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The Influence of Honey Processing Techniques on Product Quality: A Comparison of Traditional and Modern Methods

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Abstract Honey processing methods significantly impact the quality, nutritional value, and consumer appeal of the final product. Traditional techniques, including honeycomb pressing and centrifugation, have long been practiced and are known to preserve the natural properties of honey but can lead to variability in texture, flavor, and potential contamination risks. To address these limitations, modern methods such as ultrasonication, microwave, and infrared processing have been developed, offering improved efficiency, safety, and preservation of honey's bioactive compounds. This study systematically compares traditional and modern honey processing techniques, examining their effects on honey's physicochemical properties, flavor, texture, and shelf life. The findings highlight the need for careful selection of processing methods to balance natural quality preservation with production efficiency and consumer demand. This study is expected to provide insights into optimizing honey processing practices to align with industry standards and evolving consumer expectations.

Keywords Honey processing; Traditional techniques; Modern techniques; Product quality; Consumer demand

1 Introduction

Honey, a natural sweet substance produced by bees, has been valued for its nutritional and medicinal properties for centuries. Traditional honey processing techniques, such as centrifugation and honeycomb-pressing, have been widely used in beekeeping practices. These methods are known to influence the physicochemical composition and nutritional potency of honey, impacting its quality and shelf life (Hu et al., 2023). In recent years, the demand for high-quality honey has led to the development and adoption of modern processing techniques. These include advanced methods such as ultrasonication, microwave, and infrared irradiation, which aim to improve the efficiency and quality of honey processing (Luo et al., 2021; Yalçın et al., 2021). The evolution of these techniques reflects the ongoing efforts to meet consumer expectations for healthier and safer food products.

The processing techniques employed in honey production play a crucial role in determining the final product's quality. Traditional methods, while effective, can sometimes lead to variations in honey's nutritional content, taste, and physical characteristics (Ramly et al., 2021). For instance, the moisture content in honey, which is closely linked to its thickness and risk of fermentation, can be significantly affected by the processing method used. Modern techniques, on the other hand, offer the potential to enhance honey's bioactivity and safety by reducing exposure to high temperatures and minimizing the formation of harmful compounds like hydroxymethylfurfural (HMF). These advanced methods also aim to preserve the biological properties of honey, ensuring that it retains its health-promoting attributes (Scepankova et al., 2021). The choice of processing technique is therefore critical for both producers and consumers, as it directly impacts the honey's quality, safety, and marketability (Baglio, 2018; Guo, 2024).

This study attempts to explore the effects of traditional and modern honey processing techniques on product quality, discuss how different methods-including centrifugation, honeycomb-pressing, ultrasonication, and microwave processing-affect the physicochemical properties, nutritional content, and overall quality of honey, and provide an overview of the most effective processing methods that enhance honey quality while preserving its natural benefits to meet consumer demands and industry standards.

2 Traditional Honey Processing Techniques

2.1 Overview of traditional methods

Traditional honey processing methods have been utilized for centuries and are deeply rooted in cultural practices. These methods primarily involve minimal technological intervention and rely on manual labor and simple tools. The two most common traditional methods are honeycomb pressing and centrifugation. Honeycomb pressing involves manually squeezing the honey out of the comb, while centrifugation uses a hand-cranked or motorized device to extract honey by spinning the combs at high speeds (Luo et al., 2021; Hu et al., 2023).

2.2 Techniques and equipment used

In honeycomb pressing, the beekeeper crushes the honeycomb to release the honey, which is then filtered to remove wax and other debris. This method requires basic equipment such as a press or a simple strainer. On the other hand, centrifugation involves placing the honeycombs in a cylindrical drum and spinning them to force the honey out through centrifugal force. This method requires a centrifuge, which can be either manually operated or powered by electricity (Ramly et al., 2021; Hu et al., 2023).

2.3 Advantages of traditional methods

Traditional honey processing methods offer several advantages. Firstly, they are cost-effective and accessible to small-scale beekeepers who may not have the resources to invest in advanced equipment. Additionally, these methods tend to preserve the natural properties of honey better than some modern techniques. For instance, honeycomb pressing retains more of the pollen and other beneficial components, which can enhance the nutritional and medicinal value of the honey. Furthermore, traditional methods are often more environmentally friendly, as they do not require significant energy inputs or produce harmful by-products (Omondi et al., 2016; Chong et al., 2017; Puścion-Jakubik et al., 2020).

