



*Comparative Evaluation of the Antimicrobial Activities of Monofloral honeys  
from Diverse Botanical Origins*

*Çeşitli Botanik Kaynaklardan Elde Edilen Monofloral Balların  
Antimikrobiyal Aktivitelerinin Karşılaştırmalı Değerlendirmesi*

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## Abstract

This study was conducted to evaluate the antimicrobial potential of monofloral honeys of different botanical origins. The antimicrobial activities of honey samples were tested on selected pathogenic microorganisms using the disk diffusion method and minimum inhibitory concentration (MIC) analysis. The findings revealed that the antimicrobial effects of the tested honeys varied depending on their species and botanical origin. Manuka honey, in particular, stood out with its low MIC value (18.75%) and broad activity profile, while sunflower and chestnut honeys inhibited the most microorganisms, providing broad-spectrum activity. Citrus honey produced the greatest inhibition zone against *Salmonella typhimurium*. However, no honey type was effective against *Candida albicans* and *Enterococcus faecalis*. These results suggest that honey can be considered a natural antimicrobial agent and a supportive product in apitherapy applications and infection control. However, it should be noted that the effects vary depending on the microorganism species and honey composition.

**Keywords:** Microbiology, Antimicrobial activity, Honey, Disc diffusion, Minimum Inhibitory Concentration (MIC)

## Özet

Bu çalışma, farklı botanik kökenli monofloral balların antimikrobiyal potansiyelini değerlendirmek amacıyla gerçekleştirilmiştir. Bal örneklerinin antimikrobiyal aktiviteleri, disk difüzyon yöntemi ve minimum inhibisyon konsantrasyonu (MIC) analizleri kullanılarak, seçilmiş patojen mikroorganizmalar üzerinde test edilmiştir. Elde edilen bulgular, test edilen balların antimikrobiyal etkilerinin türüne ve botanik kökenine göre değişkenlik gösterdiğini ortaya koymuştur. Özellikle Manuka balı, düşük MIC değeri (%18,75) ve geniş etki profili ile öne çıkarken; ayçiçeği ve kestane balları en fazla mikroorganizma üzerinde inhibisyon göstererek geniş spektrumlu etki sunmuştur. Narenciye balı ise *Salmonella typhimurium* üzerinde en büyük inhibisyon bölgesini oluşturmuştur. Buna karşın, hiçbir bal türü *Candida albicans* ve *Enterococcus faecalis* üzerinde etkili olmamıştır. Bu sonuçlar, balın doğal bir antimikrobiyal ajan olarak apiterapi uygulamaları ve enfeksiyon kontrolünde destekleyici ürün olarak değerlendirilebileceğini göstermektedir.

**Anahtar Kelimeler:** Mikrobiyoloji, Antimikrobiyal aktivite, Bal, Disk difüzyon, Minimal inhibisyon konsantrasyonu (MIK)

**Abbreviations:** ATCC, American Type Culture Collection; CFU, colony forming unit; MIC, Minimum Inhibitory Concentration

## 1. INTRODUCTION

Honey, as a natural product, has been used throughout history as both a food and a therapeutic agent. These properties of honey, which are widely preferred in traditional medicine, especially in the treatment of wound healing, gastrointestinal diseases, and infections, are due to its antimicrobial and antioxidant activities (Kwakman & Zaat, 2012; Mandal & Mandal, 2011). The antimicrobial effect of honey is attributed to many factors such as low pH, high osmotic pressure, hydrogen peroxide production, and phenolic compounds (Mavric et al., 2008). One of the most important elements that determines the microbial activity of honey is its botanical origin. Monofloral honeys obtained from different floral sources attract attention with their unique phenolic profiles and biological activities (Beretta et al., 2005; da Silva et al., 2016; Kara et al., 2020; Usta, 2023). Manuka honey (*Leptospermum scoparium*) is known for its methylglyoxal (MGO) content and has high antimicrobial activity against a large number of bacteria (Adams et al., 2008; Carter et al., 2016). It has been reported that Manuka honey is effective even on bacteria that are resistant to antibiotics (Lu et al., 2013). However, it has been reported that other types of honey produced locally and in different geographies may also have significant antimicrobial activity (Usta, 2023). For example, chestnut honey (*Castanea sativa*) is very rich in phenolic substances and has high inhibitory activity on pathogenic bacteria such as *Staphylococcus aureus* and *Escherichia coli* (Ferreira et al., 2009; Touré et al., 2011). It is emphasized that honeys obtained from plants such as lavender (*Lavandula* spp.), citrus (*Citrus* spp.), acacia (*Robinia pseudoacacia*), and oak (*Quercus* spp.) also contain unique antioxidant

