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Investigating the Impact of Climate Parameters on Honey Yield under Migratory Beekeeping Conditions through Decision Tree Analysis: The Case of İzmir Province

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ABSTRACT: *This study has investigated how climatic parameters affect honey yield in İzmir Province under the conditions of migratory beekeeping. The climate parameters of the years 1990-2020 obtained from the Turkish Statistical Institute (TURKSTAT) and the General Directorate of Meteorology were used in this research. The data were analyzed considering the routes used by migratory beekeepers in İzmir province to transport their colonies, and the effects of climatic parameters in these regions on honey yield were determined using a decision tree algorithm. The average minimum temperature was identified as the first effective factor for honey yield. This was followed by average wind speed, average relative humidity, average maximum temperature, total precipitation and average temperature. Based on results the average honey yield per hive is predicted to be 26.29 kg in climatic conditions where the average minimum temperature is greater than 10.81°C, the relative humidity is more than 66.03% and the average temperature is more than 18.36°C.*

Keywords: *Beekeeping, climate change, decision tree, honey yield.*

İklim Parametrelerinin Gezginci Arıcılık Modeli Koşullarında Bal Verimi Üzerine Etkisinin Karar Ağaçları Yöntemi ile Araştırılması: İzmir İli Örneği

ÖZ: *Bu çalışmada göçer arıcılığın yapıldığı İzmir ilinde iklim parametrelerinin bal verimini nasıl etkilediği araştırılmıştır. Çalışmada kullanılan veriler 1990-2020 yıllarına ilişkin olup, Türkiye İstatistik Kurumu ve Meteoroloji Genel Müdürlüğünden temin edilmiştir. Verilerin analizinde İzmir ilinde göçer arıcıların, kolonilerini taşıdıkları güzergahlar dikkate alınarak bu bölgelerdeki iklim parametrelerinin İzmir ili bal verimine etkisi Karar ağacı algoritması ile ortaya konulmuştur. Sonuçlara göre bal verimine ilk etkili faktörün ortalama minimum sıcaklık değişkeni olduğu belirlenmiştir. Bunu sırasıyla ortalama rüzgâr hızı değişkeni, nispi nem, ortalama maksimum sıcaklık, toplam yağış ve ortalama sıcaklık izlemiştir. Sonuçlara göre ortalama minimum sıcaklığın 0,81 dereceden yüksek, nisbi nemin %66,03'ten fazla ve ortalama sıcaklığın 18,36 dereceden fazla olduğu iklim koşullarında kovan başına bal verim ortalamasının 26,29 kg olması beklenmektedir.*

Anahtar Kelimeler: *Arıcılık, iklim değişikliği, karar ağacı, bal verimi.*

INTRODUCTION

Beekeeping is a globally significant agricultural activity that economically and environmentally supports sustainable rural development (Novelli *et al*., 2021). It provides employment, income, and healthy food options to rural communities, contributing to their livelihoods through the production of honey and other value-added bee products (Chanie *et al.*, 2019). Additionally, bees, as insect pollinators, are essential for over 80% of wildflower species and crops, with the estimated value of ecosystem services provided by insect pollination exceeding 150 billion euros annually worldwide (Vercelli *et al.*, 2021).

Türkiye is one of the leading countries in beekeeping, with 8,733,394 hives and honey production of 96,344 tons in 2021 (TURKSTAT, 2022). Migratory beekeeping accounts for approximately 75% of beekeeping in Türkiye. Around 25,000 beekeeping farms, with an average of 129 hives, cover a distance of 2,000 km per year per apiary and visit an average of three different production regions (Yeninar, 2018). Migratory beekeepers move from overwintering and spring apiaries to the transitional regions, the Central Anatolian plateau, and in the following months to plateaus in Eastern and Southeastern Anatolia, depending on the season, pesticide use, pollination needs of crops, ecological conditions, and nectar-bearing plant development. Bees are transported to the Aegean region for pine honey production in September (Yeninar, 2018). Migratory beekeeping takes various forms, including intra-provincial, intra-regional, and inter-regional beekeeping in the province of İzmir. Beekeepers travel an average distance of 645 km to conduct their beekeeping operations. They transport their colonies to İzmir, Aydın, Muğla provinces from February to April, to İzmir, Aydın, Muğla, Manisa, Uşak, Afyon, Kütahya, Bursa, Tekirdağ, Edirne, Kırklareli provinces from May to September, and to İzmir, Aydın, and Muğla provinces for pine honey production from October to January (Şengül, 2020).

However, in recent years, factors such as climate change, pesticides, the chemicals used for bee disease and pest control, and pollution have resulted in significant losses of bee colonies. Climate change is a complex global phenomenon that has a profound impact on the distribution and population levels of ecosystems and organisms. This includes plants and pollinators that are crucial for maintaining biodiversity and ecosystem functioning (Pătruică *et al*., 2021; Vercelli *et al.*, 2021). Global warming caused by increased greenhouse gas emissions is predicted to further exacerbate climate change in the future (Öztürk, 2002). Changes in climate factors such as precipitation, humidity, air movement, and drought have already been observed as a result of global warming (Doğan, 2005).

