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OPTIMIZATION OF QUALITY CHARACTERISTICS OF ACACIA HONEY IN INDONESIA THROUGH DIFFERENT METHOD SYSTEM

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ABSTRACT

This study investigated the potential effects of implementing a water-jet vacuum cooling system on the quality attributes of honey throughout the postharvest handling stages. This study revealed that packaging honey while still hot poses a significant risk of compromising package integrity, thereby highlighting the importance of proper cooling protocols. Integral to the investigation were multiple quality parameters utilized to assess the impact of the water-jet vacuum cooling system on honey. These parameters encompassed essential aspects such as water volume, viscosity, pH, acidity, density, total dissolved solids, enzyme activity and reducing sugar content. A pivotal aspect of the experimental setup involved the initiation of pasteurization at 63°C, which served as the starting point for subsequent cooling processes. Subsequent cooling procedures were executed across a temperature gradient ranging from 63 to 35°C, allowing for a comprehensive evaluation of the efficacy of the system. Analysis of the obtained results revealed promising insights into the potential benefits of the vacuum cooling procedure in mitigating the adverse effects stemming from the heating process, thereby preserving honey quality and structural integrity. The significance of these findings extends beyond the immediate scope of honey production and has implications for broader agricultural practices, food processing industries, and food safety. By offering a viable solution to enhance post-harvest handling practices, the integration of water-jet vacuum cooling systems optimizes efficiency, reduces resource consumption, and upholds product quality standards. The vacuum-cooling procedure can reduce the harm caused by the heating process to honey quality and bodily characteristics. The values for total dissolved solids, viscosity, and density were also consistent with those reported in the literature. The values for water content, diastase enzymes, reducing sugars, and acidity of honey were in accordance with those of the Indonesian National Standard (SNI) honey. Vacuum cooling produces honey of a higher grade and physical consistency than traditional cooling methods. However, further research is required to validate and optimize the proposed methodology to ensure its scalability, cost-effectiveness, and practical feasibility in real-world applications.

Key words: Diastase enzyme, Honey, Reducing Sugar, Vacuum Cooling, Viscosity

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INTRODUCTION

Honey, a natural sweetener derived from flower nectar, contains a diverse array of nutrients that are essential for human health. According to recent research, honey is not merely a simple syrup, but a complex blend of minerals and compounds that are crucial for human well-being. For instance, studies conducted by Alvarez-Suarez *et al.* [1] revealed that honey contains significant amounts of sodium, calcium, magnesium, aluminum, iron, phosphorus and potassium among other elements. However, the benefits of honey extend beyond its nutritional value. Recent findings by Samarghandian *et al*. [2] suggest that honey exhibits antioxidant, antimicrobial and anti-inflammatory properties, making it a valuable supplement for a healthy diet. However, it is essential to note that the moisture content of honey plays a crucial role in its quality and longevity. Honey with moisture levels exceeding 22% is prone to spoilage when stored for extended periods of time, as highlighted by Lee *et al*. [3]. Thus, while honey offers numerous health benefits, proper storage and handling are essential to maintain its quality and integrity.

In accordance with the SNI (Indonesian National Standard) guidelines for honey quality, many packaged honey production companies in Indonesia have adjusted their processes to ensure that the water content of honey remains below 22% as a means of preservation [4]. This is crucial because honey is highly sensitive to heat and exposure to high temperatures can rapidly degrade its mineral composition. Research conducted by Ardha *et al.* [5] emphasized the importance of avoiding excessive heat during honey processing, as temperatures exceeding 70°C can lead to the degradation of bioactive components, consequently lowering the overall quality of honey. Furthermore, heating honey beyond 70°C not only compromises its nutritional integrity, but also alters its flavor, color and texture, as highlighted by a study conducted by Utama *et al.* [6].

The detrimental effects of heat on honey are primarily attributed to denaturation of the enzymes present in honey, a phenomenon extensively studied by Novitasari *et al.* [7]. Moreover, high-temperature processing can lead to a reduction in bioactive elements and antioxidants, further diminishing the nutritional value and quality of honey products [8]. Despite the risks associated with excessive heating, it is worth noting that controlled heating is necessary to extend the shelf life of honey products. The postharvest handling of honey is a complex process, particularly when conducted on an industrial scale. This process typically involves several steps, including honey extraction from beehives, filtration to remove impurities, and heating using methods such as pasteurization and evaporation to ensure microbial safety and stability [9]. However, it is crucial to strike a balance between preserving the quality of honey and ensuring its safety by heating. In summary, although heat treatment is necessary for honey preservation, it should be carefully controlled to

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avoid compromising the nutritional integrity and quality of the final product. Adherence to proper handling and processing techniques, as outlined in industry guidelines and supported by recent research findings, is essential for maintaining the overall quality and safety of honey.

Vacuum cooling, which is a rapid cooling technique based on the principle of evaporation, has gained prominence in the food industry in recent years. This method involves lowering the boiling point of water by creating a vacuum within the cooling chamber. Because of this reduced-pressure environment, food items can be efficiently cooled using vacuum coolers. This process relies on the principle that under vacuum pressure (1 atm) within the cooling chamber, the latent heat of food evaporates, thereby supplying energy for the cooling process.

