent years have been increasingly used for study of cultivation of various crops. Examples of these studies include those concerning apple,[41] rice,[42] citrus,[43] tropical and subtropical crops such as mango, banana, papaya, citrus and guava[44,45] and avocado.[46] Although GIS and MCDA have been used to select the most suitable sites for the above-mentioned crops, it has been observed that, to our knowledge, no study has been conducted in the literature for plants with high economic value, such as pitaya. In the study reported here, it was aimed to determine and classify the most suitable areas for commercial production of pitaya in outdoor conditions in Antalya, one of the most important tourism and agricultural destinations in Türkiye. For this purpose, in the study, firstly, the suitability criteria for the relevant layers were determined through a multi-layered decision mechanism, and then these parameters were analyzed using MCDA and GIS tools to identify suitable areas for pitaya cultivation.

STUDY AREA

The surface area of Antalya, which is the fifth most populous province of Türkiye, is 20 177 km^2.[47] It is located in the west of the Mediterranean region. Antalya province is located in the southwest of Türkiye, between 29° 20′ and 32°35′ eastern longitudes and 36° 07′ and 37° 29′ northern latitudes.[48] It is bounded by the Mediterranean Sea in the south and the Taurus Mountains running parallel to the sea in the north, and borders Mersin, Konya and Karaman in the east, Isparta and Burdur in the north and Mugla in the west (Fig. 1).

On average, 77.8% of the province's land is mountainous, 10.2% is plain and 12% is rugged. The Taurus Mountains, which cover three-quarters of the provincial area, exceed 2500 m. The topographic variability of the province creates different environments in terms of climate, agriculture, demography and settlement. The area generally falls into the Mediterranean climate.[39] The average temperature in summer is between 28 and 36 °C. In January, the temperature varies between 10 and 20 °C on average. Snow is very rare in the coastal areas, and although frost is rare, it does not occur every winter on the coasts. On days when there is no rain, the weather is clear and sunny.

The annual average relative humidity in the province is around 64%. Only 40–50 days of the year are cloudy and rainy. Antalya is one of the rare regions with an average of 300 sunny days per year, an average annual temperature of 18.8 °C and an average annual rainfall of 1060 mm, according to the measurement period of 1931–2021. The highest daily rainfall amount measured in Antalya is 232.8 kg m^{-2}, and the fastest daily wind is 155.5 km h^{-1}.[49]

Antalya province is very important in Turkish agriculture in terms of agricultural potential and ecological suitability with its Antalya Plain. The land asset of the province is 2 018 000 ha, and the agricultural area is 360 245 ha.[47] Antalya is a region

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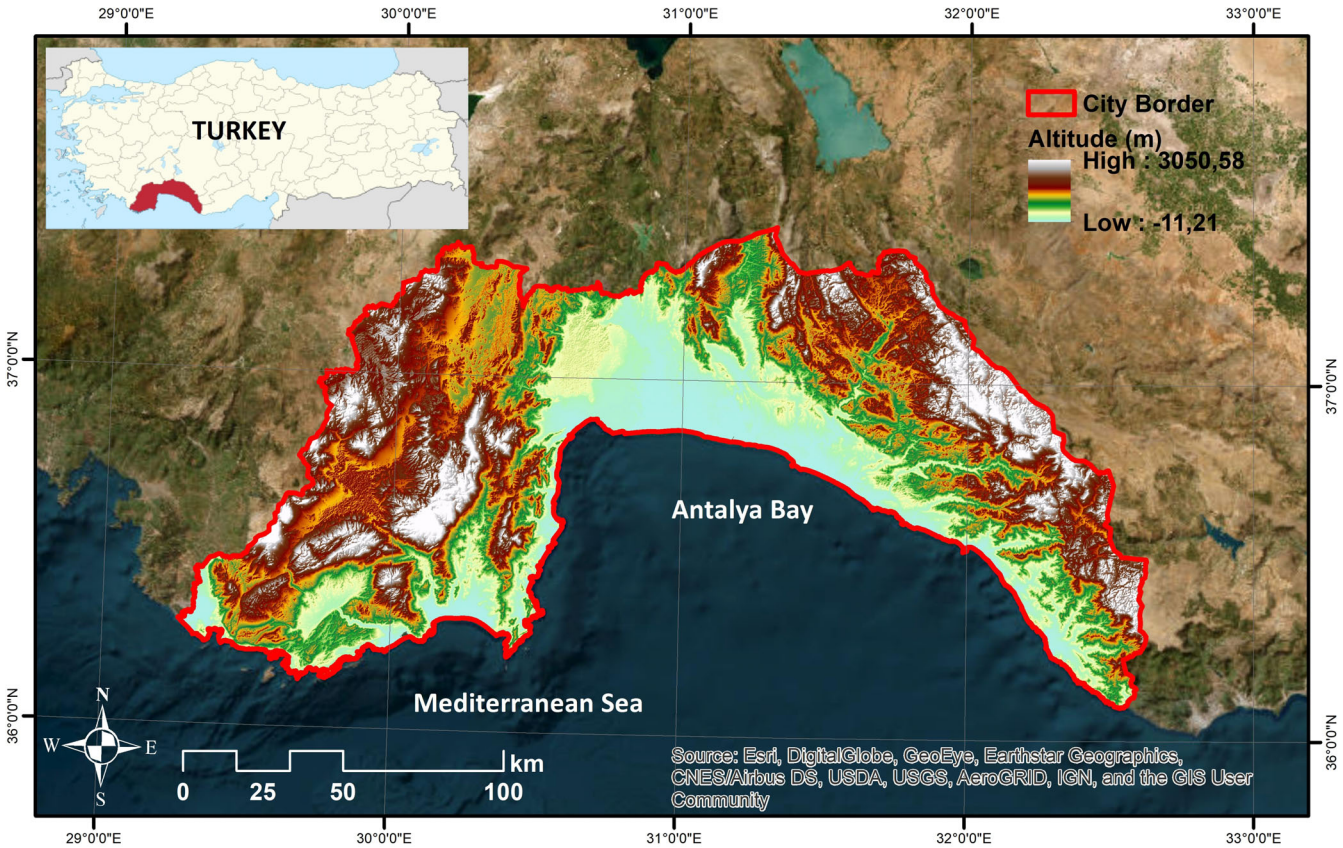