Climate change has a profound impact on honey bees at multiple levels, affecting flower development, nectar and pollen production, pollination activities, and overall productivity (Price *et al*., 2008; Reddy *et al*., 2012; Gajardo-Rojas *et al.*, 2022). Excessive rainfall and resulting flooding can lead to the loss of bee colonies, while droughts reduce water resources and create a more favorable environment for natural enemies of bees. Climate change also contributes to the emergence of new pests and pathogens that can adapt to changing environmental conditions. The increased incidence of infectious diseases and parasitic mites, such as Varroa destructor, has caused significant mortality in honey bee colonies (Klein *et al.*, 2007; Switanek *et al*., 2015). Suboptimal temperatures prolong brood development time and increase the vulnerability of bee colonies to diseases and pests.

The influence of climate on bee populations has been observed in a comprehensive study across multiple European countries. Colonies in northern regions tend to have smaller brood populations, while colonies in Southern Europe have smaller adult bee populations. This suggests that bees in hotter climates have shorter lifespans, while brood rearing periods are generally shorter in colder regions (Hatjina *et al*., 2014). Forest fires caused by extreme temperatures have also led to a decline in bee populations and honey production (Rahmad *et al*., 2021).

In addition, climate change has a direct impact on bee behavior and physiology (Syed and Urooj, 2017). Although the climatic parameters of temperature and humidity play an important role in the nectar secretion of honey plants, they also influence the feeding behaviour of bee colonies (Pătruică *et al.*, 2021). For example, honey bees self-destruct by putting their heads in the comb eyes to leave the currently limited food sources for the next generation in case the nectar and pollen sources in nature are not sufficient for the continuation of their generation (Yücel, 2008). The possible effects of climate change on bees are given in Figure 1.

Furthermore, climate change indirectly affects the socio-economic characteristics of beekeepers (Gallardo-López *et al*., 2021). Migratory beekeeping, driven by the search for honey plants to prevent population loss due to nutrient deficiencies, has resulted in increased costs for beekeepers and loss of income (Topal *et al*., 2016; Kutlu *et al*., 2019; Yaşar *et al.*, 2021). In recent years, the impacts of climate change have resulted in unpredictable fluctuations in honey yields and a concerning decline in honey production, particularly in the significant honey-producing countries of Southern and Eastern Europe (Novelli *et al*., 2021). High-value honeys, like acacia honey, have been adversely affected. Italy, for instance, has faced significant challenges in beekeeping due to climatic stresses such as droughts, late frosts, and high temperatures. These adverse weather conditions have had a profound impact on honey production, specifically acacia honey. The decline in acacia honey production in several regions has resulted in substantial economic losses exceeding 55 million Euros in Italy alone in 2019. This highlights the vulnerability of beekeepers and underscores the urgent need to address climate change and its consequences on honey production (Novelli *et al.*, 2021).

Several studies have evaluated the impact of climate change on bees and beekeeping, as well as the management strategies employed by beekeepers to adapt to these climatic changes. These studies indicate that climate change is a significant factor affecting honey yield (Folayan and Bifarin, 2013; Şahin *et al*., 2015; Aktürk and Aydın, 2019; Duru and Parlakay, 2021). Depending on changes in climatic conditions, various issues may arise, including weakened or lost bee colonies, scarcity of nectar and pollen, reduced or absent honey and other bee products, alterations in flowering and nectar secretion periods, increased Varroa infestation, decreased pollination, and decreased income for beekeepers (Bekret *et al*., 2015; Syed and Urooj, 2017; Vercelli et al., 2021; Degu, 2022; Pătruică *et al.*, 2021; Gajardo-Rojas *et al*., 2022).

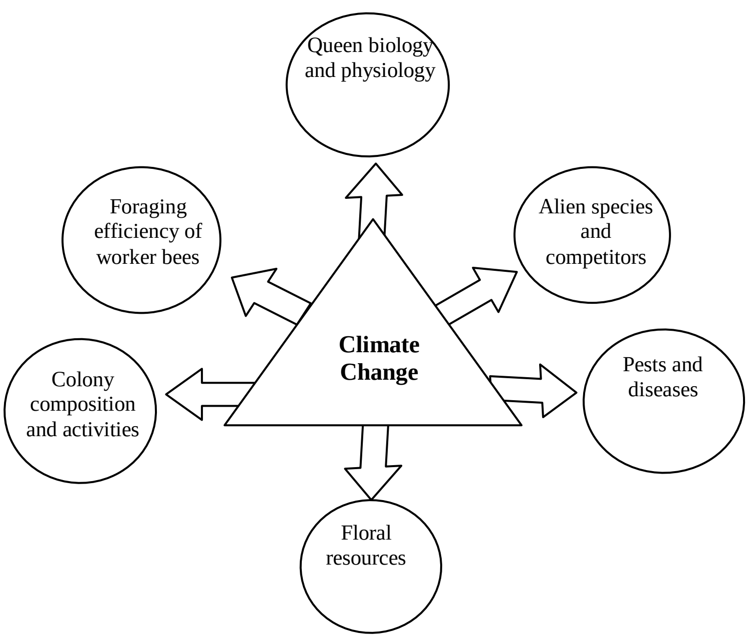

Figure 1. The effect of climate change on honey bees (Reddy *et al., 2012*).
Şekil 1. İklim değişikliğinin bal arıları üzerindeki etkisi (Reddy *et al.,* 2012).