and antimicrobial components, and these properties contribute to both the quality of the honey and its therapeutic potential (Estevinho et al., 2008; Samarghandian et al., 2017). In addition, sunflower honey (*Helianthus annuus*), which is widely produced in Türkiye, draws attention with its antimicrobial properties originating from hydrogen peroxide despite its low phenolic content (Yücel & Sorkun, 2020). Detailed examination of the biological effects of such local honeys supports the discovery of new natural agents beneficial for health and contributes to the scientific documentation of traditional products.

Recent studies have focused on evaluating not only the general antimicrobial effect of honey but also its effects on specific pathogens. For example, *in vitro* analyses on clinically important microorganisms such as *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Listeria monocytogenes* and *Candida albicans* have revealed significant differences among honey types (Maddocks et al., 2013; Boukraa & Sulaiman, 2009). In this context, the aim of this study was to comparatively evaluate the antimicrobial effects of seven different honey types (manuka, sunflower, acacia, citrus, oak, lavender, and chestnut) obtained from different botanical origins. The data to be obtained are expected to shed light on the usability of honey as a natural antimicrobial agent and support its potential use in traditional medicine.

Antimicrobial resistance is considered one of the most significant global public health threats. The World Health Organization reports that the need for new antimicrobial agents is increasing daily. In this context, investigating the antimicrobial properties of natural products, especially monofloral honeys derived from different botanical origins, is crucial for alternative or complementary treatment options. The increasing interest in honey not only in traditional medicine but also in modern healthcare practices makes the scope of our study even more significant. This study aims to fill the gap in the literature by comparatively examining the antimicrobial effects of honeys from different botanical origins and to contribute to the usability of honey in apitherapy and food safety applications.

## **2. MATERIAL AND METHODS**

### **2.1. Procurement and Storage of Honey Samples**

The seven different monofloral honey samples evaluated in the study were supplied from different regions. Floral sources of the honey samples originated from manuka (*Leptospermum scoparium*), sunflower (*Helianthus annuus*), acacia (*Robinia pseudoacacia*), citrus (*Citrus* spp.), oak (*Quercus* spp.), lavender (*Lavandula* spp.) and chestnut (*Castanea sativa*). Manuka honey was purchased commercially from a certified producer of New Zealand origin; other

honey samples were obtained from local beekeepers and the floral source was confirmed by melissopalynological analysis. The botanical origin of the honey samples was confirmed by melissopalynological analysis. For this purpose, pollen was extracted from the honey samples, and slides were prepared and examined under a light microscope. At least 500 pollen grains were counted in each sample, and monofloral classification was performed based on the dominant pollen type. For example, samples containing 45% or more of a single type of pollen were considered monofloral. All honey samples were stored in glass containers in a dark and cool environment (+4 °C) and brought to room temperature at 25 °C before analysis.

## **2.2. Test Microorganisms**

Microorganism strains used in the study were obtained from the culture collection of the Microbiology Laboratory of the Biology Department of the Faculty of Science of Karadeniz Technical University. Microorganisms such as *Klebsiella pneumoniae* ATCC 13883, *Staphylococcus aureus* ATCC 25923, *Proteus vulgaris* ATCC 13315, *Enterococcus faecalis* ATCC 29212, *Salmonella typhimurium* ATCC 14028, *Enterobacter cloacae* ATCC 13047, *Candida albicans* ATCC 10231 and *Escherichia coli* ATCC 25922 are strains standardized by the American Type Culture Collection (ATCC). *Serratia marcescens* and *Bacillus thuringiensis* species, previously isolated from nature, were included in the study as local strains maintained in the same laboratory. Microorganisms were taken from stocks stored at -80 °C in 10% glycerol and fresh cultures were prepared and diluted according to a 0.5% McFarland standard before the experiment.

