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# Exploring Temporal Patterns of American Foulbrood Disease in Türkiye Through the Seasonal-Trend Decomposition (STL) Method

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**ABSTRACT:** American Foulbrood (AFB), a highly dangerous and fatal disease of honey bees, is accountable for significant economic losses in honey harvesting. This study analyzes temporal changes in reported numbers of AFB outbreaks and cases using a new analytical tool, STL decomposition. Time-series analyses were carried out using data supplied over an 18-year period beginning in January 2005 to uncover trends and the existence of seasonal fluctuations to enable the industry strategies to track and manage this significant bee disease. STL, a seasonal-trend decomposition method developed using locally weighted regression, was used for visual statistical analysis to model the monthly number for AFB outbreaks and cases. A logistic regression model was employed to investigate the importance of the seasonality. A total of 18483 AFB cases were recorded in Türkiye from January 1, 2005 to December 31, 2022, with a mean of 86 cases per month. STL decomposition demonstrated that the outbreak trend cycle was more flexible, whereas the case trend cycle abruptly rose and fell between 2018 and 2019. The STL decomposition revealed that the highest seasonal peaks of AFB incidence occurred in the spring and summer. This disease was more likely to occur throughout these two seasons (OR = 1.66, 95% CI: 1.16–2.37 and OR = 1.93, 95% CI: 1.36–2.75, respectively, with autumn regarded as reference). These findings provide critical insights into seasonal risk periods, enabling more effective timing for surveillance and control efforts, and can support the development of data-driven action plans in combating the disease.

***Keyword:*** American Foulbrood; Honey bee diseases; Seasonal trend; STL method; Time-series analysis.

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## INTRODUCTION

Food safety for an increasing population requires sustainable solutions to preserve and increase agricultural yields on a global scale in the face of climate change and the desire to reduce carbon emissions. The pollination of honey bees is a crucial part of our food supply chain, and commercial beekeeping is an essential component of these efforts (Klein et al., 2007; McGregor, 1976; Roubik, 2002). Because they are necessary for the pollination of many different plants, honey bees are critical for healthy ecosystems and are becoming an increasingly important component of productive livestock (Genersch, 2010). Pollination is necessary for the majority of crops with high nutrient density. Additionally, the need for dependable pollination services is growing as a result of growing worry over the decline in wild pollinators (Gallai et al., 2009; Jordan et al., 2021). Although honey bees are the most commercially significant pollinators, they are endangered by several pathogens, parasites, pesticides, killer insects, habitat destruction and nutritional deficiencies (Genersch, 2010; Laurino et al., 2020; Steinhauer et al., 2018). However, no secure and efficient prophylactic treatments exist to stave off diseases. In order to maintain livestock and practice sustainable agriculture, it is essential to create innovative disease prevention strategies for industrial beekeeping.

One of the most dangerous diseases of honey bees in the world is American foulbrood (AFB), which is brought on by larvae of the gram-positive spore-forming bacterium Paenibacillus. The spores of AFB can persist in the environment for decades while remaining virulent, killing honey bee larvae and providing an ongoing threat to honey bee colonies (Haseman, 1961; Stephan et al., 2020). During the first 24-72 hours after hatching, honey bee larvae are vulnerable to AFB infection (Hitchcock et al., 1979). Worker bees carry infectious spores from damaged broods, which transport and disperse throughout the hive. Additionally, spores are dispersed outside the hives by foraging bees and can spread across hives when robbing takes place, which happens when bees from other colonies steal honey from weak and diseased hives (Dickel et al., 2022; Hitchcock et al., 1979; Stephan et al., 2020). The brood will eventually be contaminated by an AFB infection, resulting in a shortage of fresh worker bees and the colony's eventual extinction (Graaf et al., 2006). From the perspective of beekeeper finances and colony health, AFB is one of the most expensive honey bee diseases. Contrary to other honey bee diseases, AFB cannot be treated with chemicals, supplemental food, re-queening, or changing the position of the hive in order to increase hive strength (Bikaun et al., 2022). Clinical diagnosis, microscopic examination, Holst milk test, culture, bacterial isolation and identification, and molecular tests such as PCR are used to diagnose AFB. It is necessary to comply with protection and control measures in the fight against this disease (Akpınar et al., 2023).