Studies also emphasize that climate change in beekeeping is a relational phenomenon and stress the need for adaptation strategies to sustain economic activity (Gallardo-López et al., 2021). Various adaptation strategies have been reported in response to climate change, including migratory beekeeping, hive relocation to nearby areas, colony reduction, improved hive sterilization, reforestation, cultivation of honey crops, replacement of old and unproductive queens, changes in apiary management, seeking technical assistance, increased work efforts, record-keeping of blooming periods, maintaining business records, adoption of good beekeeping practices, artificial feeding, and breeding (Bekret et al., 2015; Gallardo-López et al., 2021; Gajardo-Rojas *et al*., 2022). However, studies have identified barriers to the adoption of these strategies by beekeepers, such as inadequate financing and credit resources, insufficient support, limited land availability for suitable beekeeping crops, and bureaucratic challenges in migratory beekeeping. Recommendations include the prohibition of forest burning and pollutant release, utilization of modern technologies in honey production and marketing, and provision of credit through banks and microfinance institutions for honey producers (Syed and Urooj, 2017; Gallardo-López *et al*., 2021). A study on organic beekeeping in Romania has illuminated the sector's response to challenges like climate change, pesticide use, and the pandemic. It highlights a shift towards organic beekeeping, practiced by 5.2% of Romanian beekeepers, as a sustainable and eco-friendly approach. Despite the strong awareness of organic principles among the 433 beekeepers surveyed, organic certification was limited. The Romanian experience, emphasizing the potential for growth in organic beekeeping, advocates for greater support and encouragement for beekeepers to pursue organic certification (Pocol *et al*., 2021)

In agricultural research, a variety of methodologies are utilized to investigate the impacts of climate change. Initially, field experiments were predominantly employed, subjecting crops to varying climatic conditions through both natural and controlled environmental factors, to examine their influence on crop development and yield. However, with the advent of technological progress, process-based crop models and empirical statistical models have gained prominence. Process-based models employ computer simulations for a quantitative evaluation of the physiological aspects and dynamic processes governing crop growth and yield. In contrast, empirical statistical models are designed to formulate mathematical correlations between climatic variations and crop yield, providing a more data-driven perspective (Feng *et al*., 2023). This study focuses on migratory beekeeping in the province of İzmir and utilizes decision tree techniques to evaluate the impact of climatic factors on honey yield. The methodology aligns with recent trends in apiculture research, where data mining and decision tree algorithms have been increasingly applied. These methods have been utilized in various contexts, including predicting honey production, estimating honey yields in different geographical areas, and understanding the factors influencing beekeeper behaviors and cooperative memberships (Karadas and Kadırhanogullari, 2017; Aksoy *et al*., 2018; Çukur and Çukur, 2022). Despite significant advancements in applying decision tree techniques in beekeeping, a clear understanding of how specific climatic variables impact honey yield, especially in the migratory beekeeping context, is still lacking in the existing literature. To bridge this knowledge gap, this study proposes the following research questions and hypotheses:

1. How do climatic factors such as temperature, humidity, and precipitation specifically influence honey yield within the migratory beekeeping context of İzmir? (Hypothesis: Specific climatic conditions have a measurable impact on honey yield in migratory beekeeping in İzmir).

2. What ideal climatic conditions favor maximum honey production in this region? (Hypothesis: There are optimal climatic conditions for honey production in İzmir, which can be identified and quantified through decision tree analysis).

MATERIALS AND METHODS

Research area

This study was conducted in İzmir province, which is located in the Aegean region. Balıkesir is located in the north of İzmir, Manisa in the east, Aydın in the south and the Aegean Sea in the west. The area of the province lies between 370 45' and 390 15' north latitude and 260 15' and 280 20' east longitude (Anonymous, 2009). According to the long-term (1938-2021) climate data, the average temperature in this province is 17.9 °C, the average maximum temperature is 22.7 °C, the highest temperature is 43.0 °C, the average minimum temperature is 13.6 °C, and the lowest temperature is -8.02 °C and the average total annual precipitation is 713.8 mm/year (MGM, 2022).