Recent studies have shed light on the effectiveness and applicability of vacuum cooling to various food products. Jiang *et al.* [10] explored the application of vacuum cooling to rapidly cool fresh produce, highlighting its potential to preserve quality and extend the shelf life of fruits and vegetables. Similarly, Wang *et al.* [11] investigated the use of vacuum cooling for seafood products, emphasizing its role in maintaining the freshness and enhancing the safety of seafood during postharvest handling. Moreover, vacuum cooling offers advantages over rapid cooling. A study conducted by Li *et al.* [12] examined the effect of vacuum cooling on microbial safety, revealing its efficacy in reducing microbial growth and prolonging the shelf life of perishable food items. Additionally, Chen *et al.* [13] highlighted the energy-saving potential of vacuum cooling compared with traditional cooling methods, making it an environmentally friendly option for the food processing industry. Furthermore, vacuum cooling technology continues to evolve, with recent advancements focusing on optimizing process parameters and enhancing cooling efficiency. Zhang *et al.* [14] and Xu *et al.* [15] explored novel approaches to improve the performance and reliability of vacuum cooling systems, paving the way for broader adoption and implementation in the food industry. In summary, vacuum cooling represents a promising solution for rapid and efficient cooling of various food products, offering benefits such as improved quality, extended shelf life, and energy efficiency. Continued research and innovation in this field are essential for maximizing the potential of vacuum-cooling technology and addressing the evolving needs of the food processing industry.

Vacuum refrigeration has emerged as a promising method for cooling honey, as demonstrated in studies conducted by Emerald [16] and Aulia *et al.* [17]. Their findings indicated that vacuum cooling facilitates the production of high-quality honey by effectively preserving its nutritional and sensory attributes. In their investigation, the utilization of vacuum refrigeration mitigated the detrimental effects of heat on honey quality, resulting in superior products. An innovative approach to vacuum cooling, as highlighted by Aulia *et al.* [18], involves the integration of a water jet device into the cooling system. This setup, developed with water jets positioned on both sides, optimizes the cooling process, thereby saving time and minimizing the adverse impact of residual heat on honey quality. Similarly, Emerald [19] underscored the effectiveness of vacuum refrigeration in rapidly and efficiently cooling honey, ensuring the retention of its intrinsic characteristics and nutritional value. Furthermore, recent advancements in vacuum refrigeration technology have focused on enhancing cooling efficiency and minimizing processing time. Rahman *et al*. [20] and Gupta *et al.* [21] explored novel strategies for optimizing vacuum cooling parameters and system design to achieve maximum performance and quality preservation. These efforts have contributed to the continual improvement and refinement of vacuum refrigeration techniques for hourly cooling applications. Moreover, the benefits of vacuum refrigeration extend beyond quality preservation including energy efficiency and environmental sustainability. Chen *et al*. [22] investigated the energy-saving potential of vacuum cooling systems and highlighted their role in reducing energy consumption and greenhouse gas emissions in honey processing operations. In summary, vacuum refrigeration is a valuable technology for cooling honey while maintaining its quality and nutritional integrity. Through ongoing research and innovation, the capabilities of vacuum-cooling systems can be further enhanced, offering sustainable solutions for the honey industry.

A study conducted by Sun *et al.* [23] compared the vacuum cooling speed of a water jet system with conventional cooling methods, shedding light on the effect of cooling techniques on the quality and physical properties of honey. This study highlights significant advancements in the vacuum cooling speed achieved through the implementation of a water jet system. By analyzing changes in the quality of substances and the physical characteristics of honey, this study provides valuable insights into the efficacy of water jet vacuum cooling compared to conventional cooling methods. One notable finding of this study is the superior cooling rate achieved by the water-jet vacuum cooling system, which results in faster and more efficient cooling of honey. This accelerated cooling process not only minimizes the processing time, but also plays a crucial role in preserving the sensory and nutritional attributes of honey. Furthermore, this study evaluated the lowest maximum pressure attained during the water jet vacuum cooling process, offering valuable data on the operational efficiency and safety of the system. In addition to speed and pressure considerations, this study examined the quality changes observed in honey subjected to water-jet vacuum cooling versus conventional cooling methods. By comparing key quality parameters such as moisture content, enzymatic activity, and color retention, this study provides comprehensive insights into the impact of cooling techniques on honey quality. Overall, the findings of this study underscore the potential of water jet vacuum cooling as a superior alternative to conventional cooling

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methods for honey processing. Owing to its ability to achieve higher cooling speeds, maintain quality parameters, and optimize operational efficiency, the water-jet vacuum cooling system has emerged as a promising technology for enhancing the efficiency and quality of honey production.

