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Evaluation of Marker Volatiles in Honey: A Review of Aromatic Compounds of Honey

Baldaki Uçucu Belirteçlerin Değerlendirilmesi: Balın Aromatik Bileşikleri Üzerine Bir İnceleme

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Abstract

Honey volatiles are a complex mixture of substances formed during the nectar collection, honey-making process, and storage by bees. They contribute to the honey's distinct aroma and flavor, with potential health benefits and antioxidant properties. Understanding the fragrance constituents and floral origins of honey can help standardize quality and prevent mislabeling. Honey is a complex structure with numerous components, including phenolic and volatile compounds. These volatile compounds give honey its basic aroma and are found in almost all varieties. Monofloral honey varieties have unique odors and flavors due to these compounds. Research has shown that citrus sp. pollen-containing honey's volatile fraction distinguishes it from other types of honey. Other types of honey, such as Turkish honey, lavender honey, and thyme honey, also contain volatile compounds. These compounds can be used as floral identifiers for honey types, but their significance is still unknown. Further research is needed to understand the interaction between local natural flora volatiles and honey and to determine the effectiveness of volatile compounds in classifying monofloral honey.

Keywords: Honey, Aromatic Compounds, Volatiles, Honey Adulteration, Honey Quality

Özet

Baldaki uçucu bileşenler, arılar tarafından nektar toplama, bal yapma süreci ve depolama sırasında oluşan bir madde karışımıdır. Balın kendine özgü aroma ve lezzetine katkıda bulunmakla birlikte potansiyel sağlık yararları ve antioksidan özellikleri vardır. Baldaki uçucu bileşenlerin ve çiçek orijinlerinin anlaşılması, kalitenin standartlaştırılmasına ve yanlış etiketlemenin önlenmesine yardımcı olabilir. Bal, fenolik ve uçucu bileşikler de dahil olmak üzere çok sayıda bileşene sahip karmaşık bir yapıdır. Bu uçucu bileşikler bala temel aromasını vermekte ve neredeyse tüm çeşitlerde bulunmaktadır. Monofloral bal çeşitleri, bu bileşikler sayesinde eşsiz koku ve tatlara sahip olmaktadır. Araştırmalar, narenciye poleni içeren balın uçucu fraksiyonunun onu diğer bal türlerinden ayırdığını göstermiştir. Türk balı, lavanta balı ve kekik balı gibi diğer bal türleri de farklı uçucu bileşikler içermektedir. Bu bileşikler bal türleri için çiçek tanımlayıcıları olarak kullanılabilmesine rağmen önemleri hala tam olarak bilinmemektedir. Yerel doğal flora uçucuları ile bal arasındaki etkileşimi anlamak ve uçucu bileşiklerin monofloral balların sınıflandırılmasındaki etkinliğini belirlemek için daha fazla araştırmaya ihtiyaç bulunmaktadır.

Anahtar Kelimeler: Bal, Aromatik Bileşikler, Uçucu Maddeler, Balda Tağşiş, Bal Kalitesi

1. INTRODUCTION

Honey is synthesized by the species Apis mellifera, often known as honey bees, through the utilization of carbohydrate-rich exudates secreted by plants. Certain constituents of honey are derived from botanical sources, while others are introduced by honeybees, and additional compounds arise as a result of biochemical transformations occurring throughout the maturity process of honey (Castro-Vázquez et al., 2007; Odeh et al., 2007; Pita-Calvo & Vázquez, 2017). The chemical composition of honey is influenced by the botanical origin of the nectar collected by bees (Roberts et al., 2002).