Data sets

The dataset of this study consists of monthly measurements of average climatic parameters and honey yield values of İzmir province at the migratory beekeeping route of İzmir province 1990-2020 (Table 1). Honey yield data for İzmir province were obtained from TURKSTAT and monthly climate data were obtained from the General Directorate of Meteorology. In order to obtain climate data on the migration route, the climate data of the provinces (İzmir, Aydın, Muğla, Manisa, Uşak, Kütahya, Bursa, Edirne, Tekirdağ, and Kırklareli) where the migratory beekeepers move their colonies were considered. The honey yield in İzmir was determined by dividing the total honey produced by the number of colonies.

Method

The effects of environmental conditions on honey yield per hive in İzmir were investigated using the decision tree technique, a data mining classification algorithm. This algorithm breaks down large datasets into significantly smaller groups of records by applying a set of decision rules. The division proceeds from top to bottom, creating various subgroups characterized by minimal variability within each grouping and maximal variation between different groups.

In addition, the decision tree algorithm visualizes the hierarchy and significance of the relationships between dependent and independent variables. Through the creation of a tree structure in the decision tree diagram, groups are represented at the leaf level, while the processes leading to these leaves are depicted on the branches. This division process continues until all members within a group share the same, homogenous label. Within the tree structure, the homogeneous subgroups where independent variables influence the dependent variables are termed 'child nodes.' Child nodes that do not undergo further subdivision into subsets are known as 'terminal nodes' (Hızlı *et al*., 2022).

Within the realm of decision tree algorithms in the literature, various methods such as the Chi-square Automatic Interaction Detector (CHAID), Classification and Regression Trees (CART), and Quick Unbiased Efficient Statistical Tree (QUEST) are well-recognized for variable classification (Gunduz and Al-Ajji, 2022). For the purposes of this study, the CART algorithm was selected due to its alignment with the specific data characteristics encountered.

Table 1. List of variables used in the research.
Çizelge 1. Araştırmada kullanılan değişkenlerin listesi.

Variable	Description
HYield	Honey yield in İzmir province (kg/colony)
RH	Average relative humidity in migratory beekeeping route (%)
TMax	Average maximum temperature on the migratory beekeeping route (°C)
TMin	Average minimum temperature on the migratory beekeeping route (°C)
WS	Average wind speed on the migratory beekeeping route (m/s)
T	Average temperature on the migratory beekeeping route (°C)
TP	Total precipitation on the migratory beekeeping route (mm=kg/m²)

The CART algorithm, established by Breiman *et al.* (1984), is a binary recursive partitioning method. It operates as a 'classification tree' for categorical dependent variables and as a 'regression tree' for continuous variables (Chang and Wang, 2006). In a regression tree, the algorithm segments variables based on their significance level. The variable exerting the most substantial influence on the dependent variable is positioned at the beginning of the tree structure. Subsequently, other variables are integrated into the tree based on their relative impact, dividing nodes in a similar manner. The process is guided by the 'coefficient of improvement', a metric without specific upper or lower limits, which decreases as the tree extends from top to bottom (Breiman *et al.*, 1984; Steinberg and Colla, 1997). The algorithm commences by selecting a value, splitting the data into two subsets, and then calculating the mean square error (MSE) for each subset. The iteration continues until reaching a leaf node with the minimum MSE (Almahdi, 2020).

In this study, the decision tree was constructed using the Scikit-Learn package in Python. The independent variables were relative humidity, maximum temperature, minimum temperature, wind speed, overall temperature, precipitation, and the number of rainy days, with honey yield per hive as the dependent variable. The decision tree's branching criteria included a maximum tree depth of 4, a minimum of 5 samples for both the main and child nodes, and squared error as the regression criterion (Figure 2).