This study on the vacuum cooling of honey showed significant differences compared to other vacuum cooling studies in terms of focus, methodology, tested variables, objectives, and technological applications. The main focus of this study was the effect of vacuum cooling on honey quality, including water content, viscosity, and shelf-life parameters, with the aim of maintaining the physical and chemical quality of honey. The methodology used involved temperature, pressure and time settings to test the effects of these variables on honey characteristics. Meanwhile, other studies tend to be broader, covering various food products with various variables and objectives, such as rapid temperature reduction to extend shelf life or inhibit the growth of microorganisms. This study also offers specific applications to honey, providing practical contributions to farmers and the honey industry in improving product quality and stability, which have rarely been the main focus of previous vacuum cooling studies.

MATERIALS AND METHODS

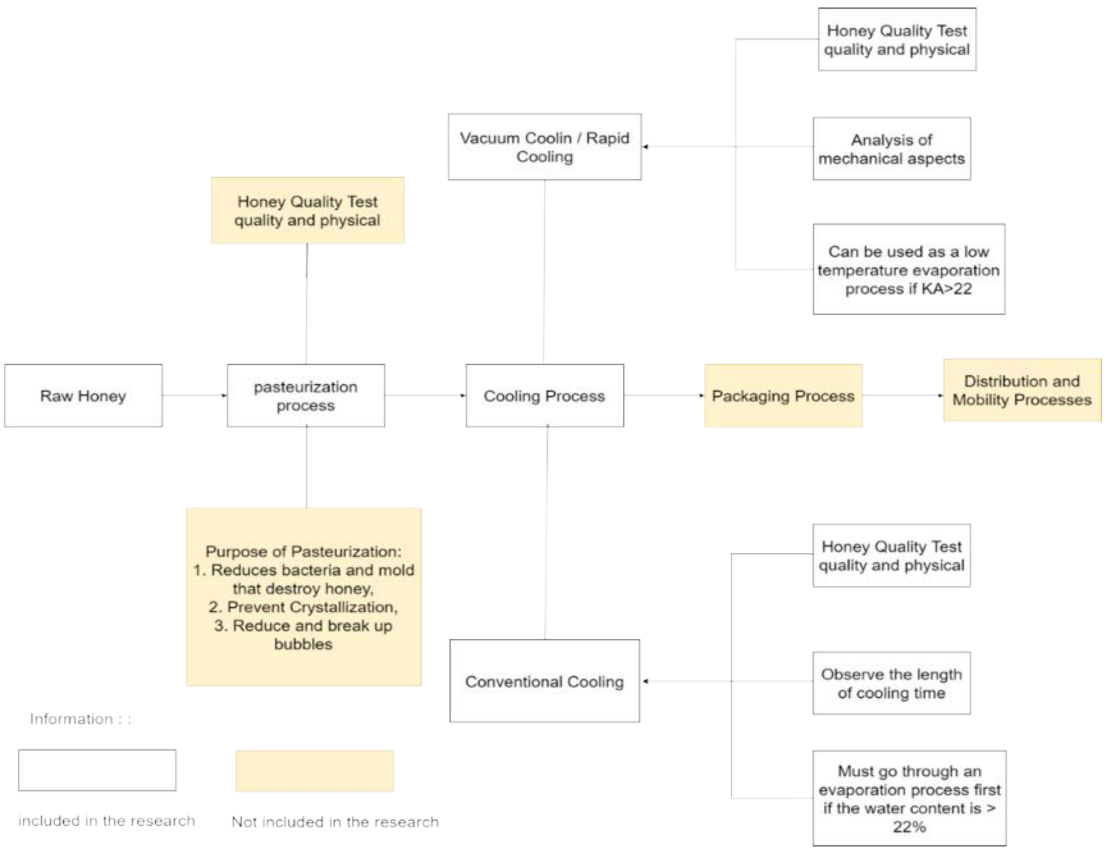

Figure 1: A flowchart for honey study on rapid cooling

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Preparation of Materials

The honey used in this study was acacia honey. The tests were conducted using three volumes of honey (12.5%, 20% and 50% v/v). The honey was pasteurized using an Ohmic heating device (Suspeed brand, model SPD-01) in the temperature range of 35–63°C. After pasteurization, honey was cooled using two methods: vacuum cooling (VC) and conventional (K). The material releases heat into the environment, which has a vacuum pressure (1 atm) to cool the material. Latent heat was acquired from this heat transfer. A water pump was used as the vacuum jet propulsion device in a water jet system vacuum cooling device to lower the pressure in the cooling tube area. To achieve equilibrium between the temperature of water and that in the cooling tube chamber, the water medium must have a temperature lower than 8°C. The results were analyzed using Analysis of Variance (ANOVA) and Statistical Package for the Social Sciences (SPSS).

Analysis of mechanical aspects

A GL-200a MIDI data logger was used to record the temperature changes for each treatment, as it was noted how quickly the vacuum cooler and conventional cooler (control) cooled. Because the rate of temperature decline in conventional coolers is very slow, the temperature changes in vacuum coolers are measured every 500 MS, whereas they are measured every 60 s. The cooling rate of each sample was determined using Equation 1.

$$LP = Ln\frac{T\theta - T\infty}{To - T\infty} \ldots\ldots (1)$$

Where:

LP: Cooling Rate (°K /sec)

TѲ: Instantaneous temperature (^{o}C)

T∞ : Equilibrium temperature (^{o}C)

To: Initial temperature (^{o}C)

The computational results were derived using Equation (1) and a graph was created.