Learning about a disease's epidemiology requires understanding its temporal trends. Time series analyses seek a clear explanation of serially connected data over time. Assessing the detailed nature of serially connected data requires both exploratory techniques and graphical displays (Diggle, 1990). Through temporal analyzes of infectious diseases, researchers have established a wide variety of research approaches, including time series analysis and seasonal analysis (Mao et al., 2019). A seasonal-trend decomposition developed using locally weighted regression (loess), generally identified as "STL" is an exploratory method that has been used successfully in various areas (Cleveland and Devlin, 1988, Hafen et al., 2009). The approach generates reliable predictions unaffected by temporary outliers, is simple to apply, and offers options in determining the degree of variance in the trend and seasonal components of time-series (Cleveland et al., 1990). Particularly, STL provides superb visual analytics (Hafen et al., 2009). Numerous disciplines, including epidemiology, environmental science, ecosystems, and health policy, have extensively used STL (Chaloupka, 2001; Cleveland et al., 1990; Hafen et al., 2009; Silawan et al., 2008).

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This study aims to analyze the 18-year pattern of AFB disease and detect seasonal fluctuations to see if the beekeeping industry has made progress in fighting this disease. This study describes a two-step time-series assessment that was conducted: first, analytical visualizations through STL were used to examine the temporal pattern of this disease, and second, logistic regression analysis was utilized to test the importance of temporal characteristics statistically.

## MATERIALS AND METHODS

### Data source and organization

The data of outputs of AFB outbreaks and cases at the province level in 2005-2022 were obtained by the World Organisation for Animal Health (WOAH). The country of Türkiye is the center of this study, consisting of 81 provinces (Fig. 1). This study used all AFB records available from Türkiye that reported in WOAH from  2005 to 2022. Since this study aims to examine the temporal presence of AFB, the time (season) observed for each outbreak location is positive and the time (season) at which each outbreak location was not observed was defined as negative. This criterion was previously applied to research season factors related to infectious disease (Bayir and Gürcan 2023).

### Spatial data mapping

This study uses Geographic Information Systems (GIS) to examine the spatial distribution of AFB cases because of its spatial visualization capabilities. Provincial-level shapefile (.shp extension) data were employed for output mapping in GIS software. The case map was created using QGIS (version 3.10.2) open-source GIS software.

### Seasonal and Trend Decomposition using Loess (STL)

Cleveland et al. (1990) introduced the STL method for time series data. Unlike more conventional seasonal decomposition methods like X-12-ARIMA and the ratio-to-moving-average approach, STL offers more reliable findings when addressing outliers in the time series under study (Xiong et al., 2018). The examination of the seasonal decomposition was based on the seasonal trend decomposition using STL, which consists of three components: trend,


**Figure 1.** Study area.

season, and remainder. Since the approach is based on additive variation components, combining the components will provide the original data. So, for any time series data, $X_t$, decomposed using STL, may be written as:

$$X_t = T_t + S_t + R_t$$

The iterative STL method consists of two recursive processes: inner and outer loops. The inner loop determines the seasonal component and fits the trend. Each inner loop has six steps (Fig. 2).

The time-series was composed of monthly outbreaks and cases. The STL approach has advantages such as speedy computation, robust results, and flexibility in the seasonal component's time period. The present study analysed outbreaks and cases by performing a seasonal decomposition of the time series. Eviews (version 10) software was used for the time series analysis.

The impact of the season (summer, spring, autumn, and winter) on AFB outbreaks in Türkiye was examined using a logistic regression analysis. A value of $p<0.05$ was regarded as statistically significant for estimating the odds ratio (OR) and 95% confidence intervals. Using SPSS 23.0 software, the statistical analysis was carried out.

## RESULTS

This study recorded AFB cases in 62 provinces (76.54%). The highest number of cases was seen in Antalya and Ordu provinces, respectively (Fig. 3). The average number of AFB cases on a provincial basis was 12.68 per provincial year or 228.19/18 provincial years. When the number of AFB cases was examined, it was seen that the average number of AFB cases was 1026.83 each year.