Figure 1. Study area location.

where one-fifth of its land is agricultural. In addition to growing tropical plants such as oranges, bananas and avocados in the coastal areas of Antalya, greenhouse agriculture is also carried out. In areas away from the coast, cold-resistant fruit species such as apples, pears and quinces are grown. The most commonly grown agricultural products are tomatoes, cucumbers and oranges. Antalya province produces 6.06% of the production in Türkiye, with an annual fruit production of 1 011 917 tons.[47]

DATA SETS

In the first stage, the environmental conditions controlling the growth and development factors of pitaya were determined in line with existing literature information. Studies explaining the parameters and habitat limitations required for pitaya cultivation outdoors are given in Table 1. Nine input parameters were used, taking into account the climate, vegetation and ecological and physical conditions of Antalya province.

In the selection of these input parameters, National Research Institute data[58] were also considered, which specify the ecological and environmental factors under which the pitaya plant is cultivated in Türkiye, as well as the optimum growth conditions. These parameters were chosen to ensure that the plant can naturally grow in open fields under Turkish conditions without experiencing ecological stress and without requiring additional infrastructure (irrigation, shading, frost protection, etc.). The objective of site selection studies is to identify the most suitable area within the existing conditions, without the need for any improvement work.

Table 1. Suitability criteria for growing pitaya

Parameters	Optimum conditions for pitaya cultivation	Related studies
Temperature	12–38 °C	50-52
Rainfall	500–2000 mm	23,51,52
Soil pH	5.5–6.5	53-55
Soil depth	0–30 cm	50,56,57
Land use capability	I, II, III, IV class soil suitable V, VI, VII, VIII class soil unsuitable	58
Altitude	0–1850 m	59-61
Slope	30% or lower slopes	62-64
Aspect	Aspects that are not exposed to long-term direct sunlight	50,56,65
Protected/ forbidden areas	Commercial-agricultural areas not allowed according to national legislation	66

Digital elevation model (DEM), geological maps, soil maps, protected area data and meteorological data required to obtain these data sets were transferred to the ArcGIS platform, a database was created and analyses were carried out.

Temperature

Pitaya can grow optimally in tropical and subtropical climates where there is no risk of frost. In cultivation, it is preferred that

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the temperature does not fall below a minimum of 0 °C and does not exceed a maximum of 38 °C. It can withstand temperatures of 0–12 °C for short periods of time.[50] Temperatures below 12 °C can cause local damage to cells in the plant body.[30] The plantation begins to be damaged at −2 °C, and deaths occur at −4 °C. Increasing the temperature to 45 °C causes deformation in plants and decreases flowering.[67,68] Optimum temperature values for ideal plant development are reported as 20–30 °C.[51]

Rainfall

Soil moisture in the plant root zone is an important factor for flower formation and final fruit size.[59] Pitaya grows naturally in regions of Mexico with 340–3500 mm yr^{-1} rainfall.[30] It has been reported that the annual rainfall requirement of this plant should be between 500 and 2000 mm.[23,51] However, for pitaya, a study has been conducted suggesting that 120 mm per year is sufficient as a minimum level.[69] Additionally, excessive water systematically causes flowers and young fruits to fall off.[32]

Soil pH

Although pitaya is not very selective in terms of soil, sandy–loamy, well-drained soils with a pH of 5.5–6.5 are preferred for cultivation.[55,64,70] Although it varies depending on the species and variety, it has been recorded to have medium and high tolerance to salt.[53] There are studies stating that this plant can grow at soil pH values between 3 and 7.[71,72] Additionally, this plant likes soils high in organic matter.[73]

Soil depth

Proper root development directly affects yield, and soil depth is a crucial factor for pitaya.[74] The majority of pitaya roots are spread in the upper part of the soil, at a depth of 15–30 cm, which is rich in organic material.[56] It is stated in the literature that, depending on fertilization, root development at a depth of 0–20 cm is greater than root development spread between 20 and 40 cm.[24,57] It has been reported that the maximum root depth for pitaya is 40 cm.[50]