Honey Quality Test

Viscosity

The viscosity measurements were performed as by Wibowo *et al.* [24]. Viscosity was measured using an NDJ-1S viscometer to determine the thickness of honey. Spindle number 2 was selected at a speed of 60 rpm because the honey poise value fell within this range.

Mass Density

The measurements were performed as by Liu *et al.* [25], using the volumetric method.

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Total Dissolved Solid

The measurement of total dissolved solids refers to the U.S. Patent applications [26]. The total dissolved solids were measured with a Brix refractometer with a scale of 60–92% to determine the difference in the total dissolved solids before and after the vacuum cooling or conventional cooling process.

Diastase Enzyme

The diastase enzyme activity test was conducted by calculating the DN (diastase number) based on SNI 001-3553-2003. The principle of the diastase enzyme activity test is to measure the absorbance of a mixture of honey and starch solution, which is periodically heated to 40 °C at 5-minute intervals and reacted with iodine reagent. Absorbance data were processed using a linear regression equation to determine the time required to reach an absorbance of 0.235.

Reducing Sugar

The reducing sugar test is generally conducted using 2,3-dinitrosalicylic acid (DNS) and Nelson-Somogyi (NS) reagents to determine the activities of polysaccharide-degrading enzymes. The test refers to SNI 01-3545-2004.

Honey acidity

The test uses the titration method, referring to SNI 01-3545-2004.

RESULTS AND DISCUSSION

The cooling rates and the lowest maximum vacuum pressure change rate that a vacuum pump can achieve while cooling each procedure are shown in Figure 2. From this comparison, it can be seen that filling 12.5% V/V (12.5 mililiters of solute / 100 militers of solution) with a processing time of 104 s is the quickest way for the pump to achieve the lowest maximum pressure during the cooling process from 63 °C to 35°C. The times required for the pump to achieve the lowest maximum pressure during the cooling process from 63 to 35°C when using vacuum cooling with a filling of 25% V/V and 50% V/V were 190 and 410 s, respectively.

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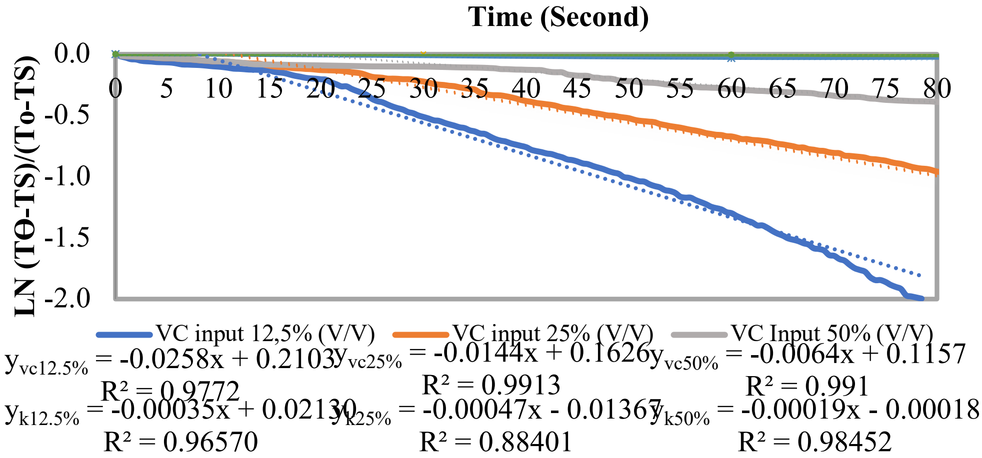