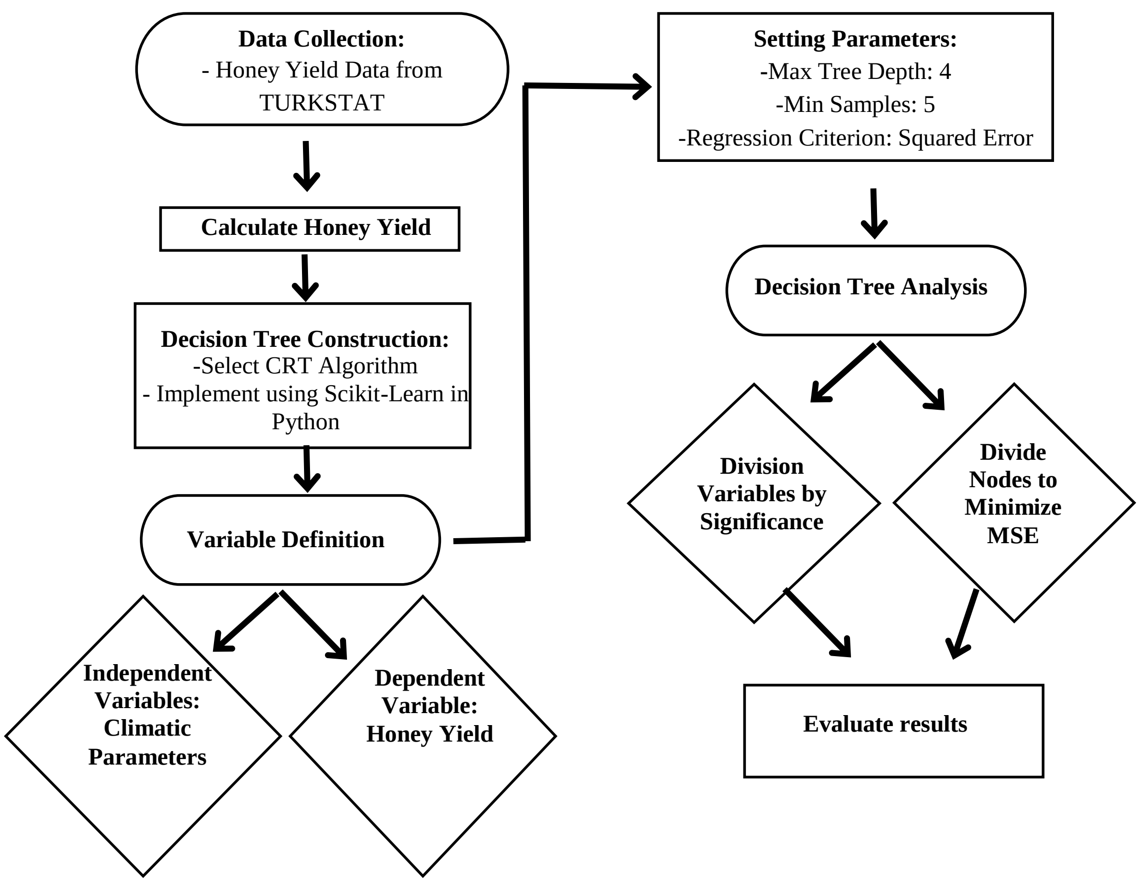

Figure 2. Decision tree analysis flowchart.
Şekil 2. Karar ağacı analizi akış diyagramı.

The application of the Decision Tree Method, offers a structured avenue for beekeepers to optimize their practices by gleaning actionable insights from complex climate data. By utilizing this method, beekeepers can ascertain the most favorable routes for migration, ensuring that they traverse locales offering optimal conditions for forage and nectar flow, which are quintessential for honey production. Moreover, the decision tree can provide pivotal guidance on the most opportune departure dates by analyzing historical and real-time climate data, thereby enabling beekeepers to synchronize their migrations with periods when forage resources are at their peak in different regions. In addition, the decision tree can guide supplemental feeding strategies by highlighting periods of forage scarcity occasioned by adverse climatic conditions. Through this, beekeepers can formulate and enact supplemental feeding regimes that ensure colonies have sufficient nutrition during such adverse periods. The iterative nature of the decision tree allows for an ongoing evaluation and refinement of migratory strategies with the inclusion of new data, fostering a dynamic approach to migratory beekeeping that is responsive to changing climatic conditions. Lastly, employing such a methodological approach engenders a culture of data-driven decision-making and promotes knowledge sharing and collaborative learning within the beekeeping community.

RESULTS AND DISCUSSION

The average values of climate parameters in relation to the migratory beekeeping route between 1990 and 2020 are given in Table 2.

The annual average relative humidity was 66.14%, the annual average maximum temperature was 20.95 °C, the annual average minimum temperature was 10.00 °C, the annual average wind speed was 1.86 m/sec, the annual average temperature was 15.04 °C, and the annual total precipitation was 686.87 mm.

The regression tree diagram created for honey yield per hive as a result of the study's analysis is shown in Figure 3. The CART diagram has the shape of an inverted tree with the root at the top, and the root node at the top is the variable of average minimum temperature. In other words, it was found that the first variable that best explains honey yield among the variables of climatic parameters is the average minimum temperature. Wind speed is shown to affect honey yield in climatic conditions where the average minimum temperature is equal to or lower than 10.81°C. When the minimum temperature exceeds 10.81°C degrees, relative humidity affects honey yield, and wind speed affects honey yield when it is low. Relative humidity was found to be effective in conditions where wind speed is equal to or less than 1.86 m/s.

Table 2. Average values of climatic parameters on the route of migratory beekeeping.
Çizelge 2. Gezici arıcılık güzergahındaki iklim parametrelerinin ortalama değerleri.