The aromatic characteristics play a significant role in evaluating food products since they contribute to the honey's distinctive qualities and genuineness. The taste and flavor of the honey varies depending on whether it is monofloral or polyfloral. Monofloral honey has its own unique flavor and is attached to the original nectar source (Cuevas-Glory et al., 2007). Pollen analysis, moisture content, 5-(hydroxymethyl) furan-2-carbaldehyde concentration, sugar composition, proline content, invertase and diastase activity, and electrical conductivity are used to characterize honey. In addition to these traditional methods, honey verification may be possible by investigating its volatile profile, which varies widely with flower origin and processing (Radovic et al., 2001; Cajka et al., 2009). The volatile components of honey, which contribute to its taste and smell, are closely tied to its source, location, and chemical properties. These volatiles also play a role in determining the quality and antioxidant properties of honey. High-quality honey, characterized by a rich and complex aroma and flavor, typically has higher levels of beneficial antioxidants. Understanding these relationships helps in appreciating the diversity and health benefits of different types of honey (Cuevas-Glory et al., 2007; Escriche et al., 2023).

2. AUTHENTICITY AND ADULTERATION CHALLENGES OF HONEY IN THE GLOBAL MARKETPLACE

Honey adulteration, where substances like sugars and syrups are added to honey, reducing its quality. Honey adulteration is a growing concern and can have adverse effects on human health. Adulterated honey, containing added sugars, can lead to increased blood sugar levels, potentially causing diabetes, obesity, and abdominal weight gain. It can also raise blood lipid levels, increasing the risk of heart-related issues like high blood pressure. The paper suggests that the liver is the most commonly affected organ. Detection methods and research studies are mentioned as important aspects of addressing this problem. To mitigate the issue, regulatory authorities should implement quality control measures, and consumers should be educated on identifying pure honey. Continued research is needed to understand the full health impact of honey adulteration. Consuming pure and unadulterated honey is recommended for its potential health benefits (Siddiqui et al., 2017; Fakhlaei et al., 2020; Jaafar et al., 2020).

Honey from particular places inside the Europian Union (EU) can be labeled as “Protected Designation of Origin” (PDO) or “Protected Geographical Identification” (PGI) based on its geographical origin. Honeys with these names typically reflect qualities distinct to a location or local area, including natural and human causes. Portugal now has the most honey registered in the EU, followed by Spain and France (Machado et al., 2020).

Food adulteration remains a significant concern inside the EU, as seen by a notable 20% rise in reported incidents in 2020 when compared to the previous year. This information is derived from the 2020 Annual report titled "The EU Agri-Food Fraud Network and the Administrative Assistance and Cooperation System" (Commission, 2021).

Understanding the composition of honey volatiles not only contributes to its sensory characteristics but also helps identify its botanical and geographical origins, which is essential for quality control and authentication purposes in the honey industry (Aronne & De micco, 2010).

At the end of the 1950s, research on honey volatiles identified several sources, including honeybee nectar or honeydew, plant compound transformation, microbial or environmental contamination, and honey processing or storage. The volatile component profile may serve as a fingerprint for honey verification, allowing for the identification of its origin (Bogdanov et al., 2004; Baroni et al., 2006). Correlating sensory analysis with instrumental data has acquired validity and attention in recent years because it permits product classification and sensory quality prediction from measures. Understanding the aroma of honey helps standardize quality, prevent adulteration, and verify authenticity (Manyi-Loh, Clarke, et al., 2011b; Soares et al., 2017).

3. VOLATILE COMPOUNDS IN HONEY

The aroma profile of a food product is an essential characteristic used to assess its organoleptic integrity and quality. This profile is primarily determined by volatile molecules, which significantly contribute to the product's flavor, taste, and physical characteristics (Nayik & Nanda, 2015).