2.4 Limitations and challenges

Despite their advantages, traditional honey processing methods also have several limitations. One major challenge is the potential for contamination. Since these methods involve more manual handling, there is a higher risk of introducing impurities or pathogens into the honey (Scepankova et al., 2021). Additionally, traditional methods can be labor-intensive and time-consuming, making them less efficient for large-scale production. Another significant drawback is the variability in product quality. Factors such as the beekeeper's skill, the condition of the equipment, and the cleanliness of the processing environment can all impact the final quality of the honey (Hu et al., 2023). Finally, traditional methods may not effectively reduce the moisture content of honey, increasing the risk of fermentation and spoilage (Singh and Singh, 2018).

3 Modern Honey Processing Techniques

3.1 Overview of modern methods

Modern honey processing techniques have evolved significantly to address the challenges associated with traditional methods, such as contamination, nutrient degradation, and quality consistency. These techniques include advanced thermal and non-thermal methods designed to enhance the safety, bioactivity, and overall quality of honey. Key modern methods include ultrasonication, microwave processing, and infrared (IR) irradiation, which are often used in combination with conventional techniques to optimize processing efficiency and product quality (Scepankova et al., 2021; Luo et al., 2021; Ramly et al., 2021).

3.2 Key technological advancements

Technological advancements in honey processing have focused on minimizing the adverse effects of heat while ensuring microbial safety and preserving the bioactive compounds. Ultrasonication, for instance, uses high-frequency sound waves to reduce microbial load and improve honey's physicochemical properties without significant heating (Chong et al., 2017). Microwave processing offers rapid heating, which reduces processing time and limits the formation of hydroxymethylfurfural (HMF), a harmful byproduct of prolonged heating (Baglio, 2018; Ramly et al., 2021). Infrared irradiation provides uniform heating and can be precisely controlled to maintain honey’s nutritional and sensory qualities （Figure 1） (Luo et al., 2021).