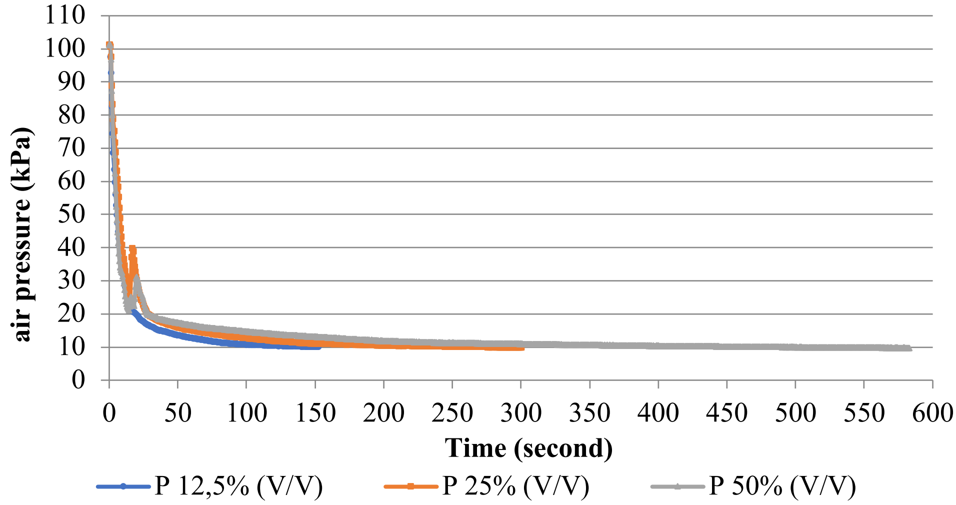
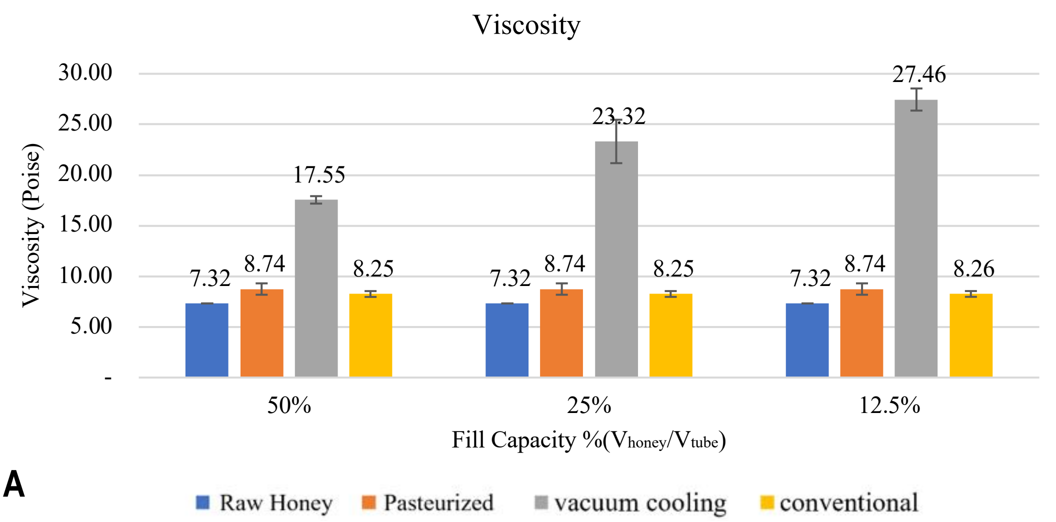


Figure 2: Temperature shifts during Vacuum Cooling (VC) and conventional (K) Chilling and Comparison of Pressure Rate (P) against Volume Time 12.5%, 25%, 50%

The physical qualities of acacia honey, such as water content, viscosity and density, as well as the quality of honey, such as diastase enzyme activity, reducing sugar, total dissolved solids, and pH, were measured based on the findings of using the water jet system during the honey cooling process. The value of the constant (K) equation can be used to estimate the cooling rate magnitude, as shown in Figure 2. The cooling rate of each tested sample was kept constant. Lastriyanto [27] used a constant-value solution to calculate the evaporation rate of pineapple. In addition, during the cooling process, the temperature of the final material was influenced by the lowest maximum pressure. Based on preliminary research, the capacity of the water-jet vacuum pump to vacuum the cooling tube, which displays a change in pressure with respect to the cooling process time toward the lowest maximum pressure point for each treatment, as shown in Figure 2, was increased by applying the chosen cold temperature of 8 °C in a water bath. Air was drawn through a vacuum pump and circulated in a cooling water bath where the cold temperature in the water bath had a cooling impact. The highest energy efficiency and vacuum cooling COP values were attained at the lowest possible maximum pressure for the honey-cooling procedure [28].



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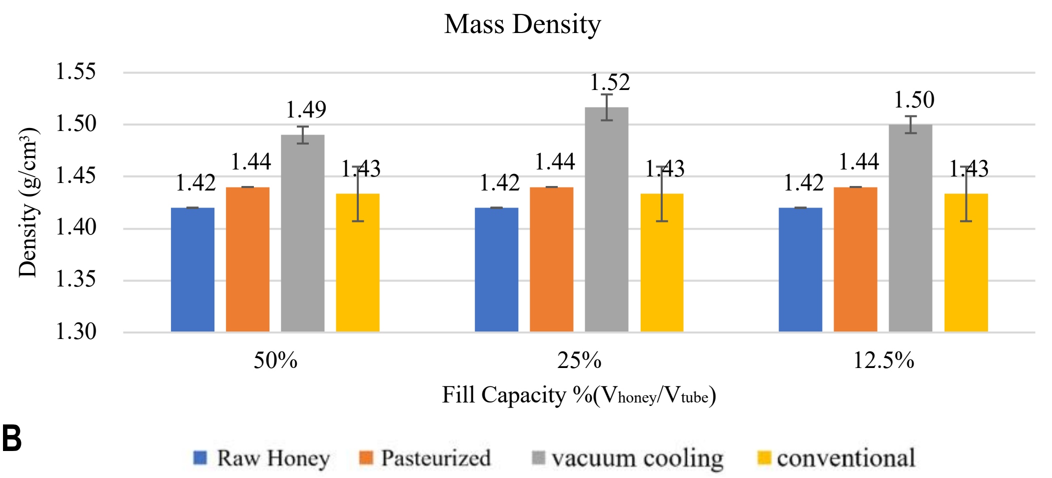