There were 18483 recorded cases of AFB in Türkiye from January 1, 2005, to December 31, 2022, with a mean of 86 cases (total case/total year*total month) per month. To see the long-term trend of reported cases over each month of the 18 years, a heat map of the monthly cases was made (Fig. 4). In May 2019, there were 1139 cases, which was the

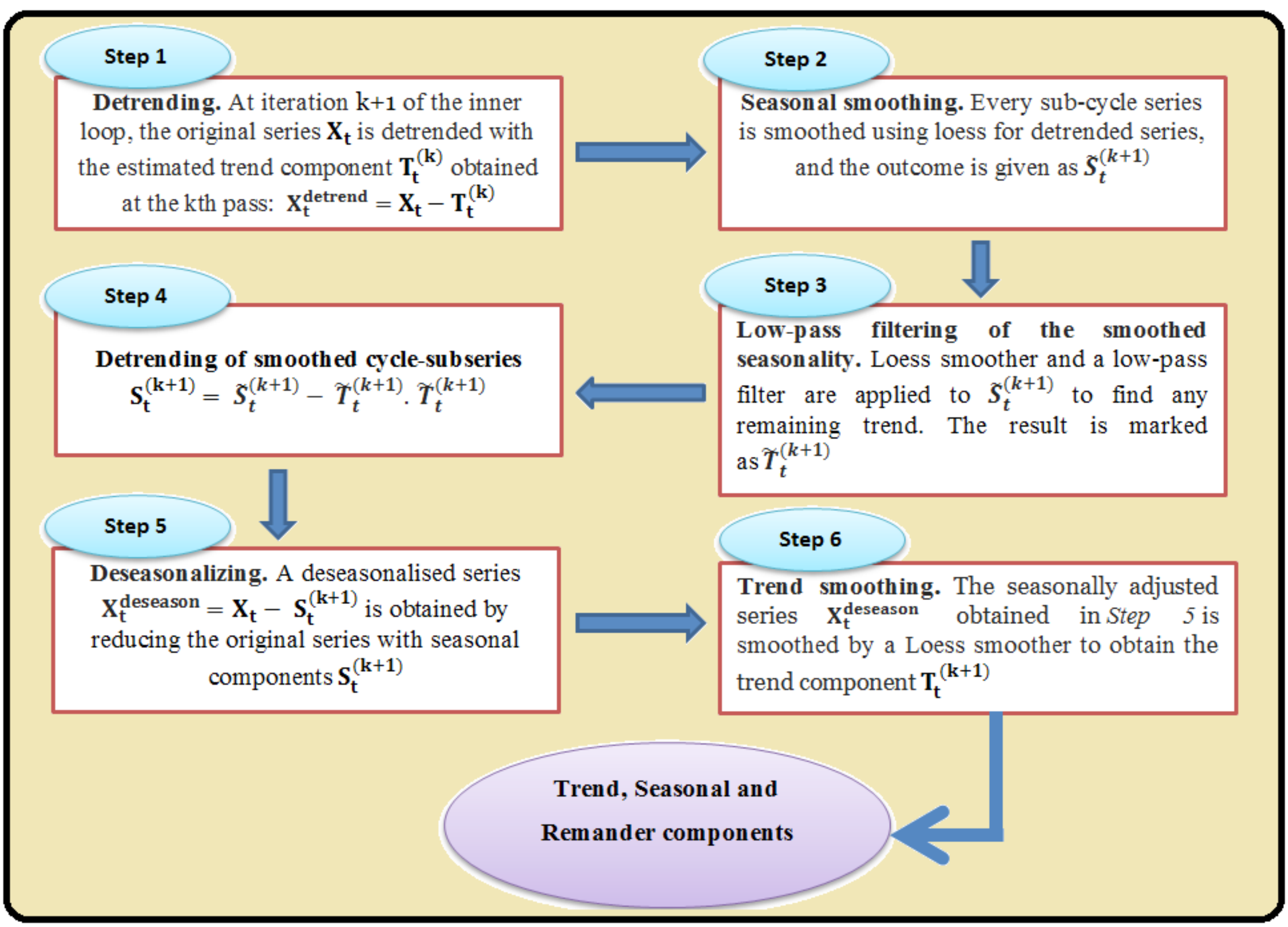


**Figure 2.** The STL inner loop procedure.

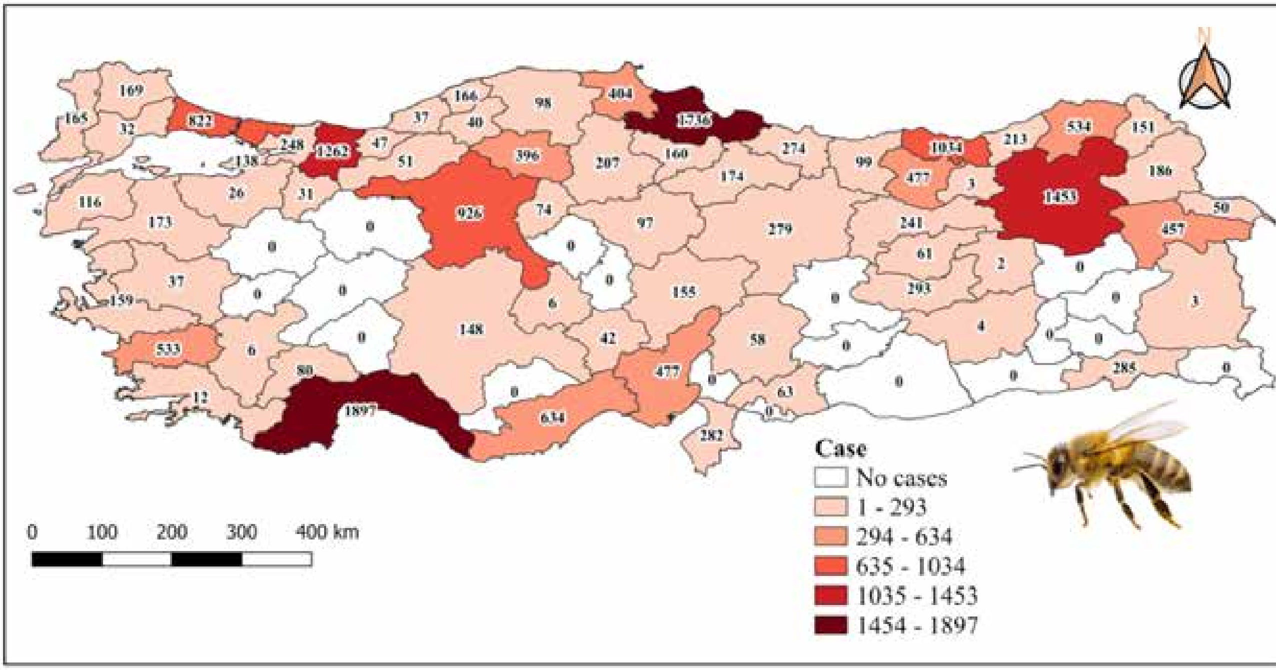


**Figure 3.** Reported cases of AFB, by province in Türkiye, January 2005–December 2022 (generated by using QGIS version 3.18.3).

highest number of monthly recorded cases. In January 2020, there were 21 outbreaks, which was the monthly outbreak peak. In some months during this time period, no outbreaks were reported. AFB cases were observed in all years of the study. Overall, the month with the most cases (3105 cases) reported was March, with the peak of reported cases (4125 cases) in 2019.

The seasonal decomposition graphs include the raw data, trend, seasonal, remainder, and adjusted components. The raw data reflect original AFB outbreaks and cases. The remainder represents the residual or unexplained variation in the data after removing both trend and seasonal effects. In the context of AFB cases in Türkiye, this component may reflect irregular, random fluctuations due to factors such as