## **2.3. Preparation of Honey Extracts**

50% (v/v) aqueous solutions were prepared from honey samples. Each honey was homogenized by mixing it with sterile distilled water at a ratio of 1:1 and filtered through a sterile 0.22 µm membrane filter. The solutions were prepared fresh before use.

## **2.4. Determination of Antimicrobial Activity**

### **2.4.1. Agar Diffusion (Disk Diffusion) Method**

The antimicrobial activity of honey samples was evaluated by the Kirby-Bauer disk diffusion method. Each microorganism was spread on Mueller-Hinton agar (for bacteria) and Sabouraud dextrose agar (for yeast) plates according to the 0.5 McFarland standard. Sterile Whatman paper disks (6 mm in diameter) were impregnated with each honey solution and placed on the inoculated surface.

The plates were incubated at 37 °C (for bacteria) or 30 °C (for *C. albicans*) for 24/48 (for *C. albicans*) hours. Antimicrobial activity was evaluated by measuring the inhibitory zone diameter (mm). Each sample was tested in triplicate.

Chemical composition analyses (phenolic compounds, flavonoid levels, and enzymatic activities) of honey samples were not performed in this study. Including these analyses in future studies will contribute to a more comprehensive explanation of the biochemical mechanisms of antimicrobial activity.

### **2.4.2. Minimum Inhibitory Concentration (MIC) Determination**

MIC values were determined by the microdilution method. Honey solutions were prepared with serial dilutions (from 50% v/v to 1%) in 96-well sterile microtiter plates. 100 µL of honey solution and 100 µL of microbial suspension ( $10^6$  CFU/mL) were added to each well. Only medium was used as a negative control and standard antibiotics were used as positive controls in MIC analyses. Gentamicin (10 µg/mL) was used for Gram-negative bacteria, vancomycin (10 µg/mL) for Gram-positive bacteria, and amphotericin B (5 µg/mL) for yeast strains. Wells containing medium alone were used as negative controls. After incubating the plates under appropriate conditions for 24 hours, growth was measured spectrophotometrically at 600 nm, and the concentration at which 90% or more decrease in optical density was observed was accepted as MIC.

### **2.4.3. Statistical Analysis**

Each experiment was conducted in triplicate, and results are presented as mean  $\pm$  standard deviation. Statistical analyses were performed using SPSS v26.0 software. Differences between groups were analyzed using one-way ANOVA, and relationships between zone diameter and MIC values were analyzed using the Pearson correlation test ( $p < 0.05$ ).

### 3. RESULTS AND DISCUSSION

The results obtained by the disk diffusion method revealed that honeys of different botanical origins exhibited different levels of antimicrobial activity against the tested microorganisms. Inhibitory zone diameters were significantly larger in manuka and citrus honeys, and the highest activity was observed on *Staphylococcus aureus* and *Salmonella typhimurium* (Table 1).