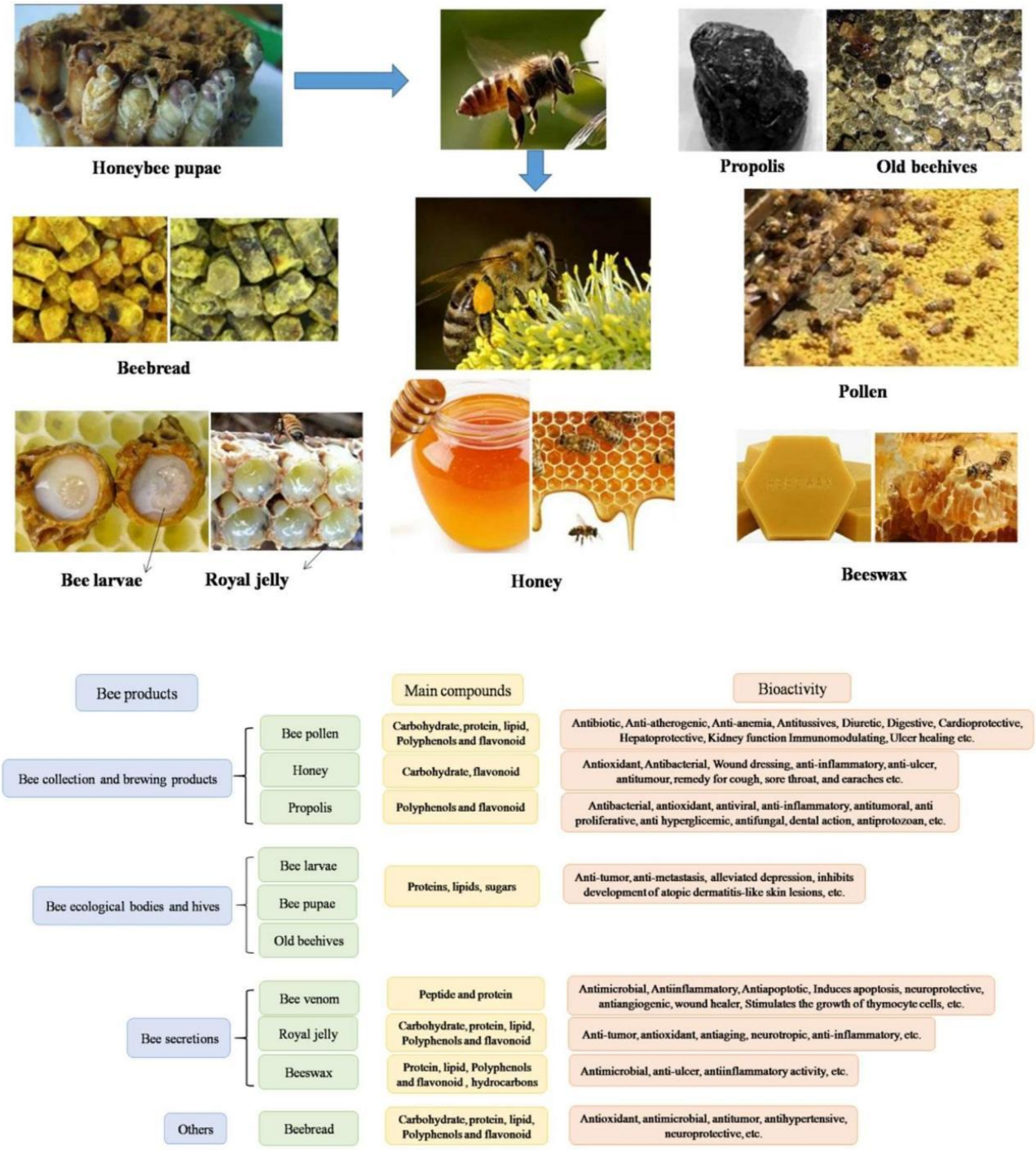

Figure 1 Bee products (A) and their bioactivities (B) (Adopted from Luo et al., 2021)

3.3 Equipment and processes in modern techniques

Modern honey processing employs specialized equipment designed to implement these advanced techniques effectively. Ultrasonication equipment includes ultrasonic baths and probes that generate high-frequency sound waves to treat honey (Chong et al., 2017). Microwave processing units are equipped with magnetrons that produce microwaves to heat honey quickly and uniformly (Ramly et al., 2021). Infrared irradiation systems use IR lamps or emitters to provide controlled heating, ensuring minimal nutrient loss and maintaining honey's natural properties (Luo et al., 2021). These processes are often integrated with conventional steps like filtration, dehumidification, and crystallization to achieve optimal results (Baglio, 2018).

3.4 Benefits of modern processing

The benefits of modern honey processing techniques are manifold. They enhance microbial safety by effectively reducing bacterial and fungal spores without excessive heating, thus preserving honey's bioactive compounds (Scepankova et al., 2021). These methods also improve the physicochemical properties of honey, such as viscosity, color, and moisture content, making it more appealing to consumers (Chong et al., 2017). Additionally, modern techniques can significantly reduce processing time and operational costs, making them economically viable for large-scale production (Luo et al., 2021; Ramly et al., 2021). The use of advanced methods also aligns with the principles of green chemistry, promoting environmentally friendly processing practices (Puścion-Jakubik et al., 2020).

3.5 Potential drawbacks and concerns

Despite their advantages, modern honey processing techniques are not without potential drawbacks. Ultrasonication, for example, may lead to the formation of free radicals, which could affect honey's antioxidant properties. Microwave processing, while efficient, requires precise control to avoid overheating and nutrient degradation (Baglio, 2018; Ramly et al., 2021). Infrared irradiation, although effective, may not be suitable for all types of honey due to variations in their thermal sensitivity (Luo et al., 2021). Additionally, the initial investment in advanced equipment can be high, posing a barrier for small-scale producers. There is also a need for standardized guidelines to ensure consistent quality across different processing methods and honey types (Eshete and Eshete, 2019).

Modern honey processing techniques, including ultrasonication, microwave processing, and infrared irradiation, offer significant improvements over traditional methods by enhancing microbial safety, preserving bioactive compounds, and improving physicochemical properties. However, these methods also present challenges such as potential nutrient degradation and high initial costs. Continued research and development are essential to optimize these techniques and establish standardized guidelines to ensure high-quality honey production.