Land use capability

Lands in Türkiye are between first class and eighth class, depending on their usability. First-class lands are those that can be cultivated in the best, easiest and most economical way. Areas that are not suitable for agriculture, cannot even be used as meadows or forests, but host wildlife or are used as recreational areas by people are eighth-class lands. In this context, I, II, III and IV class soils have suitable characteristics in terms of agricultural suitability and are suitable for growing field crops. Other than that, V, VI, VII and VIII class soils are included in the unsuitable category because they are not suitable for agriculture in terms of erosion, soil quality, soil depth and soil structure.[75]

Aspect

Pitaya, which can grow in sun and semi-shade conditions in its natural environment,[50,65] can adapt to every tropical region in terms of ecological conditions and is grown outdoors in tropical climate conditions. In addition, it is grown with partial shading in areas exposed to long-term direct sunlight or in greenhouses.[50] For example, in the Neveg Desert in Israel, the most favorable conditions for growth and fruit production were found to be 30% shade for Pitaya. However, excessive shade can also cause low yields and poor-quality fruit formation.[76] Especially, the southern slopes of Antalya province can be exposed to direct sunlight for a long time during the summer period.[77] Therefore, although the pitaya plant is tolerant of direct sunlight, it is considered appropriate to grow it in areas that do not receive direct and long-term sunlight, especially in Antalya, in terms of yield and quality.

Slope

Pitaya is mostly grown in well-drained, flat or slightly sloping areas.[62,63] It is known that naturally distributed species grow on plains and gently sloping slopes.[59] Areas with slopes of 30% and lower are suitable areas for commercial cultivation.[64]

Altitude

Pitaya mostly grows better at sea level. It is cultivated from sea level up to 1850 m.[59] It is grown in very rainy regions of Mexico up to 2750 m.[30] It is known that it develops well up to approximately 700 m.[78] At higher altitudes, prolonged temperature drops below 0 °C cause stress to the plant and reduce productivity.

Protected/forbidden areas

In Türkiye, there are various protection statuses under the authority and responsibility of public institutions and organizations that are independent from each other and have different legislation. These can be listed as national parks, nature parks, nature conservation areas, protected areas, special environmental protection zones and Ramsar areas. In general, any commercial-agricultural activities are not allowed in these areas, which are protected within the framework of the National Parks Law and the Law on the Protection of Cultural and Natural Assets, except for public interest and special permission.[66] In addition, military areas, airports and public forests were evaluated in the forbidden zone category within the scope of this study.

METHODOLOGY

This study was conducted in three main phases which were: (1) defining and classifying the growing environment criteria for pitaya cultivation, (2) creating a database based on these criteria and (3) determining the degree of suitability of the criteria using MCDA and performing overlap analyses. Basically, all input parameters were classified according to suitability criteria in the literature, then MCDA was applied to these data sets. Therefore, the study can be identified as a two-level approach. All detailed stages of the study are shown in Fig. 2.

Definition and classification of the growing environment criteria for pitaya cultivation

Suitable conditions for pitaya cultivation were already given in previous sections. According to Table 1, the input parameters were categorized into four classes which are unsuitable, less suitable, moderately suitable and most suitable conditions. Therefore, the suitability for pitaya cultivation is presented in Table 2 and these definitions were classified as the four classes as mentioned.

The study identified four classes for scoring the input data: unsuitable (0 point), less suitable (1 point), moderately suitable (2 points) and most suitable (3 points). According to FAO,[79] the Framework for Land Evaluation (FLE) consists of a set of principles and concepts on which local, national or regional land suitability evaluation systems can be constructed. The FLE system assumes that land can be ranked into distinctly different categories, each one associated with a different potential for a particular use. Commonly, as preferred in this study, the categories are divided into unsuitable, less suitable, moderately suitable and most suitable.