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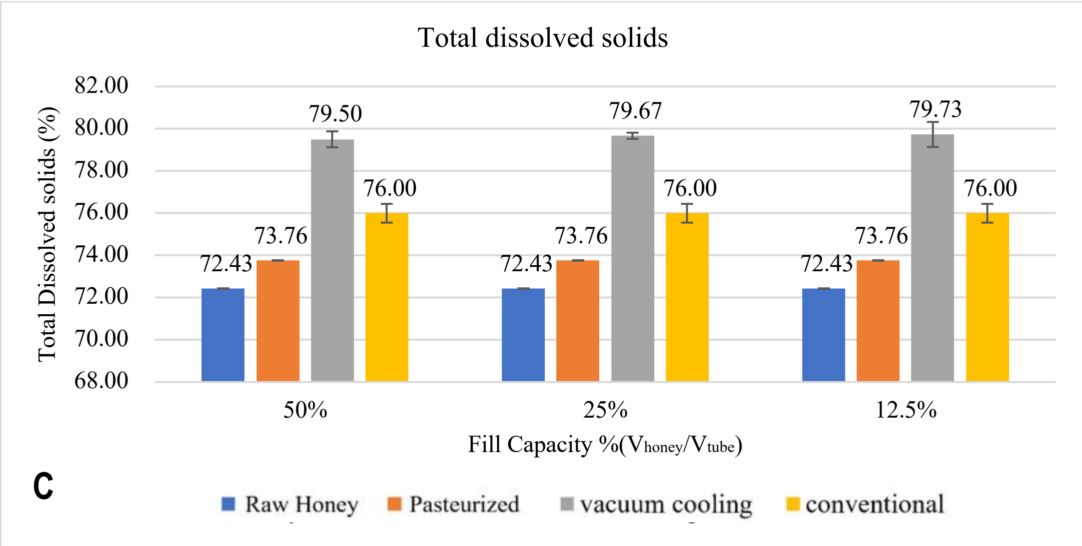