Months	RH (%)	TMax (°C)	Tmin (°C)	WS (m/sn)	T (°C)	TP (mm=kg/m²)
Jan	76.548	9.204	1.445	1.837	4.801	95.701
Feb	73.154	11.059	2.295	1.992	6.114	82.559
Mar	68.972	14.674	4.398	1.980	9.045	67.012
Apr	65.789	19.281	7.933	1.887	13.221	54.350
May	62.720	24.730	12.409	1.829	18.292	47.264
June	57.781	29.536	16.637	1.898	22.927	33.855
July	53.575	32.553	19.308	2.046	25.766	19.652
Aug	54.837	32.649	19.457	2.012	25.744	16.076
Sept	59.921	28.212	15.262	1.802	21.258	29.912
Oct	68.787	22.437	11.115	1.616	16.126	60.759
Nov	74.000	16.240	6.533	1.639	10.697	75.657
Dec	77.644	10.770	3.249	1.803	6.504	104.587
Annual average	66.144	20.946	10.004	1.863	15.042	686.867
Average relative change per year (%)	-0.004	0.201	0.480	-0.477	0.280	0.176

RH: Average relative humidity, TMax: Average maximum temperature, TMin: Average minimum temperature, WS: Average wind speed, T: Average temperature, TP: Total precipitation.

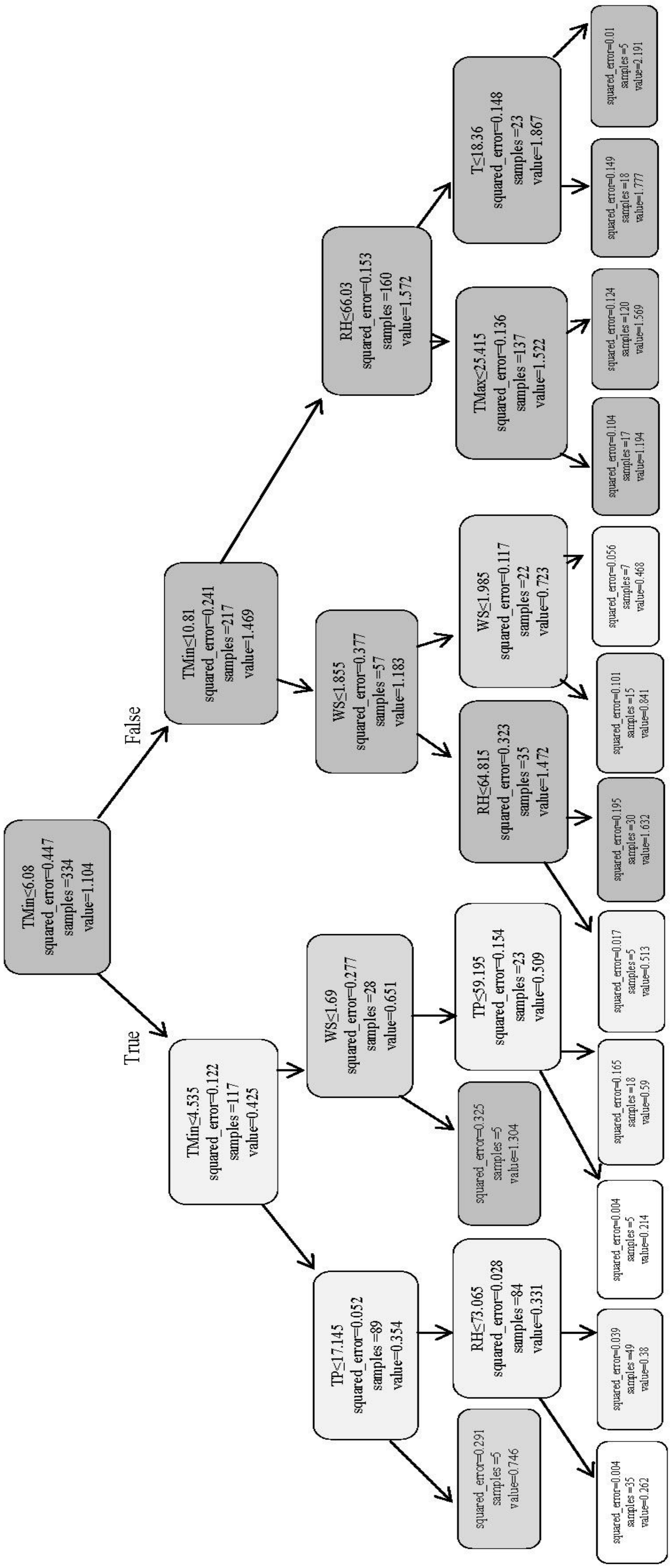

Figure 3. Decision tree for honey yield per hive (CART method).
Şekil 3. Kovan başına bal verimine ilişkin karar ağacı (CART yöntemi).

It was found that total precipitation is effective when the average minimum temperature is less than or equal to 4.54°C degrees, and wind speed is effective when it is greater than this value. Relative humidity affects honey yield when total precipitation is less than or equal to 17.15 mm. Total precipitation was found to affect honey yield when wind speed was equal to or less than 1.69 m/s. It was found that the average maximum temperature was effective when the relative humidity was 66.03% or less, and that the annual average temperature was effective on honey yield when it was higher. As a result of classifying all climatic parameters according to the regression tree, the average honey yield per hive is expected to be 26.29 kg per year in climatic conditions where the average minimum temperature is above 10.81°C, relative humidity is above 66.03%, and the average annual temperature is above 18.36 °C.