Honey volatiles are the chemical components that give honey its distinct aroma and flavor. They are a complex mixture of various substances formed during the nectar collection, honey-making process, and storage by bees. The composition of honey volatiles is incredibly diverse, with hundreds of compounds contributing to its aroma and flavor (Manyi-Loh et al., 2011b). The composition of honey volatiles can vary widely depending on factors like the plant source of the nectar, environmental conditions, bee species, and honey processing methods. Different floral sources, such as lavender, clover, or citrus blossoms, contribute distinct aromatic profiles to the honey. The volatile compounds in honey not only contribute to its fragrance and taste but also have potential health benefits and antioxidant properties. Researchers have studied these compounds for their antimicrobial, anti-inflammatory, and even therapeutic potential. Due to the abundance of volatile constituents, the fragrance profile serves as a distinctive characteristic of the product, enabling the identification of its source (Cuevas-Glory et al., 2007; Escriche et al., 2017).

Honey volatile chemicals are recovered from distinct pathways utilizing procedures with varying selectivity and efficacy. These chemicals include aldehyde, ketone, acid, alcohol, hydrocarbon, norisoprenoids, terpenes, benzene, furan, and pyran derivatives. They are a honey's fingerprint and can be used to distinguish monofloral honey from distinct floral sources, revealing the honey's botanical and geographical provenance. Only plant-derived chemicals and their metabolites may distinguish floral honey origins. However, numerous writers have reported distinct floral identifiers for the honey of the same flower origin, therefore sensory analysis and volatile analysis may help resolve this uncertainty. Volatiles also affect honey's sweet, citrus, flowery, almond, and bad odor. The odor activity of a volatile component determines its honey aroma contribution. Understanding a honey's fragrance constituents and floral origins can assist in standardizing its quality and prevent mislabeling. Low amounts of volatiles may contribute to honey's biological activities, specifically its antioxidant impact due to radical scavenging (Manyi-Loh et al., 2011a; Pino, 2012).

Honey may contain volatile chemicals due to heat processing, storage conditions, and extraction methods, which are not directly related to bee processing or botanical sources. Thermal processing or storage can cause oxidation or destruction of unstable chemicals, and Maillard and Strecker degradation processes may generate volatile molecules (Jerković & Kuś, 2014). The location of honey also affects its volatile content. Since phytochemicals (carbohydrates, polyphenolics, and volatiles) build up based on climatic conditions, soil characteristics, and other factors, honey from different countries are likely to differ due to pollen or nectar compositions, which have the greatest impact on chemical composition (Kaškonienė et al., 2008).

Some volatile chemicals affect honey aroma. A compound's influence depends on how much its concentration exceeds its odor threshold, but synergistic and antagonistic interactions between components should also be considered. Such low-concentration chemicals may add to the honey aroma. The volatiles found in different honey samples exhibit a diverse variety of scent descriptors, including bitter, rancid, fishy, sweet, and flowery. Honeys, rich in volatile compounds like lilac aldehydes, have diverse botanical origins. However, measurement methods often lack sufficient chemical information, requiring further development in analysis techniques to accurately identify and quantify these compounds. (Kaškonienė & Venskutonis, 2010).

Over 600 volatile substances have been found in honey, belonging to diverse chemical molecules and originating from diverse metabolic paths (Montenegro et al., 2009; Jerković et al., 2010). These volatiles include aldehydes, ketones, esters, alcohols, acids, and more. Aldehydes contribute to the nutty or grassy aroma of honey. Examples include benzaldehyde (almond-like scent) and furfural (sweet, caramel-like aroma). Ketones often provide fruity or floral notes. For instance, 2,3-butanedione contributes a buttery aroma. Esters are responsible for the fruity and sweet aromas of honey. Examples include ethyl acetate (fruity scent) and methyl salicylate (sweet, wintergreen aroma). Alcohol can contribute to the floral, fruity, or spicy scent of honey. For instance, ethanol provides a characteristic alcohol aroma (Čajka et al., 2007). The employing of octanol and 2-octanol as indicators has the potential to differentiate between oak and pine honey based on their absence or presence, respectively (Yildiz et al., 2022). Acids in honey, such as acetic acid, formic acid, and gluconic acid, contribute to its overall flavor profile. Terpenes are common in floral sources like citrus blossom honey and contribute to their characteristic scents. Terpenes, the primary secondary metabolites of aromatic plants, are known. Honey bees collect nectar from aromatic plants which contains terpene and terpenoids.. Honey comprises primarily regular monoterpenes generated from geranyl pyrophosphate, including linalool derivatives including linalool, trans-linalool oxides, and hotrienol (Jerković & Kuś, 2014).