Outbreak (A)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 6 |
| 2006 | 0 | 0 | 1 | 4 | 0 | 9 | 4 | 2 | 3 | 1 | 0 | 0 | 24 |
| 2007 | 0 | 1 | 3 | 1 | 2 | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 14 |
| 2008 | 0 | 0 | 1 | 3 | 3 | 3 | 2 | 4 | 0 | 1 | 1 | 0 | 18 |
| 2009 | 0 | 2 | 1 | 2 | 1 | 0 | 3 | 2 | 2 | 3 | 1 | 2 | 19 |
| 2010 | 0 | 2 | 2 | 1 | 1 | 3 | 0 | 0 | 1 | 0 | 0 | 1 | 11 |
| 2011 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 13 |
| 2012 | 3 | 2 | 5 | 1 | 0 | 0 | 2 | 1 | 4 | 2 | 0 | 0 | 20 |
| 2013 | 0 | 1 | 0 | 3 | 4 | 2 | 3 | 1 | 4 | 2 | 0 | 0 | 20 |
| 2014 | 0 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 8 |
| 2015 | 3 | 0 | 3 | 1 | 5 | 0 | 3 | 1 | 1 | 3 | 1 | 1 | 22 |
| 2016 | 0 | 2 | 3 | 1 | 3 | 4 | 5 | 1 | 0 | 1 | 0 | 1 | 21 |
| 2017 | 1 | 2 | 8 | 3 | 2 | 6 | 3 | 3 | 0 | 2 | 3 | 0 | 33 |
| 2018 | 1 | 0 | 0 | 1 | 1 | 1 | 7 | 1 | 4 | 7 | 2 | 0 | 25 |
| 2019 | 13 | 5 | 0 | 0 | 20 | 11 | 1 | 15 | 2 | 5 | 0 | 2 | 74 |
| 2020 | 21 | 8 | 5 | 4 | 1 | 0 | 3 | 0 | 0 | 3 | 3 | 1 | 49 |
| 2021 | 0 | 0 | 3 | 0 | 4 | 2 | 2 | 0 | 1 | 1 | 1 | 1 | 15 |
| 2022 | 0 | 1 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 2 | 11 |
| Total | 43 | 29 | 41 | 31 | 49 | 47 | 43 | 34 | 27 | 32 | 15 | 12 | 403 |