4 Comparative Analysis of Traditional and Modern Methods

4.1 Processing time and efficiency

Traditional honey processing methods, such as centrifugation and honeycomb-pressing, are often time-consuming and labor-intensive. Centrifugation, while effective, requires significant manual effort and time to extract honey from the combs (Hu et al., 2023). In contrast, modern methods like ultrasonication, microwave, and infrared irradiation have been developed to enhance processing efficiency. These advanced techniques not only reduce processing time but also lower operational costs, making them more suitable for large-scale production (Luo et al., 2021). Additionally, low-temperature spray drying has been shown to maintain high antioxidant activity and aroma compounds, further optimizing the processing time without compromising quality (Samborska et al., 2019).

4.2 Effects on nutritional content and bioactive compounds

The nutritional content and bioactive compounds in honey are significantly influenced by the processing method used. Traditional methods like honeycomb-pressing tend to preserve more of the honey's natural nutrients and bioactive compounds compared to centrifugation (Hu et al., 2023). However, modern methods such as thermal treatment and high-pressure processing can alter the nutritional quality and physicochemical characteristics of honey. For instance, thermal processing can degrade thermolabile components, reducing the bioactivity of honey (Scepankova et al., 2021). On the other hand, emerging technologies like thermosonication and microwave processing have been shown to better preserve these bioactive compounds, ensuring higher nutritional quality (Ramly et al., 2021).

4.3 Impact on flavor, aroma, and texture

Flavor, aroma, and texture are critical quality attributes of honey that are affected by the processing method. Traditional methods like honeycomb-pressing often result in honey with a richer flavor and aroma due to the higher pollen content (Hu et al., 2023). However, these methods can also lead to variations in texture, with pressed honey being thicker and more prone to crystallization. Modern methods, such as low-temperature spray drying,

have been found to enhance the aroma profile and create a desirable fragrance in honey powders (Samborska et al., 2019). Additionally, the use of advanced techniques like near-infrared spectroscopy and electronic noses can help in better assessing and maintaining the sensory properties of honey (Puścion-Jakubik et al., 2020).

4.4 Shelf life and preservation of honey

The shelf life and preservation of honey are crucial for maintaining its quality over time. Traditional methods may not effectively control moisture content, leading to a higher risk of fermentation and spoilage (Ramly et al., 2021). Modern processing techniques, such as high-pressure processing and low-temperature spray drying, have been shown to improve the shelf life of honey by reducing moisture content and preventing the formation of hydroxymethylfurfural (HMF), a compound that forms during heating and can compromise honey quality (Samborska et al., 2019; Scepankova et al., 2021). These methods ensure that honey remains stable and retains its beneficial properties for a longer period.

4.5 Consumer perception and market demand

Consumer perception and market demand for honey are influenced by various factors, including flavor, aroma, texture, and nutritional content. Traditional honey processing methods are often perceived as more natural and may be preferred by consumers who value minimally processed products (Piana et al., 2023). However, modern methods that enhance the sensory properties and nutritional quality of honey are gaining popularity. For instance, creamy and fine-grained textures produced by advanced processing techniques are becoming more appealing to consumers. Additionally, the use of modern quality assessment methods ensures that honey meets high standards, further boosting consumer confidence and market demand (Puścion-Jakubik et al., 2020).

In summary, both traditional and modern honey processing methods have their advantages and limitations. Traditional methods like honeycomb-pressing preserve more natural nutrients and bioactive compounds but are less efficient and may lead to variations in texture. Modern methods, including ultrasonication, microwave processing, and low-temperature spray drying, offer improved efficiency, better preservation of bioactive compounds, and enhanced sensory properties. These advancements not only extend the shelf life of honey but also align with consumer preferences for high-quality, natural products. Therefore, the choice of processing method should consider the specific quality attributes desired and the market demand (Testa et al., 2019; Piana et al., 2023).

5 Case Study: The Impact of Traditional vs Modern Processing on Manuka Honey Quality

5.1 Background on manuka honey and its unique qualities

Manuka honey, primarily produced in New Zealand, is renowned for its unique antibacterial properties and specific taste, attributed to compounds such as methylglyoxal (MGO) and dihydroxyacetone (DHA) (Spiteri et al., 2017). These properties make it highly sought after for both culinary and medicinal purposes. The honey's distinctiveness is further enhanced by its complex chemical composition, which includes various phenolic compounds and antioxidants (Carter et al., 2016).