The composition and relative concentrations of these compounds can vary significantly based on the floral source of the nectar. Different flowers impart distinct aromatic profiles to honey. For instance, orange blossom honey might contain compounds that create a citrus aroma, while lavender honey might have compounds producing a floral scent. Honey volatiles can also be affected by various environmental contaminants, such as 1,2-dibromoethane, 1,4-dichlorobenzene, and naphthalene (Tananaki et al., 2005).

Differences can be found in the content of volatile compounds and the level of antioxidant activity. As recommended, the identification of certain chemicals such as 1-(2-furanyl)-ethanone, 2,3-butanediol, 3-hydroxy-2-butanone, and 1-hydroxy-2-propanone could be employed to differentiate between these varieties of honey. Unifloral honey vary from one another in several aspects, including their volatile content, which significantly affects the distinct sensory qualities of each form of honey (Soria et al., 2004; Jerković & Marijanović, 2010).

Light-colored honey tastes soft, whereas darker honey tastes stronger in terms of aromatic compounds. The honey aroma profile is complex and depends on isolation, including many volatile components. Some volatile chemicals affect the honey aroma, but not all (Alissandrakis et al., 2005). It is observed that a decrease in volatile alcohols, esters, and terpenes during ripening (Vyviurska et al., 2016). Furthermore, buckwheat honey contains esters and alcohols at lower maturity levels, while higher maturity honey is dominated by aldehydes and acids (Wang et al., 2020).

3.1. Chemical Structure Effects of Volatile Organic Compounds in Honey

Volatile organic compounds encompass a broad range of organic molecules that possess relatively low boiling points, allowing them to easily vaporize at room temperature. These compounds often contain specific chemical structures that contribute to their volatility.

Chiral carbon atoms, which create molecules with non-superimposable mirror images (enantiomers), can be present in some volatiles found in honey. However, not all volatiles in honey contain chiral centers. Honey's aroma and flavor arise from a wide array of volatile organic compounds (VOCs) present in its composition. These compounds are responsible for the distinctive sensory characteristics of honey. These compounds' structures can indeed include chiral centers, double bonds, functional groups, and varied carbon backbones, all of which influence their volatility, aroma, and taste. Analytical techniques like gas chromatography coupled with mass spectrometry allow the identification and quantification of these volatile compounds, aiding in understanding honey's chemical composition and sensory properties. Honey's aroma quality is influenced by its chiral isomers, which impart specific aromas. The botanical origin of honey samples influences the distribution of enantiomers of linalool, cis- and trans-furanoid linalool oxides, hotrienol, and lilac aldehydes. However, the influence of chiral configuration on honey's aroma contribution remains uninvestigated. (Li et al., 2023).

4. IDENTIFICATION OF VOLATILE COMPOUNDS IN HONEY

Honey has small quantities of aroma compounds, which are complex combinations of volatile components with varied functions and low molecular weight. For aroma profile analysis, Gas chromatography-mass spectrometry (GC-MS) is preferred because of its high separation efficiency, sensitivity, and qualitative and quantitative data for these substances. Recent tests have used mass spectrometry, piezoelectric effects, and electrical resistance electronic noses on honey's volatile percentage Analyzing honey volatiles is complex due to the multitude of compounds present. GC-MS is commonly used to identify and quantify these volatile compounds (Ampuero et al., 2004; Lammertyn et al., 2004). The column extraction method is a viable approach for separating volatile substances in the absence of heat, by utilizing both a solvent and a porous polymer (Cuevas-Glory et al., 2007). Many volatiles in honey are odorless, and only a small fraction affects aroma and flavor. Thus, GC–olfactometry is used to identify important volatiles for honey aroma and flavor in addition to instrumental methods like GC-FID or GC-MS. The Osme GC– olfactometry method quantifies aroma intensity over time using a time-intensity scale (Costa et al., 2019).