Case (B)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 0 | 0 | 50 | 90 | 0 | 6 | 5 | 1 | 0 | 50 | 0 | 0 | 202 |
| 2006 | 0 | 0 | 47 | 218 | 0 | 99 | 21 | 3 | 418 | 18 | 0 | 0 | 824 |
| 2007 | 0 | 121 | 358 | 6 | 21 | 23 | 26 | 37 | 13 | 0 | 0 | 0 | 605 |
| 2008 | 0 | 0 | 7 | 23 | 50 | 94 | 8 | 37 | 0 | 8 | 11 | 0 | 238 |
| 2009 | 0 | 221 | 337 | 205 | 16 | 0 | 7 | 17 | 8 | 121 | 24 | 151 | 1107 |
| 2010 | 0 | 31 | 5 | 2 | 4 | 8 | 0 | 0 | 50 | 0 | 0 | 7 | 107 |
| 2011 | 12 | 150 | 191 | 285 | 30 | 35 | 7 | 0 | 7 | 0 | 0 | 0 | 717 |
| 2012 | 126 | 42 | 220 | 13 | 0 | 0 | 21 | 20 | 76 | 8 | 0 | 0 | 526 |
| 2013 | 0 | 70 | 0 | 20 | 21 | 6 | 10 | 3 | 102 | 15 | 0 | 0 | 247 |
| 2014 | 0 | 24 | 0 | 32 | 2 | 0 | 0 | 0 | 58 | 0 | 1 | 1 | 118 |
| 2015 | 141 | 0 | 80 | 1 | 83 | 0 | 9 | 3 | 25 | 81 | 1 | 19 | 443 |
| 2016 | 0 | 171 | 73 | 26 | 19 | 99 | 71 | 32 | 0 | 35 | 0 | 2 | 528 |
| 2017 | 119 | 1002 | 1082 | 333 | 194 | 92 | 88 | 139 | 0 | 208 | 183 | 0 | 3440 |
| 2018 | 5 | 0 | 0 | 34 | 5 | 30 | 283 | 20 | 701 | 248 | 290 | 0 | 1616 |
| 2019 | 1100 | 373 | 0 | 0 | 1139 | 680 | 135 | 375 | 240 | 55 | 0 | 28 | 4125 |
| 2020 | 131 | 97 | 388 | 116 | 16 | 0 | 774 | 0 | 0 | 161 | 92 | 13 | 1788 |
| 2021 | 0 | 0 | 117 | 0 | 793 | 24 | 19 | 0 | 185 | 6 | 122 | 104 | 1370 |
| 2022 | 0 | 10 | 150 | 21 | 0 | 6 | 0 | 0 | 148 | 0 | 106 | 41 | 482 |
| Total | 1634 | 2312 | 3105 | 1425 | 2393 | 1202 | 1484 | 687 | 2031 | 1014 | 830 | 366 | 18483 |