5.2 Processing techniques used for manuka honey

Manuka honey undergoes various processing techniques to ensure its quality and safety. Traditional methods often involve simple filtration and heating to reduce moisture content and prevent fermentation (Baglio, 2018). However, these methods can affect the honey's nutritional and bioactive properties due to the thermal sensitivity of its components (Scepankova et al., 2021; Islam et al., 2022). Modern techniques, such as high-pressure processing (HPP) and ultrasonication, have been developed to mitigate these effects. HPP, for instance, has been shown to maintain the honey’s nutritional and rheological properties over long-term storage without significant changes in moisture content, pH, or viscosity (Fauzi and Farid, 2017). Other advanced methods like microwave and infrared irradiation are also being explored to enhance the quality and safety of Manuka honey (Luo et al., 2021).

5.3 Comparison of quality attributes in traditional and modern processing

The quality of Manuka honey is significantly influenced by the processing method used. Traditional thermal processing can lead to the formation of hydroxymethylfurfural (HMF), a compound formed during the Maillard reaction, which can degrade the honey's quality and bioactivity (Scepankova et al., 2021; Islam et al., 2022). In contrast, modern non-thermal techniques like HPP have been shown to preserve the honey's antioxidant activity and phenolic content better than traditional methods. Studies have demonstrated that HPP-treated Manuka honey retains higher levels of antioxidants and phenolic compounds over extended storage periods, indicating a superior preservation of its bioactive properties (Fauzi and Farid, 2017; Ramly et al., 2021). Additionally, modern methods can reduce the processing time and operational costs while maintaining or even enhancing the honey's quality (Luo et al., 2021).

5.4 Market impact and consumer preferences for manuka honey

The market for Manuka honey is influenced by both its perceived quality and the processing methods used. Consumers are increasingly aware of the benefits of non-thermal processing techniques, which are seen as preserving the natural qualities of the honey better than traditional methods (Ramly et al., 2021). This awareness has led to a growing preference for Manuka honey processed using modern techniques, which is often marketed as having superior nutritional and bioactive properties (Fauzi and Farid, 2017). The premium price commanded by high-quality Manuka honey further drives the adoption of advanced processing methods in the industry, as producers seek to meet consumer demand for high-quality, minimally processed products (Carter et al., 2016).

6 Environmental and Economic Implications of Honey Processing Techniques

6.1 Energy and resource use in traditional vs modern techniques

The energy and resource use in honey processing techniques vary significantly between traditional and modern methods. Traditional methods, such as honeycomb-pressing and centrifugation, typically require less energy but may be less efficient in terms of resource utilization. For instance, honeycomb-pressing, a common traditional method, is labor-intensive and may result in higher waste due to the destruction of the comb (Hu et al., 2023). On the other hand, modern techniques like ultrasonication, microwave, and infrared irradiation are designed to be more energy-efficient and reduce processing time, thereby conserving resources (Luo et al., 2021). These advanced methods also aim to maintain the nutritional and bioactive properties of honey, which can be compromised by traditional methods (Eshete and Eshete, 2019; Scepankova et al., 2021).

6.2 Cost comparison and economic feasibility

The economic feasibility of honey processing techniques is a critical factor for producers. Traditional methods generally have lower initial costs due to the minimal equipment required. However, they may incur higher labor costs and result in lower yields, which can affect overall profitability (Hu et al., 2023). Modern methods, while requiring significant initial investment in advanced equipment, can lead to higher efficiency and better quality control, potentially increasing market value and consumer trust (Baglio et al., 2018; Luo et al., 2021). For example, the use of high-pressure processing and thermosonication can enhance the safety and quality of honey, making it more competitive in international markets (Ramly et al., 2021; Scepankova et al., 2021). Additionally, modern methods can reduce the formation of hydroxymethylfurfural (HMF), a compound that can negatively impact honey quality and marketability (Lopes et al., 2018).