Before isolating the volatiles, it is essential to eliminate the sugars, which constitute the main constituents of honey, due to their low concentration. The honey volatiles exhibit substantial variation in their composition based on the extraction systems used, as the collection is greatly influenced by the volatility and polarity of each molecule (Kaškonienė et al., 2008; Jerković et al., 2011).

The study proposes a two-step protocol for fractionating honey volatiles, involving preliminary acetone extraction, steam distillation, and solvent extraction, to prevent sugar interference. (Cuevas-Glory et al., 2007). Honey volatile extraction using solvents, either directly or simultaneously, is frequent. As indicated, heat causes artifacts in samples. This approach reduced hotrienol in citrus honey, which is thermally synthesized from its precursor (E)-2,6-dimethyl-6-acetoxy-2,7-octadienal found in citrus flowers. The prevalence of linalool compounds in citrus honey and flowers can characterize this honey. When evaluated for honey aroma compound extraction, ultrasound-assisted solvent extraction, and solid phase micro-extraction (SPME) performed better than hydrodistillation and microsimultaneous steam distillation-solvent extraction (Cuevas-Glory et al., 2007).

New approaches have been developed to prevent some compounds such as furan and pyran derivatives, and expensive, harmful chemical solvents. Solid phase extraction (SPE), headspace (HS), and SPME are these approaches. The fundamental benefit of HS analysis is that it is done on an untreated material and the isolated volatiles closely match sensory perception (Radovic et al., 2001; Kaškonienė et al., 2008; Petretto et al., 2017).

SPME is simple, uses no (toxic) organic solvents, quantifies many molecules, requires little or no sample manipulation, shortens analysis time, and covers in situ and air sampling. It's also easy to connect to measurement devices. In this manner, SPME effectively overcomes the limitations associated with the previous methods (Cuevas-Glory et al., 2007; Manyi-Loh et al., 2011b; Yang et al., 2018). Direct extraction, headspace extraction, and membrane protection are the primary approaches. Therefore, the performance of the SPME method is affected by factors such as fiber coating, sample amount, matrix modification, agitation, extraction temperature, time and analytical desorption. The best sampling option is HS extraction because it protects the fiber from non-volatile chemicals in the sample matrix (such as sugars) and enables pH changes without harming the fiber (Peña et al., 2004; Pontes et al., 2007). The effectiveness of volatile extraction has been reported in various types of fibers used in HS-SPME analysis. Among these fibers, divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) offered the most favorable outcomes compared to the fibers stated earlier (Čajka et al., 2007; Plutowska et al., 2011). SPME Arrow was tested for extracting volatile constituents from honey samples before separation and determination using GC-×-GC–MS. The combination enabled the identification of over 290 compounds from various honey samples. SPME Arrow's larger sorptive phase volume improved sensitivity and precision, making it a powerful analytical tool for quality control and identifying botanical and geographical origins (Manousi et al., 2023). On the other hand, GC-MS and vacuum-assisted SPME can quickly and reliably evaluate volatile and semi-volatile profiles in honey matrices. The Vac-SPME approach exhibits a greater sensitivity towards volatile and semi-volatile substances (Mamedova & Alimzhanova, 2023).

Volatiles can be accurately identified using GC–TOF-MS instrumentation, offering improved detection limits, faster separation, and improved signal-to-noise ratio compared to conventional MS detectors. (Čajka et al., 2007).

An aroma profile of chemicals such as aldehydes, alcohols, ketones, fatty acid esters, and monoterpenoids is what distinguishes litchi honey, which is a popular form of honey, from other kinds of honey. Electronic nose fingerprints are demonstrated to be able to determine the floral genesis of samples together with the quality components of honey, thereby eliminating fraud and simplifying the process of sample preparation (Uma Bharathi et al., 2023).