Percentile: 0 – 50 – 100

**Figure 4.** Reported outbreaks (A) and cases (B) of AFB, by month of the year, in Türkiye, January 2005–December 2022.

sporadic underreporting, local interventions, weather anomalies, or unknown epidemiological events not captured by seasonality or long-term trends. The trend represents how the data has changed over time. A decomposition technique was used to separate the seasonality and trend fluctuation from the remainder or residual in monthly data. Fig. 5 shows an alternate STL decomposition when the robust option has been employed. The graphs demonstrate that the outbreak trend cycle is more flexible, whereas the case trend cycle abruptly rises and falls between 2018 and 2019. The season graph represents the STL seasonal pattern for a year. As 0 reflects an inflection point in the STL derived trend, values on 0 show no seasonal variation; anything above 0 suggests a rising seasonal pattern (i.e., above trend) in the proportion of AFB, and anything below 0 shows a declining seasonal pattern (i.e., below trend). After the decomposition, it was determined that higher outbreak and case rates could be observed for AFB in the summer and spring months according to the determined seasonal component. STL decomposition methods showed regular yearly fluctuations of the seasonal component. In other words, the seasonal component appears to not change over time (Fig. 5).

Seasons were identified as a significant risk factor by the logistic regression analysis. Significantly higher odds ratio of AFB were determined in spring [OR 1.66 (95% CI 1.16-2.37)] and summer [OR 1.93 (95% CI 1.36-2.75)] than autumn season and showed statistical significance ($p<0.05$) (Table 1).

## DISCUSSION

This work used the STL methodology to accurately pinpoint the 18-year trend and seasonal pattern for AFB in bees in Türkiye. The World Animal Health Information System was the data source. By employing STL to pinpoint the sources of variance in time series (such as trend, season, and residual), this study upholds research transparency. The inferential statistical testing supported the findings from the exploratory analysis because the STL and logistic regression results are both consistent.