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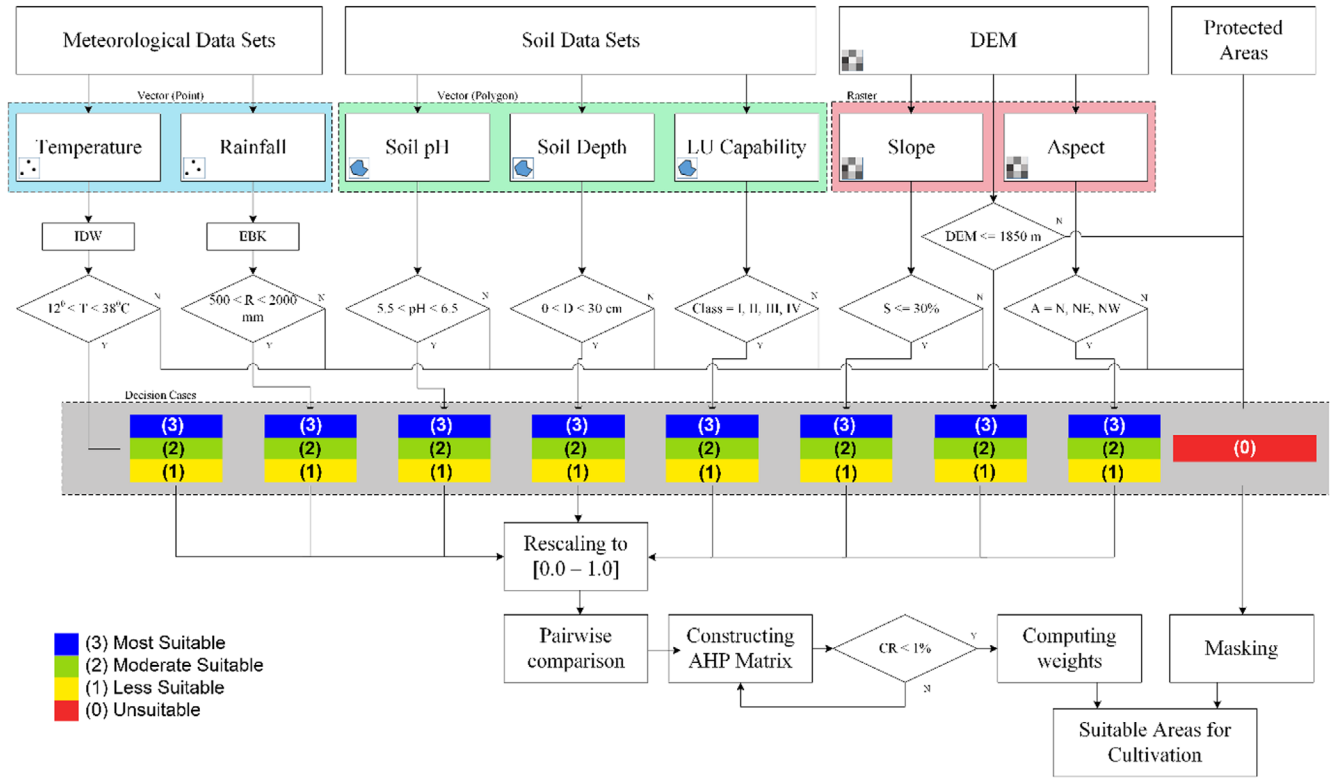


Figure 2. Flow chart for the applied algorithm.

Suitability is assessed by comparing land characteristics or land qualities to the requirements of the pitaya plant. Therefore, the justifications for the scores corresponding to these classes are as follows. Unsuitable, 0 point; conditions exist in the land that are so restrictive for the successful and sustained cultivation of pitaya that they would prevent its use. Less suitable, 1 point; environmental conditions exist that have collectively serious limitations for the sustainable cultivation of pitaya and would reduce productivity or increase the required inputs and costs. Moderately suitable, 2 points; there are land conditions with moderately serious limitations for the sustainable cultivation of pitaya. These limitations will reduce productivity or benefits, but the expected yield can still be achieved to a reasonable extent. The labor and costs incurred are proportional to the benefits derived from production, and in some cases, the benefits might even exceed the costs. Most suitable, 3 points; these are land conditions that do not pose significant limitations for the sustainable cultivation of pitaya, do not significantly reduce productivity and do not increase input requirements beyond acceptable levels. Under these conditions, the plant can naturally reach its full yield without requiring additional input. These conditions are optimal where the benefits far outweigh the labor and costs involved.

To summarize in the context of this study, as stated in the previous section regarding the limitations of each input parameter, a score of 0 represents areas where cultivation is entirely unsuitable or where the benefit is almost nonexistent. Under these conditions, the plant is likely to face significant ecological stress, and the expected yield will be very low. Improving these conditions would require high costs and additional infrastructure. A score of 1 represents areas that require substantial additional costs and infrastructure for the cultivation of the plant. Despite the stress conditions being high, agricultural production could still occur with extra costs. A score of 2 represents areas suitable for cultivation but still requiring certain conditions to achieve optimal yield. When these conditions are met, they could be upgraded to the most suitable class and support agricultural production. A score of 3 represents optimal areas where the best yields can be naturally achieved.

Temperature and rainfall data sets were generated from a meteorological database from the Turkish State Meteorological Service with 10 years of data.[49] In this study, data from 32 meteorological stations located not only within the study area polygon but also outside the study area polygon were used for better and more realistic interpolation of the study area boundaries. Temperature and rainfall data were generated using inverse distance weighting (IDW) and empirical Bayesian kriging (EBK) techniques, respectively. The IDW method is suitable for interpretation of temperature data sets due to temperature values depending on distance. In addition, the EBK method is appropriate for producing rainfall interpolation. EBK has been preferred in many academic studies evaluating rainfall distribution as a fast and reliable solution for interactive data interpolation.[80-84] The EBK interpolation method has been compared with various interpolation methods in the literature (i.e. IDW, radial basis function, diffusion interpolation with barrier, kernel interpolation with barrier, ordinary kriging) and models (i.e. circular, spherical, exponential, Gaussian, hole effect, K-Bessel and J-Bessel) and found to be the most appropriate method for characterizing the spatial distribution of precipitation.[85-87] Figure 3(a),(b) shows the spatial distribution of temperature and rainfall data sets. In this study, the meteorological data sets were generated with a pixel size of 30 m.