5. POSSIBLE MARKERS USED TO DETERMINE THE AUTHENTICITY OF CERTAIN HONEY

Multiple challenges may prevent a correct correlation between honey's floral origin and volatile composition. The geographical origin, extraction method, and climate may affect honey's volatile composition. Besides, monofloral honey is not completely monofloral, and flower nectar may contribute to their aroma. Regrettably, there is a lack of data about any potential correlation between honey samples' comprehensive pollen profile and their volatile composition (Kaškonienė & Venskutonis, 2010; Patrignani et al., 2018). Certain biological and botanical chemicals in honey are unstable, especially volatiles, and their structures may change throughout maturation and storage (Kaškonienė et al., 2008).

Table 1. Some volatile aromatic compounds found in honey that contribute to its distinct scent and flavor

Honey bee honey	**Identified volatiles as marker**	**Origin**	**Reference**
Citrus honey	Methyl anthranilate Lilac-aldehydes	Spain	(Ferreres *et al.*, 1994; Escriche *et al.*, 2023)
Strawberry tree honey	Isophorone	Spain	(de la Fuente *et al.*, 2005)
Ling heather honey	Phenylacetic acid	Britain	(Guyot *et al.*, 1999)
Chestnut honey & Eucalyptus honey	3-aminoacetophenone; 2-hydroxy-5-methyl-3-hexanone	Greece	(Alissandrakis *et al.*, 2011)
Cypriot honey	1-(2-furanyl-ethanone); cis-linalool oxide; paracymenene	Cyprus	(Ioannis K Karabagias *et al.*, 2019)

Blossom honey	Pentanal	Türkiye	(Tornuk *et al.*, 2013)
Castanea sativa L. honey	Benzoic, vanillic and phenylacetic acids	Croatia	(Jerković *et al.*, 2007)
Rhododendron honey; Chestnut honey	Lilac aldehyde and 2-aminoacetophenone; *p*-anisaldehyde	Türkiye	(Senyuva *et al.*, 2009)
Lavender honey	Hexanal, heptanal, nerolidol oxide, and coumarin	Spain	(Escriche *et al.*, 2017)
Aristotelia chilensis and T. *Baccharis* honeys	3,8-*p*-menthatriene; *α*-pinene; isopropyl 2-methylbutanoate; cymene;	Argentina	(Patrignani *et al.*, 2018)
Acacia honey; Buckwheat honey; Chestnut honey; Heather honey	cis-linalool oxide, 3-methyl 3-buten-1-ol, and heptanal; 3-methylbutanal, 2-methylbutanal, isovaleric acid; 2-aminoacetophenone, acetophenone, 1-phenylethanol; *α*-isophorone, 2-hydroxyisophorone; Lilac aldehyde isomers, and methyl anthranilate		(Machado *et al.*, 2020)
Manuka honey	2-methoxybenzoic acid and 3-phenyllactic acid	New Zealand	(Beitlich *et al.*, 2014)
Winter honey; Sapium honey	Benzaldehyde dimer, phenylacetaldehyde dimer; Phenylethyl acetate dimer	China	(X. Wang *et al.*, 2019)

Consumers like monofloral honey, especially from a specific region, and the beekeeping industry knows this. Identifying volatile components to label monofloral honey correctly helps ensure authenticity and quality. Research on the production of monofloral honey is limited and dispersed mainly due to the difficulties in collecting data caused by factors such as environmental variations, aroma identification, component separation, and processes. Due to the diversity, the main analysis identified the five major volatiles from twenty monofloral honeys most often reported in many investigations as potential markers. These key components may not necessarily define honey varieties, as other chemicals, though present in lower levels, may be more common in monofloral honey from different nations. Because they are found in much monofloral honey, some key volatile chemicals cannot be utilised as reliable indicators (Almeida-Muradian et al., 2018; Costa et al., 2019; Machado et al., 2020).