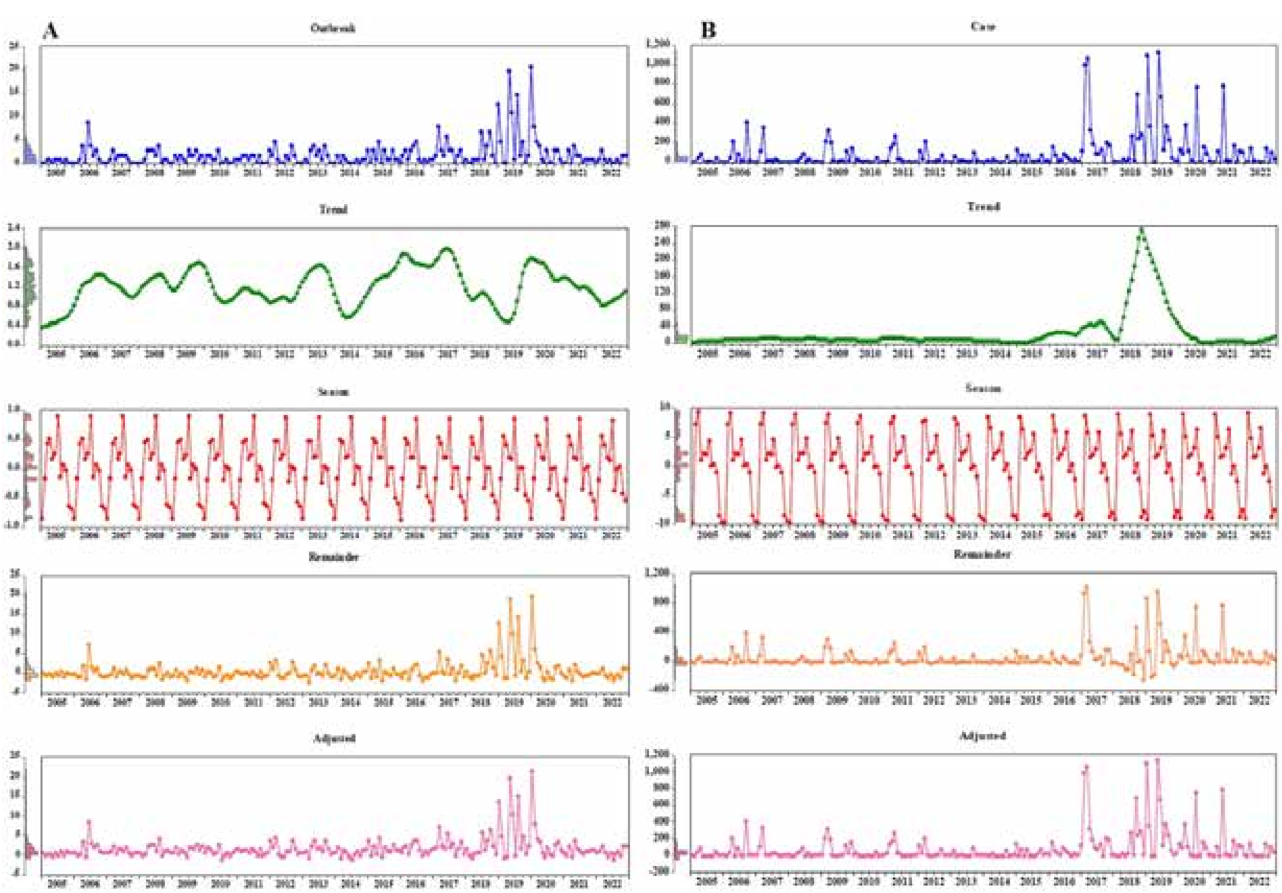


**Figure 5.** Seasonal trend decomposition of the monthly reported outbreaks (A) and cases (B) of AFB in Türkiye, January 2005–December 2022.

**Table 1:** Results of an association the season and the AFB outbreaks in Türkiye using logistic regression

| Factor | Categories | Estimate | SE | OR (95% CI) | p-value |
|---|---|---|---|---|---|
| Season | **Autumn (Sept-Nov)** | 1.00 | Reference | - | - |
| | **Spring (March-May)** | 0.51 | 0.18 | 1.66 (1.16-2.37) | 0.006 |
| | **Summer (Jun-Aug)** | 0.66 | 0.18 | 1.93 (1.34-2.75) | 0.000 |
| | **Winter (Dec-Feb)** | 0.06 | 0.19 | 1.06 (0.73-1.54) | 0.773 |

The veterinary literature lacks time-series studies, especially those that concentrate on seasonal trend decomposition. Examples in the field of veterinary science may be observed for three of the most common methodologies: Moving average (MA) models (Arc Moretti et al., 2010), generalized additive models (GAM) (Jore et al., 2010), and linear regression or its generalizations (GLM) (Ward, 2002) are the three types of models. Since STL and MA are both filtering techniques, MA is possibly the basic statistical method for decomposing time-series. It is also the only one of these three methods that can be directly compared to STL. In MA, a succession of subsets with averaged values is produced by averaging the results over a predetermined slide time window. The STL model is more adaptable than MA models and a superior match to the data because the loess iterations are guided by specified parameters. The GLM and GAM belong to a distinct class of analytical procedures compared to STL. These inference models offer the choice of determining the statistical significance of the temporal components and adjusting for numerous factors (Sanchez-Vazquez et al., 2012). The present study presents STL as a resource that veterinary epidemiologists can utilize to analyze time-series explorations.

The importance of honey bee diseases, such as parasitic, bacterial, viral, and fungal infections, for the bee business goes hand in hand with the importance of beekeeping in Türkiye and worldwide. Globally, much research has been done on the diseases that cause losses in commerce and manufacturing (Balkaya et al., 2016). Diseases and pests that affect honey bees are some of the most significant obstacles to expanding beekeeping and impact output. Temporal studies play a significant role in evaluating the epidemiology of infectious diseases and preventing infections. However, temporal analyzes have not been examined in previous studies and a comprehensive temporal analysis of AFB has not been conducted in Türkiye. The temporal analysis used in this study adds information to data from earlier studies on AFB disease.

According to FAO statistics, Türkiye ranks third in terms of the number of colonies and first after China with 96 344 (tons) of honey production. It ranks first in Europe in terms of the number of colonies and honey production (TEPGE, 2023). AFB disease may be one reason why the amount of honey produced remains at low levels compared to the number of colonies.