6.3 Environmental impact and sustainability considerations

The environmental impact of honey processing techniques is an important consideration for sustainable production. Traditional methods often have a lower carbon footprint due to their minimal reliance on machinery and energy (Hu et al., 2023). However, they may not be as effective in preserving the quality and safety of honey, which can lead to higher spoilage rates and waste (Lopes et al., 2018). Modern processing techniques, while potentially having a higher initial environmental impact due to energy consumption, can be optimized to reduce overall environmental footprint. Techniques such as microwave-assisted drying and ultrasonication not only improve processing efficiency but also reduce waste and enhance the shelf life of honey (Eshete and Eshete, 2019;

Luo et al., 2021). Furthermore, the adoption of green chemistry principles in modern methods can lead to more sustainable practices, ensuring that honey production remains environmentally friendly while meeting high-quality standards (Pita-Calvo et al., 2017; Puścion-Jakubik et al., 2020).

In conclusion, the choice between traditional and modern honey processing techniques involves a trade-off between energy use, cost, and environmental impact. While traditional methods are less energy-intensive and have lower initial costs, modern techniques offer higher efficiency, better quality control, and potential environmental benefits when optimized. Producers must consider these factors to choose the most suitable processing method that aligns with their economic goals and sustainability commitments.

7 Quality Standards and Regulatory Aspects

7.1 International standards for honey quality

International standards for honey quality are primarily governed by the Codex Alimentarius and various regional regulations, such as those from the European Union. These standards define the essential quality parameters for honey, including moisture content, hydroxymethylfurfural (HMF) levels, diastase activity, electrical conductivity, and sugar composition (Silva et al., 2016; Thrasyvoulou et al., 2018). The Codex Alimentarius, for instance, sets specific limits for these parameters to ensure the authenticity and safety of honey. However, discrepancies exist between different countries' regulations, particularly concerning the definition of honey, the declaration of geographical origin, and the quality criteria for monofloral honey.

7.2 Influence of processing techniques on compliance with quality standards

The processing techniques employed in honey production significantly impact its compliance with established quality standards. Traditional methods, such as thermal treatment, can lead to the formation of HMF and the degradation of thermolabile components, thereby affecting honey's nutritional and bioactive properties (Scepankova et al., 2021; Ramly et al., 2021). Modern methods, including high-pressure processing, thermosonication, and microwave processing, have been developed to mitigate these issues by reducing the exposure time to high temperatures, thus preserving the honey's quality (Luo et al., 2021). These advanced techniques aim to maintain the physicochemical and microbiological integrity of honey, ensuring it meets the stringent quality standards set by international regulations (Baglio, 2018; Puścion-Jakubik et al., 2020).

7.3 Key regulatory challenges in honey processing

One of the primary regulatory challenges in honey processing is the variability in quality standards across different regions. This inconsistency can lead to difficulties in international trade and consumer confusion (Thrasyvoulou et al., 2018). Additionally, the complexity of honey's composition, influenced by factors such as botanical and geographical origin, makes it challenging to develop universal standards that accurately reflect its quality. Another significant challenge is the detection and prevention of honey adulteration, which requires sophisticated analytical techniques to ensure authenticity and compliance with labeling regulations (Siddiqui et al., 2017; Mădaş et al., 2020; Tsagkaris et al., 2021). The ongoing development of rapid and precise methods for assessing honey quality, such as near-infrared spectroscopy and nuclear magnetic resonance, is crucial for addressing these regulatory challenges and ensuring the integrity of honey in the global market (Puścion-Jakubik et al., 2020).

8 Future Directions and Innovations

8.1 Emerging technologies in honey processing

The future of honey processing is poised to benefit significantly from the integration of emerging technologies. Advanced food processing techniques such as ultrasonication, microwave, and infrared (IR) irradiation are gaining traction as alternatives or complements to conventional methods. These technologies aim to enhance the quality of honey by reducing processing time and operational costs while preserving its nutritional and bioactive properties (Luo et al., 2021; Scepankova et al., 2021). For instance, non-thermal processing methods are being explored to minimize the formation of hydroxymethylfurfural (HMF), a compound that forms during heating and can degrade honey quality. Additionally, modern methods like near-infrared spectroscopy (NIR), nuclear magnetic

resonance (NMR), and chemometric techniques are being developed to assess honey quality more accurately and efficiently (Puścion-Jakubik et al., 2020). These advancements not only ensure the safety and quality of honey but also cater to the growing consumer demand for high-quality, minimally processed products.