Monofloral honey categorisation continues to be an issue. Because optical microscopy-based melissopalynological analysis is not routine. Pollen identification from botanical species is complex and expensive, requiring specialist analysers. The nectar contribution of citrus, lavender and rosemary to honey varies. This requires various markers(Pérez et al., 2002; Aronne & De micco, 2010). Therefore, finding objective methods to define monofloral honey is difficult and necessary. This would give regulatory bodies, beekeepers, and commercial agents an objective instrument to elucidate the uncertainty associated with monofloral honey classification problems easily. It would also apply proper labeling, giving consumers more transparency. The optimization of objective analytical techniques that can definitively define its monoflorality is recommended (Siegmund et al., 2017; Escriche et al., 2023). The pollen composition differs based on the nectar source. Therefore, a honey's pollen spectrum can demonstrate its geographical origin but not its principal nectar source (Patrignani et al., 2018).

Honey is a complicated structure with many components, including many phenolic and volatiles. These volatile compounds give honey its basic aroma, thus, they're found in practically all varieties. Certain monofloral honey varieties have unique odors and flavors due to volatile compounds. It would be interesting to uncover the markers that designate a monofloral honey, a work that has been researched in recent years but has not been solved (Zhao et al., 2022).

According to Escriche et al. (2023), principal component analysis and Hierarchical Cluster Analysis demonstrated that citrus sp. pollen-containing honey's volatile fraction distinguishes it from other kinds of honey. The Orthogonal Partial Least Squares analysis model for citrus honey identified 5 volatile chemicals as significant predictors of the HPLC result of methyl anthranilate. Detecting 4 lilac-aldehydes and the volatile methyl-anthranilate together provides more accurate results. Therefore, it could be used as a consistent identifier to classify citrus honey and improve labeling reliability. A total of 88 volatile compounds were identified in 20 different types of blossom honey obtained from beekeepers residing in the towns of Sivas, Konya, and Kayseri in Central Anatolia, Türkiye (Tornuk et al., 2013). A total of eight distinct varieties of Turkish honey samples were evaluated by Yildiz et al. (2022), revealing the presence of volatile compounds. These compounds were categorized into different groups, including 15 esters, 30 aldehydes and ketones, 31 alcohols, 18 terpenes, and 9 acids. All analyzed samples contained several aldehydes and ketones, such as acetone, 4-methyl-3-penten-2-one, 6-methyl-5-hepten-2-one, nonanal, decanal, and benzaldehyde. Due to their presence in many floral honeys, linear aldehydes like nonanal and decanal are considered typical honey flavor components (Karabagias et al., 2019).

Differences in plant varieties, regional origins, and beekeeping procedures make it difficult to determine which components are floral identifiers for honey types. Volatile fraction extraction methods may be selective and successful depending on the substance. To distinguish honey's floral origins, plant-derived chemicals and their metabolites, including terpenes, benzene, and norisoprenoids need to be used. These chemicals are floral markers since they are only found in certain honey (Castro-Vázquez et al., 2007; Jerković, 2013; Karabagias, 2018).

Several components have been found in floral honey. Lilac aldehyde helps characterize citrus honey (Karabagias et al., 2017). In Turkish honey, lilac aldehyde and 2-aminoacetophenone identify rhododendron, whereas p-anisaldehyde indicates chestnut (Senyuva et al., 2009). Other characteristics of lavender honey include hexanal, heptanal, nerolidol oxide, and coumarin. Some volatile components can distinguish thyme honey from Greece, Spain, Morocco, and Egypt by their volatile profile (Escriche et al., 2017; Patrignani et al., 2018).