The present study temporal trend cycles differed according to the number of outbreaks and cases recorded from 2005 to 2022. The graphs demonstrate that the outbreak trend cycle is more flexible and the case trend cycle abruptly rises and falls between 2018 and 2019. It was determined that there were many fluctuations within different months of a year. However, it was observed that the total number of cases decreased significantly after 2019. The study's results showed an irregular trend in the spread of American foulbrood throughout the time under investigation. These findings are consistent with the results of the study by Rusenova and Parvanov (2015), who reported an irregular tendency towards AFB. Also, the results of this study show that significantly higher odds ratios of AFB were determined in spring and summer than in the autumn season and showed statistical significance. These results are in line with earlier research's conclusions (Jacques et al., 2017; Sık et al., 2022). The reason why it is more common in spring and summer may be parasitic mite infection, queen bee complications, weakening of colonies causing dryness and more susceptibility to diseases in these months. Additionally, spore accumulation in adult bees throughout the winter may make infections more likely in the spring. But, numerous internal and external factors influence how many vulnerable hosts for AFB are available or how much larval brood is present in any given season (Donkersley et al., 2017; Walton et al., 2018). Since AFB kills the brood, a change in the brood-to-worker ratio can be anticipated; however, it is uncertain if bigger honey bee colonies are more capable of adjusting to this change than smaller colonies (Stephan et al., 2020).

In the present study, although summer and spring were determined to be more risky seasons, it was determined that the disease was seen in all months of a year and in the entire time period examined. It has been stated that the incidence of AFB disease varies between 27% and 31% in studies conducted by other researchers in various regions in Türkiye using survey, clinical examination or culture analysis methods (Özden, 2017; Sık, 2022; Yalcinkaya et al., 2009). The fact that the disease was identified in these studies conducted at different times confirms the findings of our research.

Although this study determined the spring and summer seasons as risky, the disease was also recorded in the cold winter months. American foulbrood generally increases when temperatures and humidity are high. However, if desired, disease agent analysis can be done by opening the hives and taking samples from the sealed brood in the honeycomb. Türkiye is a country with a broad geography and beekeeping is carried out in different regions and at different temperatures in the same time period. In our country, migratory beekeeping is carried out intensively, as the flowering periods of plants vary from region to region (Akpınar et al., 2023). For this reason, beekeepers are mainly on the move during the honey season. Apart from this, he winters its bees in more temperate regions and prepares his hives for the spring period more quickly. In Türkiye, he is taken to areas with high air temperature, especially in the winter, and the bees prepare for the season without hibernating. During this period, there are offspring even during winter, and the queen continues to lay eggs. The AFB disease agent is detected especially with samples taken from the sealed brood in the comb. Also, beekeepers apply pesticides to control Varroa destructor in their hives during the winter (Karahan et al., 2022). During this period, it is possible to diagnose AFB by taking samples from the honeycombs of the beekeepers from the hives.

The definitive and effective method of combating the disease in our country is to destroy diseased colonies by burning them. To prevent the disease from spreading, the hive body should be passed through the flame with a blowtorch. Equipment and materials used in beekeeping, such as bee smoker, masks, hive tool, feeders and queen excluder, should be carefully disinfected. Quarantining diseased colonies, destroying diseased hives and honey, and not transferring combs, bees and equipment from one colony to another prevent the spread of the disease (Akpınar et al., 2023).

In Türkiye, American foulbrood is considered a notifiable disease, and once clinical signs are observed, beekeepers are legally required to report the suspected infection to veterinary authorities. Following confirmation, strict control measures are implemented, including the destruction of infected colonies by fire and the sanitation of related equipment to prevent further transmission. However, in practice, the actual number of cases may be underreported due to concerns about economic loss or the fear of hive destruction. This reporting gap is important to consider when interpreting the official data, as it may not fully reflect the true extent of the disease's prevalence across the country.

## CONCLUSIONS

Our findings provide crucial new information about the epidemiology of AFB and reveal the temporal evaluation of AFB in Türkiye over the last 18 years. By identifying high-risk seasons (spring and summer) through STL decomposition and confirming seasonal effects statistically, the study supports the development of evidence-based strategies for disease monitoring, early intervention, and policymaking in the apiculture sector. These results are of great importance for planning national disease control programs and strengthening preventive measures in high-incidence periods. While no commercially available vaccines currently exist for American foulbrood, recent experimental studies have investigated oral bacterin-based immunization approaches to reduce susceptibility in honey bees. Our reference to vaccination refers to these emerging efforts in experimental veterinary immunology. In parallel, the reinforcement of basic good beekeeping practices such as early brood inspection, hygienic comb management, and strict hive disinfection is essential. These preventive strategies, combined with data-driven temporal analysis as presented in this study, form a holistic basis for disease management planning.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## ETHICS APPROVAL

Ethical approval was not required for this work. Data gathered from the official website of WOAH regarding AFB is public use data.

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