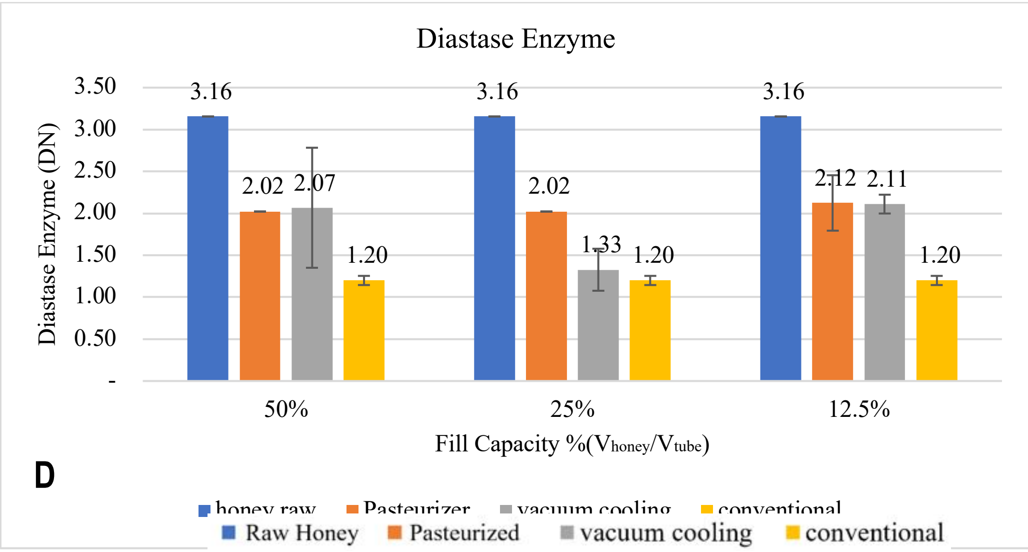

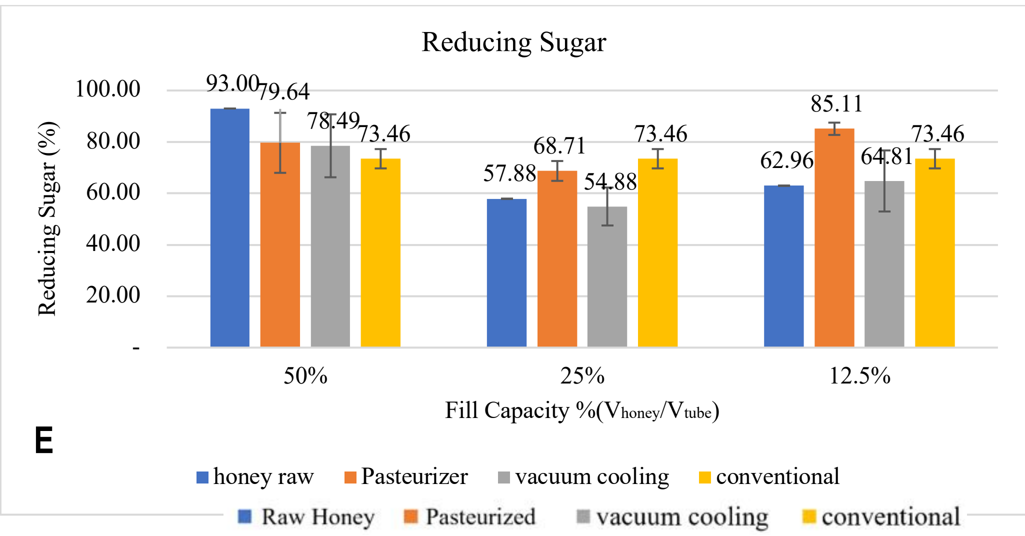

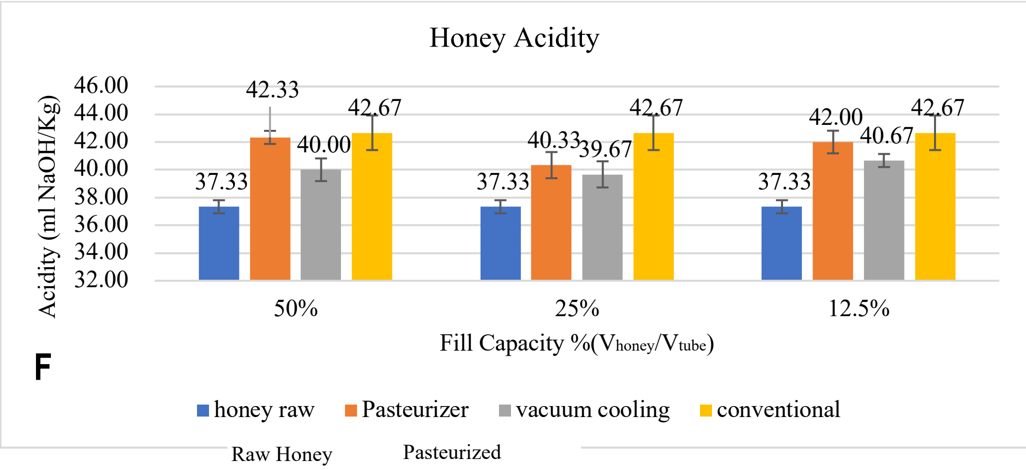

Figure 3: Variations in characteristics of honey by different processing methods

Viscosity

Figure 3a presents the data regarding the impact of different treatment processes on the viscosity of honey. Following pasteurization, there was a noticeable increase in viscosity compared to that of the unprocessed honey. This decrease in viscosity from 7.32 to 8.74 Poise indicates alterations in the physical properties of honey owing to thermal treatment. Furthermore, the effect of vacuum cooling on the viscosity of honey at vacuum concentrations (12.5% (V/V), 25% (V/V), and 50% (V/V)) was evaluated. The results reveal that vacuum cooling leads to a further increase in viscosity, with values of 27.46, 23.32 and 17.55 Poise observed for the respective concentrations. These findings are consistent with previous research, indicating that thermal processing and cooling techniques can influence the viscosity of honey [29].

Moreover, the statistical significance ($p<0.05$) of the observed differences in honey viscosity highlights the robustness of the experimental findings and reinforces the importance of considering treatment methods in honey processing to maintain desired product characteristics. Overall, the data presented in Figure 3 offers insights into the rheological behavior of honey under various processing conditions, providing strategies for optimizing honey quality and production efficiency.

Density

Figure 3b presents the data regarding the impact of various treatment processes, including pasteurization, conventional cooling, and vacuum cooling, on honey density. Following pasteurization, there was a slight decrease in honey density, indicating alterations in its physical properties due to the thermal treatment. Conversely, the honey density increased significantly after vacuum cooling, with varying degrees observed across different concentrations (12.5% (v/v), 25% (v/v),

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and 50% (v/v)). These results suggest that vacuum cooling may induce densification of honey, potentially due to the removal of air bubbles and homogenization of the product. The significant differences in honey density observed across treatment processes underscore the importance of considering cooling methods in honey processing to achieve desired product characteristics.

Furthermore, the statistical significance (P <0.05) of the observed differences in honey density reinforces the robustness of the experimental findings and underscores the importance of optimizing processing parameters to maintain honey quality. These findings are consistent with previous research indicating the influence of processing techniques on honey density and physical properties [30,31,32].

Total Dissolved Solids (TDS)

Figure 3c shows the impact of different treatment processes on the concentration of dissolved solids in the honey. Using a Brix refractometer, the TDS percentage (%) was calculated under various treatment conditions, including pasteurization, vacuum cooling, and conventional cooling, during the filling procedure at different concentrations (12.5%, 25% and 50% v/v). Following pasteurization, the filling procedure resulted in a TDS percentage of 12.5% V/V, whereas at 25% and 50% V/V, the TDS values ranged from 72.43% to 73.76%. Notably, the TDS values observed during vacuum cooling were slightly higher, with percentages of 79.73, 79.67 and 79.50% recorded at 12.5, 25 and 50% V/V concentrations, respectively. In comparison, conventional cooling yielded a TDS value of 76.00%.