Volatile benzene derivatives dominate various honeys, making them significant. These molecules include benzene acetaldehyde, benzaldehyde, 1-phenylbutane-2, 3-diol, 1, 4-dihydroxybenzene, and benzene ethanol. In New Zealand honey, methyl 4hydroxy-3, 5-dimethoxy benzoate, and methyl 3, 4, 5-trimethoxy benzoate were the main antibacterial components. The most curious solvent extracts of selected South African honey included thiophene and N-methyl-D3-aziridine compounds. Heterocyclic small molecules are crucial precursors of natural products and medicines having biological activities such as antiviral, antibacterial, antifungal, anticancer, and anti-immunomodulatory actions (Tan et al., 1988; Viuda-Martos et al., 2010; Manyi-Loh, Clarke, et al., 2011c).

Specific volatile compounds can identify monofloral honey, including cis-linalool oxide, 3-methyl 3-buten-1-ol, and heptanal for acacia honey, 3-methylbutanal, 2-methylbutanal, and isovaleric acid for buckwheat honey, 2-aminoacetophenone, acetophenone, and 1-phenylethanol for chestnut honey, α-isophorone, 2-hydroxyisophorone for heather honey, lilac aldehyde isomers, and methyl anthranilate for heather honey. However, further research is required to confirm the significance of these chemicals as volatile identifiers for the six monofloral honey varieties. Different locations may have various volatile indicators for monofloral honey due to the presence or absence of certain chemicals in the host flora. Comparative studies are recommended to understand better the interaction between local natural flora volatiles and honey. Further research should combine melissopalynological and physicochemical data to determine the effectiveness of volatile compounds in classifying monofloral honey (Machado et al., 2020).

Winter honey contains benzaldehyde dimer and phenylacetaldehyde dimer, while sapium honey contains phenylethyl acetate dimer (Wang et al., 2019). Two-methyl ethyl butyrate and 3-methyl valeric acid are specific to Agastache honey,13 while pulegone, thymol, and six other volatiles may indicate linden honey (Liang et al., 2023). Lavender honey has 44 volatile chemicals, mostly alcohols and aldehydes. The significant 1-hexanol content in lavender honey was consistent with published data (Guyot-Declerck et al., 2002). It has been reported that honeydew honey contained the highest number of volatiles, with a total of 203. The total number of detected volatile compounds in floral honey and pine honey was 147 and 149, respectively (Manousi et al., 2023).

The presence of certain volatile compounds in Euphorbia honey, which are considered identifiers of honey, should be highlighted. The compounds mentioned are furfural, benzaldehyde, nonanal, isophorone, and decanal (Sotiropoulou et al., 2021). Manuka honey can be identified by its biomarkers, which include 2-methoxybenzoic acid and 3-phenyllactic acid (Beitlich et al., 2014).

6. CONCLUSION

Honey derived from the origin of plants can exhibit variations owing to climate or regional factors. Monofloral or unifloral honey contains volatiles from nectar from a single species or plant. Thus, volatiles can distinguish monofloral honey from diverse floral origins since their high amount of volatiles creates a unique profile that could reflect each honey type's fingerprint (Piasenzotto et al., 2003). The chemical composition of honey is influenced by the botanical origin of the nectar collected by bees. The aroma and flavor of honey vary depending on whether it is monofloral or polyfloral. Pollen analysis, moisture content, sugar composition, proline content, invertase and diastase activity, and electrical conductivity are used to characterize honey. Understanding the composition of honey volatiles is essential for quality control and authentication purposes in the honey industry. In general, volatiles may originate from the flowers or nectar, as the conversion of plant components through the activities of bees, the processing that occurs throughout the handling and safekeeping of honey, or threats from microorganisms or the environment.

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No conflict of interest or common interest has been declared by the authors.

AUTHOR CONTRUBITIONS

The authors confirm contribution to the paper as follows: Study conception and design, data collection, draft manuscript preparation: Nurullah DEMİR. The author reviewed the results and approved the final version of the manuscript.

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