Temperatures below 10°C prevent the flight activity of honeybees (Joshi and Joshi, 2010). On the other hand, honey bee eggs, larvae and pupae require a constant temperature between 33 and 36 °C during their development, with the optimal temperature being 35 °C. Exposure of honey bees to lower than optimal temperatures (e.g., 20 °C) during development leads to various developmental abnormalities such as malformation of wings or legs, higher mortality, or abnormal stinger and wing development (Szentgyörgyi et al., 2018). On the other hand, extreme temperatures adversely affect the bees' foraging activities (Abou-Shaara *et al*., 2012). In the study conducted by Langowska *et al.* (2017), it was found that the annual honey yield is significantly and positively related to the temperature value in the period April-August. In particular, during spring, honeybee hives exhibit higher daily relative changes in weight when the temperature is at its optimum of 17°C. Similarly, the temperature optimum for these changes in hive weight is 26°C in summer. On the other hand, Honeybee productivity increases within a temperature range of 14 to 28°C daily. However, when temperatures exceed this range, productivity tends to decrease, showing negative values (Gounari *et al*., 2022). High humidity is often required for brood development, and a relative humidity of about 75% is considered suitable for the immature stages of colonies (Abou-Shaara *et al.,* 2012). The importance levels of the factors influencing honey yield per hive according to the results of the decision tree analysis are shown in Table 3 and Figure 4. The average minimum temperature variable was determined as the first and 100% effective factor on honey yield. This was followed by the variable of average wind speed (11.91%), relative humidity (8.77%), average maximum temperature (2.29%), total precipitation (1.50%) and average temperature (0.73%). A study using data from Pennsylvania beekeepers assessed the influence of weather, topography, land use, and management factors on overwintering mortality. This research identified growing degree days and precipitation during the warmest quarter as key predictors of survival (Calovi *et al*., 2021).

The results of this study are consistent with the results of other studies (Schweitzer *et al.,* 2013; Hillayová et al., 2022; Gounari *et al*., 2022). Temperature, solar radiation or sunlight, wind and precipitation are considered the most effective factors for honey bee productivity, and the effects of these factors can be positive or negative. On the other hand, relative humidity is considered an effective factor for honey productivity, as it affects the ripening of honey in the hive (Gounari *et al*., 2022). Environmental factors, such as air temperature and humidity, have a significant impact on various aspects of the bee life cycle. These factors influence the metabolism of bees, their growth rate, and the overall quality of the colony.

Additionally, temperature and humidity levels affect important activities such as nectar and pollen foraging by worker bees, as well as queen rearing and mating processes (Hillayová *et al*., 2022). The results of the study by Oluwaseyi *et al.* (2022) show that temperature and relative humidity affect honey production in the modern hive. This result means that environmental conditions must be taken into account when setting up a modern hive for optimal honey production, as bees are more likely to thrive at high temperature and low relative humidity.

Table 3. Importance levels of the independent variables obtained as a result of the regression tree.
Çizelge 3. Regresyon ağacı sonucunda elde edilen bağımsız değişkenlerin önem düzeyleri.

Independent variables	Importance of factors	Normalized importance of factors (%)
Average minimum temperature (TMin)	0.799	100
Average wind speed (WS)	0.095	11.91
Average relative humidity (RH)	0.070	8.77
Average maximum temperature (TMax)	0.018	2.29
Total precipitation (TP)	0.012	1.50
Average temperature (T)	0.006	0.73

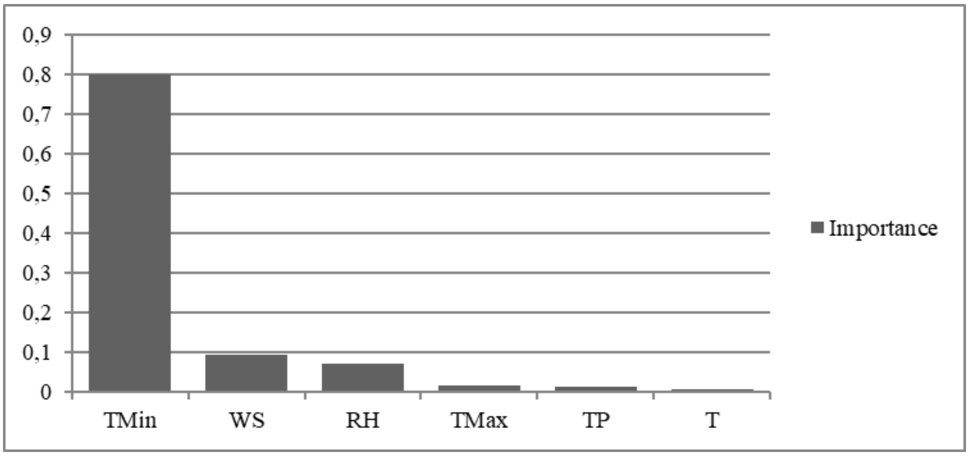

Figure 4. Importance levels of variables based on decision tree regressor.
Şekil 4. Karar ağacı regresörüne göre değişkenlerin önem düzeyleri.