8.2 Trends in consumer demand and quality preferences

Consumer preferences are increasingly leaning towards natural, minimally processed, and high-quality honey products. This shift is driven by a growing awareness of the health benefits associated with natural bee products and a desire for transparency in food sourcing and processing (Pasupuleti et al., 2017; Luo et al., 2021). Consumers are also becoming more discerning about the physical characteristics of honey, such as color, thickness, and taste, which are influenced by processing methods (Ramly et al., 2021). The demand for honey with low moisture content to reduce fermentation risk and high bioactive compound retention is on the rise. As a result, the honey industry is under pressure to adopt processing techniques that maintain the natural quality and nutritional value of honey while ensuring safety and shelf stability (Baglio, 2018; Eshete and Eshete, 2019). This trend underscores the importance of developing standardized guidelines for optimal processing conditions tailored to different types and origins of honey.

8.3 Potential innovations for sustainable and high-quality processing

Sustainability and quality are at the forefront of innovations in honey processing. Emerging technologies that align with the principles of green chemistry are being prioritized to reduce environmental impact while ensuring high precision and accuracy in quality assessments (Puścion-Jakubik et al., 2020). Techniques such as low-temperature high-velocity-assisted fluidized bed drying and vacuum drying are being explored to enhance the efficiency and sustainability of honey processing (Luo et al., 2021). Moreover, the development of fast and accurate methods for detecting adulteration and assessing honey quality, such as electronic noses and potentiometric tongues, is crucial for maintaining consumer trust and product integrity. The industry is also looking into optimizing process models for large-scale operations to ensure consistent quality and cost-effectiveness. These innovations are essential for meeting the dual goals of sustainability and high-quality production, ultimately benefiting both producers and consumers.

The future of honey processing is set to be transformed by emerging technologies, evolving consumer preferences, and a focus on sustainability. Advanced processing techniques and modern quality assessment methods promise to enhance the safety, nutritional value, and overall quality of honey. As consumer demand for natural and high-quality products grows, the industry must continue to innovate and adopt sustainable practices to meet these expectations. By doing so, the honey industry can ensure the production of superior products that cater to the health and quality preferences of consumers worldwide.

9 Concluding Remarks

The study explored the influence of various honey processing techniques on the quality of the final product, comparing traditional methods such as centrifugation and honeycomb-pressing with modern methods including thermosonication, microwave processing, and high-pressure processing. It was found that all processing methods alter the nutritional quality and physicochemical characteristics of honey, albeit in different ways. Traditional methods like honeycomb-pressing were shown to produce honey with superior nutritional composition and antioxidant capacity compared to centrifugation. Modern techniques, such as thermosonication, were effective in reducing moisture content and increasing phenolic content and radical scavenging activity, while maintaining acceptable levels of hydroxymethylfurfural (HMF). Additionally, the study highlighted the importance of controlled processing conditions to prevent the degradation of honey's bioactive components and ensure microbiological safety.

The findings have significant implications for the honey industry. First, the choice of processing method can greatly influence the quality of honey, affecting its marketability and consumer acceptance. Traditional methods, while producing high-quality honey, may not be as efficient or scalable as modern techniques. On the other hand, modern methods like thermosonication and high-pressure processing offer advantages in terms of processing time, cost, and consistency of product quality. The industry must balance these factors to meet consumer demand for

high-quality, natural honey while ensuring safety and compliance with international standards. Furthermore, the development and adoption of standardized guidelines for processing conditions, particularly for heating, are crucial to maintaining the integrity of honey's nutritional and bioactive properties.

Future research should focus on optimizing processing conditions for different types of honey, considering their geographical and botanical origins. Studies should aim to establish standardized guidelines for temperature and time combinations during processing to minimize the loss of bioactive compounds and prevent the formation of harmful substances like HMF. Additionally, there is a need for further investigation into the long-term effects of different processing methods on honey's shelf life and quality, particularly under varying storage conditions. The development of advanced, non-destructive techniques for assessing honey quality in real-time could also benefit the industry by enabling more precise control over processing parameters. Finally, exploring the potential of combining traditional and modern methods could offer a balanced approach, leveraging the strengths of each to produce high-quality honey that meets both consumer expectations and regulatory requirements.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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