**Table 1.** The results of antimicrobial activity test

Microorganisms	Manuka (mm)	Sunflower (mm)	Acacia (mm)	Citrus (mm)	Oak (mm)	Lavender (mm)	Chestnut (mm)	Positive Control (Antibiotics) (mm)	Negative Control (medium) (mm)
<i>Candida albicans</i> ATCC 10231	NZ	NZ	NZ	NZ	NZ	NZ	NZ	25± 1.1	NZ
<i>Enterobacter aerogenes</i> ATCC 13047	NZ	11± 1.3 <sup>b</sup>	NZ	12± 1.1 <sup>b</sup>	7 ± 1.0 <sup>a</sup>	NZ	7 ± 0.9 <sup>a</sup>	25± 1.1	NZ
<i>Enterococcus faecalis</i> ATCC 29212	NZ	NZ	NZ	NZ	NZ	NZ	NZ	20± 0.6	NZ
<i>Escherichia coli</i> ATCC 25922	NZ	NZ	NZ	NZ	7 ± 1.2 <sup>a</sup>	NZ	NZ	25± 1.1	NZ
<i>Klebsiella pneumoniae</i> ATCC 13883	NZ	9± 0.9 <sup>a</sup>	NZ	NZ	10 ± 1.3 <sup>b</sup>	NZ	8 ± 0.7 <sup>a</sup>	28± 1.0	NZ
<i>Proteus vulgaris</i> ATCC 13315	NZ	NZ	NZ	NZ	8 ± 0.9 <sup>a</sup>	NZ	NZ	20± 0.6	NZ
<i>Salmonella typhimurium</i> ATCC 14028	24± 1.2 <sup>b</sup>	22± 1.0 <sup>b</sup>	NZ	30± 1.2 <sup>c</sup>	NZ	21± 0.8 <sup>b</sup>	NZ	25± 1.0	NZ
<i>Staphylococcus aureus</i> ATCC 25923	11± 1.1 <sup>b</sup>	8± 0.8 <sup>a</sup>	NZ	NZ	9± 0.7 <sup>a</sup>	7 ± 0.9 <sup>a</sup>	7 ± 0.9 <sup>a</sup>	25± 1.0	NZ
<i>Serratia marcescens</i>	NZ	8± 0.8 <sup>a</sup>	NZ	NZ	NZ	NZ	7 ± 0.8 <sup>a</sup>	25± 1.3	NZ
<i>Bacillus thuringiensis</i>	9± 1.0 <sup>a</sup>	10± 1.0 <sup>a</sup>	7± 0.8 <sup>a</sup>	NZ	7± 1.0 <sup>a</sup>	NZ	7± 0.9 <sup>a</sup>	25± 1.3	NZ

NZ: No zone

The widest inhibitory zone was observed with a diameter of 30 mm formed by citrus honey on *S. typhimurium*. Lavender honey showed an effect only against *Salmonella typhimurium* and *Staphylococcus aureus*.

MIC values of honey samples were calculated as the lowest honey concentration that provided 90% and above growth inhibition against microorganisms. MIC analyses showed that there were significant differences among honey types ( $p < 0.05$ ) (Table 2)

**Table 2.** Minimal inhibition concentrations (MIC) of honey samples (v/v %)

Microorganisms	Manuka (mm)	Sunflower (mm)	Acacia (mm)	Citrus (mm)	Oak (mm)	Lavender (mm)	Chestnut (mm)	Positive Control (Antibiotics)	Negative Control (medium)
<i>Candida albicans</i> ATCC 10231	NZ	NZ	NZ	NZ	NZ	NZ	NZ	0.5 µg/mL (Amphotericin B)	NZ
<i>Enterobacter aerogenes</i> ATCC 13047	NZ	25 ± 1.2 <sup>b</sup>	NZ	25 ± 1.1 <sup>b</sup>	50 ± 2.1 <sup>c</sup>	NZ	50 ± 2.0 <sup>c</sup>	2 µg/mL (Gentamicin)	NZ
<i>Enterococcus faecalis</i> ATCC 29212	NZ	NZ	NZ	NZ	NZ	NZ	NZ	1 µg/mL (Vancomycin)	NZ
<i>Escherichia coli</i> ATCC 25922	NZ	NZ	NZ	NZ	50 ± 1.8 <sup>b</sup>	NZ	NZ	1 µg/mL (Gentamicin)	NZ
<i>Klebsiella pneumoniae</i> ATCC 13883	NZ	50 ± 2.3 <sup>c</sup>	NZ	NZ	25 ± 1.5 <sup>b</sup>	NZ	50 ± 1.7 <sup>c</sup>	2 µg/mL (Gentamicin)	NZ
<i>Proteus vulgaris</i> ATCC 13315	NZ	NZ	NZ	NZ	25 ± 1.3 <sup>b</sup>	NZ	NZ	2 µg/mL (Gentamicin)	NZ
<i>Salmonella typhimurium</i> ATCC 14028	12.5 ± 0.9 <sup>b</sup>	25 ± 1.1 <sup>c</sup>	NZ	6.25 ± 0.6 <sup>a</sup>	NZ	25 ± 1.0 <sup>c</sup>	NZ	1 µg/mL (Gentamicin)	NZ
<i>Staphylococcus aureus</i> ATCC 25923	25 ± 1.1 <sup>b</sup>	25 ± 1.2 <sup>b</sup>	NZ	NZ	50 ± 2.0 <sup>c</sup>	50 ± 1.9 <sup>c</sup>	50 ± 2.1 <sup>c</sup>	1 µg/mL (Vancomycin)	NZ
<i>Serratia marcescens</i>	NZ	50 ± 2.2 <sup>c</sup>	NZ	NZ	NZ	NZ	50 ± 2.0 <sup>c</sup>	2 µg/mL (Gentamicin)	NZ
<i>Bacillus thuringiensis</i>	25 ± 1.0 <sup>b</sup>	25 ± 1.2 <sup>b</sup>	50 ± 2.0 <sup>c</sup>	NZ	50 ± 2.2 <sup>c</sup>	NZ	50 ± 1.9 <sup>c</sup>	1 µg/mL (Vancomycin)	NZ