Soil data sets were generated from soil maps.[88] These data have been generated from field observations and measurements. In this study, soil pH, soil depth and land use capability attributes

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Table 2. Categorical perspective of suitable conditions of pitaya cultivation

Data	Parameters	Value range	Status	Score
Meteorological data sets	Temperature	<0 °C	Unsuitable	0
		0–12 °C	Less suitable	1
		12–20 °C	Moderately suitable	2
		20–30 °C	Most suitable	3
		30–38 °C	Moderately suitable	2
		>38 °C	Unsuitable	0
	Rainfall	<120 mm yr^{-1}	Unsuitable	0
		120–500 mm yr^{-1}	Moderately suitable	2
		500–2000 mm yr^{-1}	Most suitable	3
Soil data sets	Soil pH + other soil parameters	<3	Unsuitable	0
		3 < pH <7	Most suitable	3
		>7	Unsuitable	0
		Stony, rocky and poorly drained soil	Unsuitable	0
	Soil depth	>20 cm	Most suitable	3
		0–20 cm	Moderately suitable	2
		Lithologic	Unsuitable	0
	Land use capability	I and II class soil	Most suitable	3
		III and IV class soil	Moderately suitable	2
		V, VI, VII and VIII class soil	Unsuitable	0
DEM data	Altitude	0–700 m	Most suitable	3
		700–1850 m	Moderately suitable	2
		1850–2750 m	Less Suitable	1
		>2750 m	Unsuitable	0
	Slope	0–15%	Most suitable	3
		15–30%	Moderately suitable	2
		>30%	Unsuitable	0
	Aspect	South	Less Suitable	1
		Others	Moderately suitable	2
		North	Most suitable	3
	Protected/forbidden areas	Commercial-agricultural areas not allowed according to national legislation	Unsuitable	0

were selected as input parameters for analysis. In this data set, stony, rocky, poorly drained classes are also assigned to the category of unsuitable for cultivation of pitaya. Figure 3(c)–(e) shows the soil pH, soil depth and land use capability, respectively.

Other data sets, DEM data and its derivatives, were generated from ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model). ASTER GDEM has a 30 m spatial resolution.[89] In this study, altitude data were classified into four classes which are most suitable for elevation between 0 and 700 m, moderately suitable for elevation between 700 and 1850 m, less suitable for elevation between 1850 and 2750 m and unsuitable for elevation above 2750 m. As stated by Cálix de Dios *et al.*[60] and Osuna-Enciso *et al.*,[61] pitaya cultivation is suitable at altitudes ranging from 0 to 1850 m. As the altitude increases from sea level, the plant's optimal growth weakens due to climatic factors. Therefore, areas between 0 and 700 m are the most suitable for pitaya cultivation, while cultivation can also occur between 700 and 1850 m. However, there are significant limitations between 1850 and 2750 m. At these altitudes, additional infrastructure is required for the cultivation of the plant, and costs increase. Above 2750 m, there are stress factors for pitaya under the current conditions, and cultivation is not beneficial. Slope is also another important criterion for suitable site selection of pitaya cultivation. Slope data were generated using the D8 algorithm from DEM data set. In this study, according to suitability for pitaya cultivation, slope data were classified into three main classes, which are most suitable, moderately suitable and unsuitable. Pitaya generally performs well in well-drained, flat or gently sloping areas, and commercial cultivation is not recommended on slopes steeper than 30%.[63,64] The study area is mostly characterized by high slopes, with flat areas found in the coastal regions. This condition presents a significant limitation for pitaya cultivation. Therefore, areas with slopes up to 15% are classified as most suitable, areas with slopes between 15% and 30% are classified as moderately suitable and areas with slopes greater than 30%, as stated in the literature, are classified as unsuitable due to the expected lack of profitability based on the yield–cost ratio. The other DEM derivative used in this study is aspect which also affects the microclimatic conditions, i.e. sun exposure and wind direction. The pitaya plant does not thrive under direct sunlight. Since the study area is located in the northern hemisphere, the areas exposed to the sun are on south-facing surfaces. Especially during the months with high temperatures, exposure to direct sunlight can cause burn marks on the stem and branches, leading to setbacks in plant growth.[58] Although the plant can be cultivated on south-facing slopes that receive direct sunlight, it is expected that its growth will not reach the desired level, which is why it has been classified as less suitable. North-facing slopes,