The significant differences ($p<0.05$) in TDS observed among the various treatment processes underscored the influence of the processing techniques on the concentration of dissolved solids in honey. These findings align with previous research indicating that thermal treatment and cooling methods can affect the chemical composition and concentration of solutes in honey [33,34]. Furthermore, the observed variations in TDS values highlight the importance of optimizing the processing parameters to achieve the desired product characteristics and consistency [35]. The ability to control TDS levels through processing methods may not seem significant, but can directly affect the quality, flavor, and storage stability of honey [36,37]. In summary, the data presented in this study offers valuable insights into the effects of different treatment processes on the TDS of honey. Understanding these effects is crucial for optimizing honey-processing techniques to ensure product quality and consistency.

Enzyme Diastase

Figure 3d highlights the changes in diastase activity, an essential enzyme in honey, as a result of pasteurization and various cooling treatments. Before treatment, raw honey exhibited a diastase enzyme value of 3.156 DN. Following pasteurization,

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there was a noticeable decrease in diastase activity, with values ranging from 2.12 DN to 3.16 DN observed during the filling procedure at different concentrations (12.5% V/V, 25% V/V, and 50% V/V). Similarly, vacuum-cooling treatments also led to reductions in diastase enzyme activity, with values of 2.11 DN, 1.32 DN, and 2.06 DN recorded at the respective concentrations. The differences were statistically significant ($P < 0.05$).

The observed variations in diastase enzyme activity among the different treatment processes underscore the significant impact of thermal processing and cooling techniques on enzyme stability and activity in honey [37,38]. These findings align with previous research indicating that heat treatment can affect the enzymatic profile of honey, potentially influencing its nutritional and functional properties [39, 40, 41].

Reducing Sugar

Figure 3e shows the diverse effects of different treatment methods on the reducing sugar content of honey. Before treatment, the reducing sugar content of the raw honey ranged from 62.96% to 93.00%. However, after pasteurization, there was a significant increase in the reducing sugar content, with values ranging from 57.88% to 85.11% observed during the filling procedure at different concentrations (12.5%, 25% and 50% V/V). Similarly, vacuum-cooling treatments also resulted in fluctuations in the reducing sugar content, with values of 64.81%, 54.88% and 78.46% recorded at the respective concentrations. Comparatively, conventional cooling methods yielded a reducing sugar content of 73.46%, indicating a moderate effect on sugar content compared with other treatments. These findings suggest that thermal processing, including both pasteurization and vacuum cooling, may lead to changes in the carbohydrate composition of honey, potentially influencing its nutritional profile and sensory characteristics. The observed variations in the reducing sugar content among the different treatment processes underscore the importance of optimizing the processing parameters to achieve the desired product characteristics and consistency [42,43]. These findings align with previous research indicating that heat treatment and cooling methods can affect the carbohydrate composition and overall honey quality [44,45,46]. Furthermore, the statistical significance ($p<0.05$) of the observed differences in reducing sugar content reinforces the robustness of the experimental findings and underscores the importance of understanding the impact of processing techniques on honey composition.

Acidity

Figure 3f shows notable fluctuations in honey acidity, highlighting the impact of processing methods on this key parameter. Initially, the raw honey exhibited an acidity value of 37.33 ml NaOH/kg. Following pasteurization, there was a discernible increase in acidity, with values ranging from 40.33 ml NaOH/kg to 42.33 ml NaOH/kg observed at different concentrations (12.5% V/V, 25% V/V, and 50% V/V). In contrast, vacuum cooling treatments resulted in a slight decrease in acidity, with values of 39.66 ml NaOH/kg, 40 ml NaOH/kg, and 40.67 ml NaOH/kg recorded at the respective concentrations. The differences were statistically significant ($P < 0.05$).

Comparatively, conventional cooling methods yielded an acidity value of 42.67 ml NaOH/kg, indicating a slightly higher acidity compared to the other treatments. Notably, all the treatment processes produced acidity levels within the acceptable range specified by the SNI 2018 standard, which does not exceed 50 ml of acidity in honey. These findings align with those of previous studies, indicating that thermal processing and cooling techniques can influence the acidity of honey [47,48, 49].

According to a study by Istianah [50], the evaporation process can increase the total dissolved solid content, which supports an increase in the total dissolved solid content during the vacuum-cooling process. Consumers prefer honey with a high total dissolved solids (TDS) value owing to its unique sweet flavor [51]. The sweetness of a liquid or food product is inversely correlated with the total amount of dissolved solids [52]. According to Suhaela *et al.* [53], the heating temperature affects the sucrose content of honey, which changes the value of reducing sugars. The higher the heat treatment, the lower the reducing sugar content. Water volume, harvest time and humidity affect the amount of sugar reduced in honey. The grade of honey is also influenced by the pH, in addition to the value of reducing sugars. Because honey has a low pH, harmful microorganisms are unable to grow.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The vacuum-cooling procedure can reduce the harm caused by the heating process to honey quality and bodily characteristics. The values for total dissolved solids, viscosity, and density were also consistent with those reported in the literature. The values for water content, diastase enzymes, reducing sugars, and acidity of honey were in accordance with those of the SNI honey. Vacuum cooling produces honey of a higher grade and physical consistency than traditional cooling methods.

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