NZ: "No Zone", i.e., no inhibitory zone observed; no or very low antimicrobial effect. MIC values are expressed as % v/v, with a lower MIC indicating a stronger antimicrobial effect

MIC analyses showed significant differences among honey types ( $p < 0.05$ ). A strong negative correlation was found between zone diameters and MIC values ( $r = -0.72$ ,  $p < 0.01$ ). This finding indicates that larger zone diameters are compatible with lower MIC values.

Chestnut and sunflower honeys share the first place in terms of the number of microorganisms it is most effective against ( $n=5$ ) (Table 3).

**Table 3.** Spectrum of Antimicrobial Effect of Different Monofloral Honeys

Honey Type	Number of Microorganisms Showing Inhibition	Effective Microorganisms
Lavender	4	<i>Salmonella typhimurium</i> , <i>Staphylococcus aureus</i> , <i>Proteus vulgaris</i> , <i>Bacillus thuringiensis</i>
Chestnut	5	<i>Enterobacter aerogenes</i> , <i>Klebsiella pneumoniae</i> , <i>Staphylococcus aureus</i> , <i>Serratia marcescens</i> , <i>Bacillus thuringiensis</i>
Oak	3	<i>Escherichia coli</i> , <i>Klebsiella pneumoniae</i> , <i>Proteus vulgaris</i>
Citrus	2	<i>Enterobacter aerogenes</i> , <i>Salmonella typhimurium</i>
Acacia	2	<i>Staphylococcus aureus</i> , <i>Bacillus thuringiensis</i>

Sunflower	5	<i>Enterobacter aerogenes, Klebsiella pneumoniae, Salmonella typhimurium, Serratia marcescens, Bacillus thuringiensis</i>
Manuka	3	<i>Salmonella typhimurium, Staphylococcus aureus, Bacillus thuringiensis</i>

Manuka honey had the most potent and consistent antimicrobial activity with both a low mean MIC value (18.75%) and a low standard deviation (Table 4).