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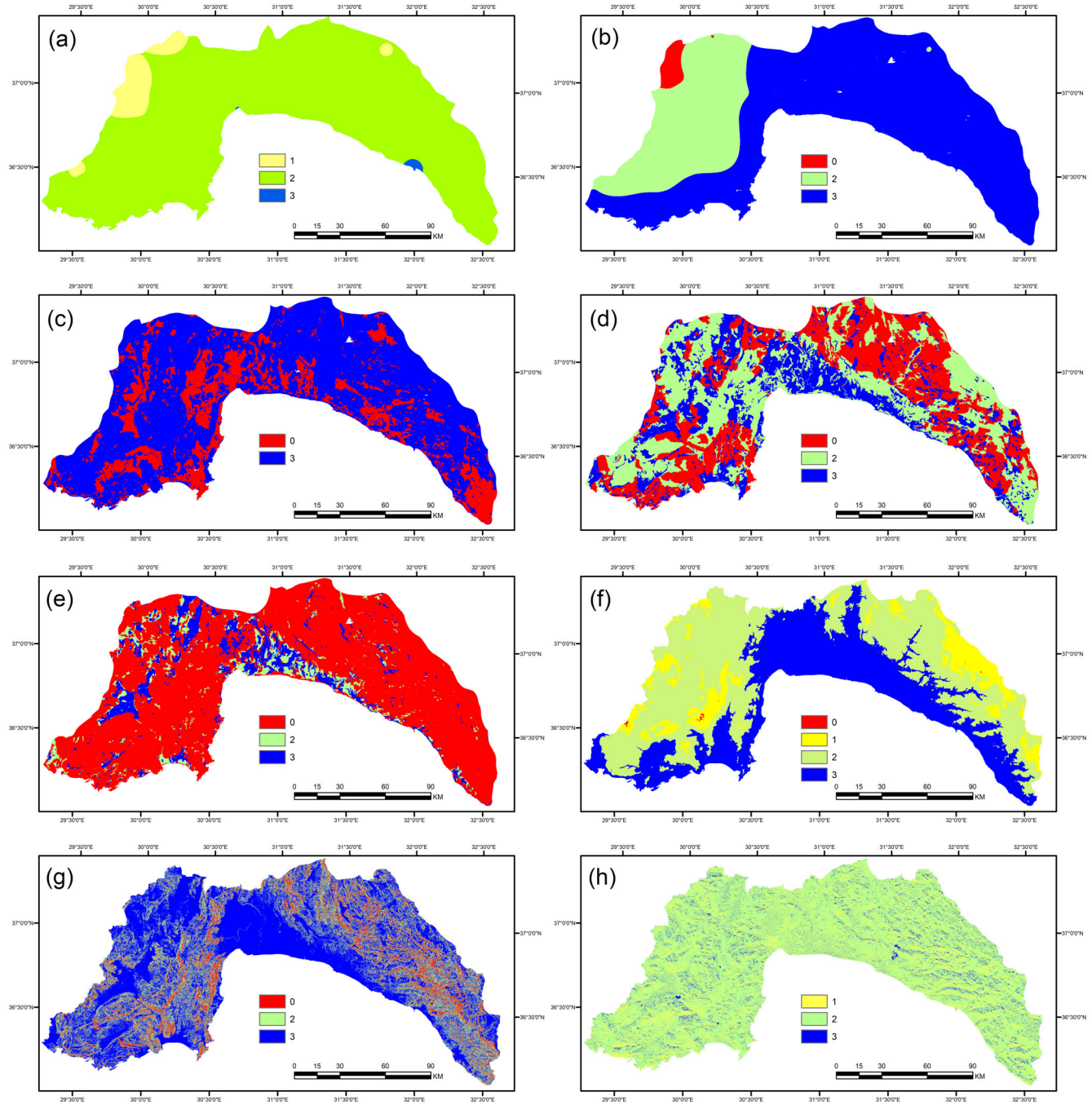


Figure 3. Input parameters for suitable site selection for pitaya cultivation: (a) temperature, (b) rainfall, (c) soil pH, (d) soil depth, (e) land use capability, (f) altitude, (g) slope and (h) aspect.

which do not receive direct sunlight, have been assigned to the most suitable class, where optimal growth can be achieved, while other directions have been classified as moderately suitable. South-facing areas are drier than those of the other aspect directions. Therefore, it is very difficult to grow in these areas. In the study, northern and southern parts are defined as suitable and less suitable, respectively. The rest of the directions are defined as moderately suitable.

Creating a database using determined criteria

In this stage all defined input parameters were converted as 30 m spatial resolution. For each input parameter, the pixel value of most suitable areas was assigned as 3 (Table 2). The value of unsuitable areas was assigned as 0. In addition, the values of moderately and less suitable areas were assigned as 2 and 1, respectively. In Fig. 3, all suitable areas are presented as blue color. The unsuitable areas are presented as red color. The other colors, green and yellow, indicate moderately suitable and less suitable areas, respectively, for all input parameters.

Determining the degree of suitability of the criteria using MCDA and performing overlap analyses

In this step, the weights of each parameter were computed. In order to perform this operation, the analytic hierarchy process

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(AHP) method, which is one aspect of MCDA, was used in this study to determine the weights of the input parameters. AHP is an analysis that uses pairwise comparisons of each input parameter for the case. Each comparison is scored between 1 and 9, indicating equal importance and extreme importance, respectively.[38,90,91]

RESULTS AND DISCUSSION

In this study, eight data sets, which are temperature, rainfall, soil pH, soil depth, land use capability, altitude, slope and aspect, were used as input parameters for multi-criteria decision. Before using all data sets, a decision classification was made according to the growing criteria of the pitaya plant. According to these classifications, the highest value of 3 and the lowest value of 0 were given. The pairwise comparison matrix used is presented in Table 3. Afterwards, the weight values obtained for each parameter according to the pairwise comparison matrix were used to produce the result map. In this study, the AHP matrix was constructed and the related weights for the parameters were generated using Python code which was written by the authors using the Google Colab platform[92] which is flexible for writing Python code.