As for the wind speed, which is of secondary importance in the study, since strong winds can negatively affect the flight of bees, it also affects the productivity of the hive. Daily average wind speed values of less than 7 km/h support hive productivity. When winds become stronger, productivity decreases at a rate of -0.080% per 1 km/h increase in average daily wind speed (Gounari *et al*., 2022).

While relative humidity affects the ripening process of honey, moisture loss from nectar (through transpiration) is greatly reduced under conditions of high relative humidity (Schweitzer *et al*., 2013). A study by Hillayová *et al.* (2022) has shown that relative humidity in outdoor hives at a certain temperature is an important abiotic factor for the decline of Varroa mite.

In terms of precipitation, Malisa and Yanda (2016) observed that nectar production is directly proportional to precipitation. The results of the study by Uffia *et al.* (2021) showed higher concentrations of vitamins and sugars in the nectar of honey plant species during the dry season than during the rainy season, suggesting that high temperatures and radiation increase nectar production.

CONCLUSIONS

Climate change and unstable climatic events affect the dynamics of vegetation and compromise the potential of bees to produce honey and other bee products, leading to instability in beekeepers' income. The aim of this study was to reveal the important climatic parameters affecting honey yield in migratory beekeeping in İzmir province. In the study, based on the years 1990-2020, the decision tree algorithm was used, which is a data mining classification algorithm.

According to the results, the average minimum temperature, average wind speed and average relative humidity were identified as the three most important climatic parameters affecting honey yield in İzmir province on the migratory beekeeping route. As a result of classifying all climatic parameters according to the regression tree, the average honey yield per hive is expected to be 26.29 kg per year in climatic conditions where the average minimum temperature is above 10.81°C, relative humidity is above 66.03%, and the average annual temperature is above 18.36 °C.

The yield of honey, as this study indicates, can be significantly influenced by climatic conditions, both positively and negatively. It is imperative for beekeepers to adopt practices that minimize the negative impacts of these climatic factors. Traditional beekeeping often relies on conventional practices, which may not be flexible enough to adapt to the unpredictability of climatic events. For instance, a beekeeper who migrates his colonies annually for specific harvests like blackthorn or chasteberry honey could face a failed harvest and bear high transportation costs due to unforeseen climatic changes like unpredictable north winds. In response to such instability, adopting a more adaptable management approach is crucial. This includes situating bee colonies in diverse apiaries with varied flora to reduce the risk of income loss and planting successive honey plants to ensure a steady food source for bees, thus supporting consistent honey production.

Moreover, given the reliance of honey production on natural conditions, it is advisable for producers to diversify into other high-value bee products. This diversification not only buffers against the uncertainties of honey production but also enhances the overall resilience of their beekeeping operations.

To maximize the utility of this study, translating the insights from decision tree analyses into practical, operational strategies is essential. By doing so, beekeepers will be endowed with enhanced decision-making capabilities, enabling them to proactively adapt to and mitigate the varied impacts of climatic changes on honey production. Specialized training programs and interactive workshops can be established to educate beekeepers on the nuances of decision tree analysis and provide hands-on experience in integrating these tools into their daily management practices. Such initiatives will foster a more resilient beekeeping community.

On the social front, the results of this study obtained consider not only ecological but also social sustainability. Therefore, by analyzing the case of İzmir province, this study has helped to understand the complex relationships between climate change, beekeeping and social interaction, and to guide future sustainable beekeeping practices. In addition, the study underscores the need for increased community involvement and the establishment of comprehensive support structures for beekeepers. A collaborative approach, where beekeepers, farmers, environmental experts, and policymakers work together, is essential to develop sustainable and resilient beekeeping practices. This collective effort is critical to effectively address the challenges posed by climate change. Promoting beekeeping as an eco-friendly and sustainable practice can catalyze positive changes in local economies and support biodiversity conservation efforts. This holistic approach benefits not only individual beekeepers but also contributes to the health of broader ecological and economic systems.

Ultimately, the insights from this research offer tangible, action-oriented guidance for beekeepers and stakeholders, crucial in equipping them to navigate and thrive in the evolving landscape of environmental and climatic conditions. The study's findings thus serve as a guide, leading the beekeeping community towards sustainable practices and resilience in the face of climatic uncertainties.

This study, while providing crucial insights into the climatic impacts on honey yield in migratory beekeeping, may not fully represent the critical roles of economic, and policy factors in apiculture. Additionally, the climate change models utilized in this study are subject to the inherent uncertainties associated with long-term climate predictions. Given these limitations, future research could aim to integrate a more holistic approach that encompasses economic and policy aspects of beekeeping alongside climatic factors. Furthermore, research efforts could be directed towards employing a variety of predictive tools to account for the uncertainties and complexities in long-term climate forecasting.

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