**Table 4.** Mean MIC Values and Antimicrobial Performance of Different Honey Types

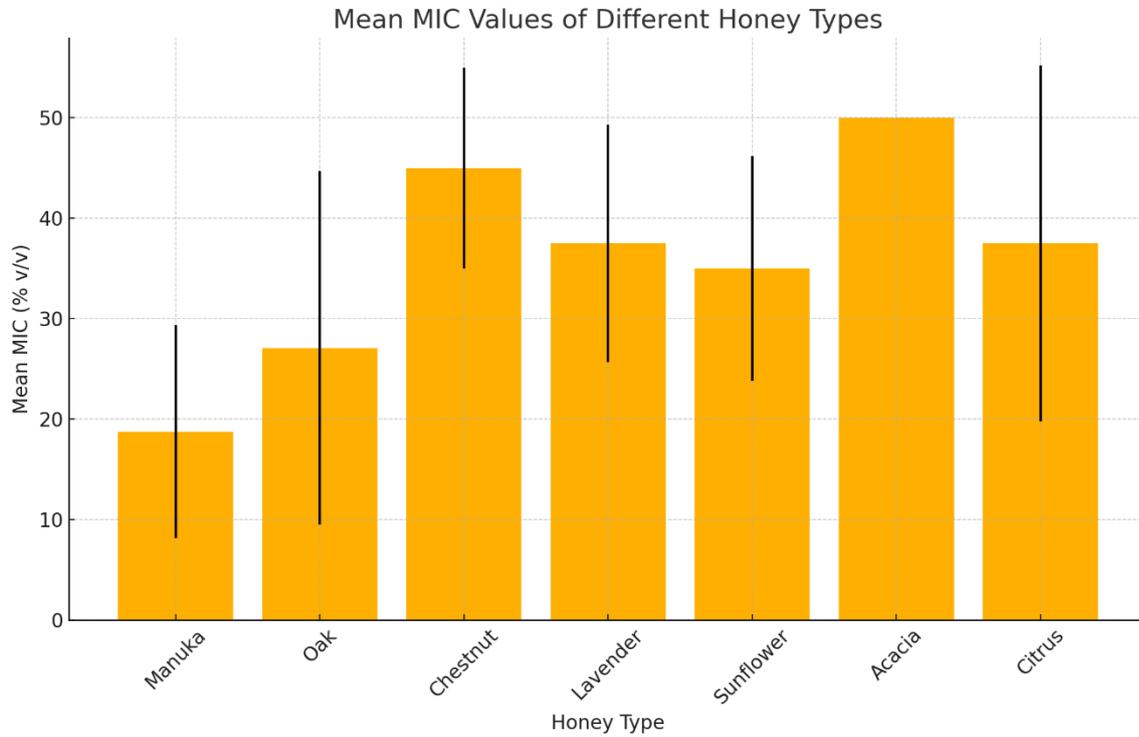
Honey Type	Mean MIC (% v/v)	Standard Deviation (SD)	Interpretation
Manuka	18.75	±10.6	Strong and consistent effect (lowest mean MIC)
Oak	27.08	±17.6	Strong effect when present
Chestnut	45.00	±10.0	Broad spectrum, weak intensity
Lavender	37.50	±11.8	Moderate activity
Sunflower	35.00	±11.2	Broad spectrum but low intensity
Acacia	50.00	±0.0	Weakest effect (limited and low-level activity)
Citrus	37.50	±17.7	Limited targets but low MIC values

While *Salmonella typhimurium* stood out as the most affected species, no honey type was effective against *Candida albicans* and *Enterococcus faecalis* (Table 5).

**Table 5.** Most Effective Honey Type Against Each Tested Microorganism

Microorganism	Most Susceptible Honey Type (Lowest MIC)
<i>Salmonella typhimurium</i> ATCC 14028	Oak (6.25%)
<i>Bacillus thuringiensis</i>	Manuka (25%)
<i>Staphylococcus aureus</i> ATCC 25923	Lavender (25%)
<i>Klebsiella pneumoniae</i> ATCC 13883	Oak (25%)
<i>Proteus vulgaris</i> ATCC 13315	Lavender (25%)
<i>Enterobacter aerogenes</i> ATCC 13047	Sunflower, Citrus (25%)

The average MIC values of Manuka, Oak, Chestnut, Lavender, Sunflower, Acacia and Citrus honeys were compared. The lowest MIC value was observed in Manuka honey, representing the highest antimicrobial effect (Figure 1).



**Figure 1.** Average MIC Values of Different Types of Honey

Manuka honey was the most effective type of honey with the lowest average MIC value and showed more pronounced effects, especially on Gram-negative pathogens. Chestnut and sunflower honeys have the broadest spectrum in terms of the number of microorganisms they affect, but these effects were observed at higher MIC values. Some pathogens, such as *Candida albicans* and *Enterococcus faecalis*, were not sensitive to any of the honey types in the study. Gram-positive bacteria were generally more sensitive to the effect of honey, but this cannot be generalized to all species.

In this study, the antimicrobial activities of honeys from different botanical origins were comparatively evaluated using both disk diffusion and MIC analyses. The findings revealed that monofloral honeys exhibited variable antimicrobial activities against microbial species. Manuka and citrus honeys, in particular, were observed to produce significant inhibition of pathogens such as *Salmonella typhimurium* and *Staphylococcus aureus*.

Recent studies emphasize that the antimicrobial activity of honey depends on multiple factors, including phenolic compounds, low pH, high osmotic pressure, and hydrogen peroxide production (Lu et al., 2021; Rao et al., 2021). The methylglyoxal (MGO) compound in Manuka honey has attracted attention as a potent antibacterial agent, particularly shown to be effective against Gram-negative bacteria (Bawa et al., 2025). This study similarly demonstrated that Manuka honey exhibited both effective and consistent antimicrobial properties with a low MIC value (18.75%).