In the study, the eight input parameters mentioned previously were used for the AHP matrix. The consistency index (CI) and consistency ratio (CR) for the eight parameters were computed as 0.0412 and 0.0292, respectively. According to Saaty,[93] a CR value of 0.10 is appropriate for carrying out additional research. Furthermore, the judgment must be re-examined from the beginning to determine the reason for the disparity and make any necessary adjustments if the CR value is greater than 0.10. If the CR value is perfect 0, it is assumed that the pairwise comparison matrix has perfect accuracy. Therefore, the results of this study indicate that the obtained CI and CR values are within acceptable limits. These values indicate that the given values for the pairwise comparison matrix are consistent. Then, computed weights for each parameter were applied for all data sets and the final weighted overlay results were prepared using ArcGIS software. Because the input data sets have values between 3.0 and 0.0, the output data set is bounded by 3.0 and 0.0. The values close to 3.0 and 0.0 show the most suitable and unsuitable areas, respectively. Figure 4 shows the suitability map for pitaya cultivation. In this study, the result data sets were categorized into four classes using natural breaks (Jenks) algorithm for visualization. In natural breaks

Table 3. AHP matrix and computed weights for each input parameter

	A	B	C	D	E	F	G	H	Weight
Temperature (A)	1.00	2.00	2.00	3.00	3.00	4.00	4.00	5.00	**0.274800**
Rainfall (B)	0.50	1.00	1.00	2.00	2.00	3.00	3.00	5.00	**0.174580**
Land use capability (C)	0.50	1.00	1.00	2.00	2.00	3.00	3.00	4.00	**0.170413**
Soil pH (D)	0.33	0.50	0.5	1.00	1.00	2.00	3.00	5.00	**0.114364**
Soil depth (E)	0.25	0.50	0.50	1.00	1.00	2.00	3.00	5.00	**0.114364**
Altitude (F)	0.25	0.33	0.33	0.50	0.50	1.00	2.00	3.00	**0.069100**
Slope (G)	0.25	0.33	0.33	0.33	0.33	0.50	1.00	2.00	**0.050423**
Aspect (H)	0.20	0.20	0.25	0.20	0.20	0.33	0.50	1.00	**0.031956**

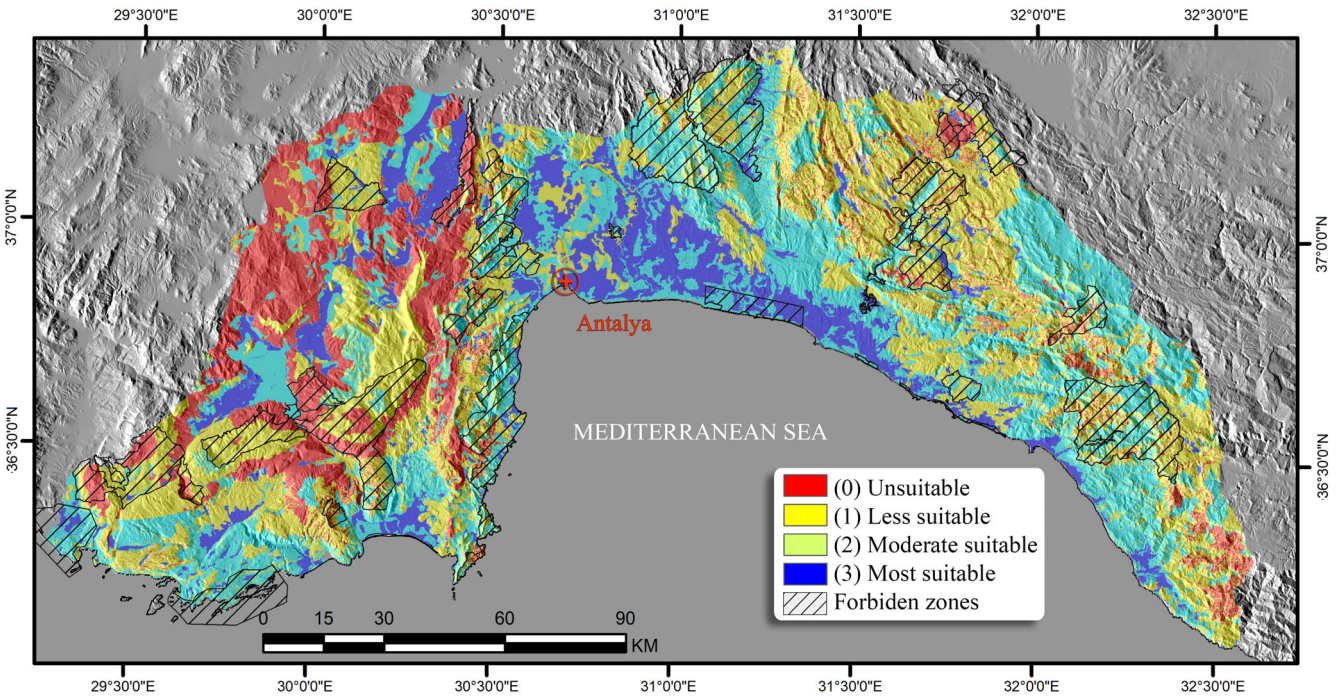


Figure 4. Map of the suitable areas for pitaya cultivation obtained from AHP-supported GIS analysis.

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classification, the data set classifies into a certain number of classes (in our case, four) with natural groups in the data distribution.[94,95] In this classification, classes are obtained by grouping the most similar values together and assigning the most divergent values to different classes. In the figure, blue color shows the most suitable places to grow pitaya. Red color shows unsuitable areas on the map. The yellow and green areas indicate less suitable and moderately suitable areas, respectively. The area of the most suitable sites was computed as 9245.7 ha which is 11.7% of the whole study area. The percentages of the moderately suitable, less suitable and unsuitable areas were calculated as 32.63%, 37.57% and 18.1%, respectively.

As of 2025, there is no clear information available in national official sources regarding the current pitaya cultivation areas and production volumes in Antalya. The 'Production of Fruits, Beverages and Spices Crops' document published by the Turkish Statistical Institute[96] does not include any mention of the pitaya plant. Therefore, an accuracy assessment could not be conducted. However, it is known that local farmers cultivate and harvest this plant in coastal areas of Gazipasa, Alanya, Konyaalti and Kumluca within Antalya province.[97,98] Based on the results of the study, the current production locations overlap with the suitability maps produced. It is observed that regions where this plant is currently produced by individual farmers fall within the most and moderate suitability classes in the suitability maps. However, it is clear that suitable areas outside of these regions have not yet been evaluated, and their potential remains untapped. Due to significant demand in both local and global markets, pitaya cultivation can be profitable for farmers and producers.[99] In addition, the high economic value-added product of the plant and the existence of potential production areas mentioned in this study should not overlook the possibility that alternative land uses – such as agroforestry or mixed-use zones – could be considered for pitaya cultivation. The largest area of pitaya cultivation and production is in Vietnam, followed by China, Indonesia, Thailand, Malaysia, the Philippines and others. Vietnam's land area is approximately 42% of Türkiye's land area, yet it is the world's largest producer of dragon fruit.[100] The high global demand for pitaya[101] presents a significant opportunity for Türkiye to enter the pitaya production market. To capitalize on this opportunity, it is essential that the suitable areas identified in this study are carefully evaluated by central and local authorities.

The study shows that MCDA using GIS is suitable for the selection of pitaya plantations. This approach enables the identification of optimal pitaya cultivation areas in sustainable agricultural planning.[102] The coverage of the whole study area is about 2 060 000 ha. It is quite difficult to find almost all relevant data sets for this area. In this study, eight data sets could be obtained for use in the analysis of pitaya plantation selection. These data sets were generated from three main sources: meteorological data, soil data sets and satellite DEM data. Therefore, it is not always possible to obtain data from these data sources and this directly affects the results obtained. In this case, it is important to use the most important and indispensable data sets for the pitaya plant and to determine the criteria accordingly. Nowadays, since DEMs at different scales can be obtained with satellite images, the most frequently used data set in such studies is obtained. In addition, slope and aspect data sets can also be derived from this data set. However, in cases where it is not possible to access the records of meteorological measurement data, some meteorological data can also be obtained from satellite images such as MODIS. This study has shown that using GIS and MCDA to select the location for pitaya in the light of expert opinion and available statistical data contributes positively to the accuracy and duration of the analysis and contributes to revealing the potential of the region.

CONCLUSION

In this study, the aim was to determine the areas where pitaya plant is suitable for growing by using GIS with multi-criteria decision making. While the eight parameters obtained for this purpose were used as input data, areas that were not suitable due to legal regulations or conditions were also considered as a limiting parameter for the result data. Unlike other multi-criteria decision studies, the study was divided into four classes at the initial stage and a limitation similar to a decision tree structure was made. For each parameter, the most suitable, moderately suitable, less suitable and unsuitable classes were determined and entered as input into the AHP analysis. Values for the input parameters were assigned between 4 and 1 as the most suitable and inappropriate values, respectively. The weights obtained with the AHP matrix were calculated with these values and the result map was produced.

With this study, an area of 9245.7 ha within the borders of Antalya province was determined as the most suitable for pitaya production. The study will guide the selection of similar types of production sites. As the cultivation of the pitaya plant, which has a high commercial value for economically developing countries, will play an important role in the development of agricultural employment in these countries, such suitable site selection studies are highly valuable. This study will guide future studies in terms of methodology and analysis techniques.

AUTHOR CONTRIBUTIONS

Serdar Selim: Project Administration; Conceptualization; Software; Data Curation; Methodology; Formal Analysis. Bekir Taner San: Conceptualization; Data Curation; Methodology; Writing – Original Draft; Formal analysis; Visualization. Dilek Koç-San: Investigation; Writing – Review and Editing; Validation; Visualization. Ceren Selim: Conceptualization; Resources; Investigation; Writing – Original Draft; Writing – Review and Editing.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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