While lavender, sunflower, and chestnut honeys inhibited a broad spectrum of microorganisms, this effect was observed at higher MIC values. This suggests that the antimicrobial activity of these honey types becomes apparent only at higher concentrations. Consistent with these findings, literature reports suggest that honeys high in polyphenols can exhibit broader-spectrum but concentration-dependent effects (Bose et al., 2024).

On the other hand, some microorganisms, such as *Candida albicans* and *Enterococcus faecalis*, were observed to be resistant to the tested honey types. This resistance can be explained by the higher tolerance of yeast and Gram-positive cocci, in particular, to the antimicrobial agents contained in honey (Usta, 2023). This finding suggests that the target microorganism type should be taken into consideration when using honey as a potential natural antimicrobial agent.

MIC analyses revealed statistically significant differences among honey types ( $p < 0.05$ ). These results suggest that the antimicrobial activity of honey depends not only on the flora but also on the time of collection, geographic region, and processing conditions. Indeed, recent studies have demonstrated that even honeys of the same botanical origin collected under different climatic conditions can exhibit varying levels of antimicrobial activity (Obeidat et al., 2024). These findings demonstrate that antimicrobial effects depend not only on the botanical origin of honey but also on the structure, quantity, and interactions of its active compounds. Manuka honey is the most effective type of honey, while chestnut and sunflower honeys have advantages in terms of spectrum. However, the fact that no honey type is effective against *Candida albicans* and *Enterococcus faecalis* suggests that honey is inadequate against some pathogens. This suggests that in the future, honey should be used not alone, but in combination with ingredients that exhibit synergistic effects.

The findings from this study demonstrate that the antimicrobial potential of monofloral honeys can not only be evaluated at the laboratory scale but also has a significant role in food safety, wound healing, and apitherapy applications. Especially in today's world, where

antibiotic resistance is steadily increasing, the investigation of natural antimicrobial agents is of paramount importance. In this regard, our study provides a comparative assessment of honeys of different botanical origins, enabling a broader discussion of the biological effects of honey in terms of public health. Future studies, supported by analyses of honey's phenolic content and enzymatic activity, as well as investigation of its antibiofilm effects, will contribute to a more comprehensive understanding of the antimicrobial mechanisms of honey.

#### **4. CONCLUSION**

This study comparatively evaluated the antimicrobial effects of monofloral honeys of different botanical origins against selected pathogenic microorganisms. Results from disk diffusion and MIC analyses revealed significant differences in the antimicrobial potential of honey types. Manuka honey was identified as the most effective honey type, with its low mean MIC value and low standard deviation. This honey demonstrated particularly high activity against microorganisms such as *Salmonella typhimurium* and *Bacillus thuringiensis*. Chestnut and sunflower honeys exhibited a broad spectrum of activity, being effective against the most diverse microorganisms, but this activity was achieved at higher concentrations. Lavender and oak honeys exhibited selective but effective antimicrobial properties. In contrast, acacia honey exhibited the weakest antimicrobial performance due to its limited activity and high MIC value. Specifically, *Candida albicans* and *Enterococcus faecalis* were observed to be resistant to the tested honey types, suggesting that honey may not be effective against all pathogens. Overall, the findings indicate that the antimicrobial activity of honey depends not only on its flora but also on its phenolic compounds, enzymatic activities, and physicochemical properties. In this context, honey has the potential to be considered a natural and biologically safe antimicrobial agent and an alternative or complementary solution for health, food safety, and wound care. Future studies will be beneficial in further elucidating the antimicrobial properties of honey by examining the chemical composition and synergistic effects of honey samples collected from different geographical regions.

#### **DECLARATIONS**

The authors have no competing interests to declare that are relevant to the content of this article.

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## AUTHORS' CONTRIBUTIONS

KZ: Methodology, Validation, Data Curation and Investigation. MU: Methodology, Project administration, Formal analysis, Writing—review & editing, Supervision, and Funding acquisition. SO: Methodology and Investigation, SS: Methodology and Investigation. RN: Methodology, Writing—review & editing. ZD: Methodology, Writing—review & editing.

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