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Experimental Investigation of Increasing the Liquefaction Velocity of Crystallized Flower Honey

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Abstract

After the honey is harvested from the bee colony, it is removed from the honeycomb with mechanization and stored as a liquid in cans or barrels. Honey crystallizes depending on the chemical structure, type of its, and impurity or ambient temperature. In Turkey, liquid (wax) honey is generally not consumed as crystallized. For this reason, honey is liquefied and packaged again. When the honey crystallizes, which is stored in tin cans, an air oven or hot water pool is usually used as a liquefaction medium. The liquefaction time of honey depends on the type of its, melting medium, the ambient temperature, and the geometry of the honey container. As the ambient temperature and melting time increase, both chemical and color-taste changes occur in honey. In this experimental study, crystallized honey stored in tin cans (18 dm^3) was liquefied in an air-type oven at 50^oC using two different methods (conventional and mechanical vibratory). During liquefaction, time-dependent temperature changes were determined in honey's x and y axes. Moisture, diastase, proline, and HMF (Hidroksimetilfurfural) changes in the heat-treated honey were measured. As a result of the obtained data, it was determined that the mechanical vibration liquefaction time was 35% shorter than the conventional liquefaction time. At the end of the heat treatment with both methods, the change of chemical values in honey was found to be in accordance with the Turkish Food Code.

Keywords: flower honey, crystallization, liquefaction methods, characteristics of honey, mechanical vibration

Kristallenmiş Çiçek Balının Sıvılaşma Hızının Artırılmasının Deneysel İncelenmesi

Öz

Ballar arı kolonisinden hasat edildikten sonra mekanizasyonla bal peteğinden çıkarılarak kutu veya fıçılarda sıvı olarak depolanmaktadır. Balın kimyasal yapısı, türü ve içerdiği yabancı maddeler veya ortam sıcaklığına bağlı olarak bal kristalize olmaktadır. Türkiye'de genel olarak sıvı (wax) bal kristalize olarak tüketilmemektedir. Bu nedenle bal tekrar sıvılaştırılarak paketlenmektedir. Dikdörtgen prizma kutularda depolanan bal kristalleşdiğinde sıvılaştırma ortamı olarak genellikle havalı fırın veya sıcak su havuzu kullanılmaktadır. Balın sıvılaşma süresi balın tipine, sıvılaşma ortamına, ortam sıcaklığına ve bal kabının geometrisine bağlıdır. Ortam sıcaklığı ve sıvılaşma süresi arttıkça balda hem kimyasal hem de renk ve tat değişimleri olmaktadır. Bu deneysel çalışmada, dikdörtgen prizma kutularda (18 dm3) depolanan kristarilize bal 50 ^oC'deki havalı tip fırında sıvılaştırılması iki farklı yöntem (geleneksel ve mekanik titreştirici) ile gerçekleştirildi. Sıvılaşma sırasında balın x ve y eksenlerinde zamana bağlı sıcaklık değişimi belirlenmiştir. Isıl işlem görmüş balın içeriğindeki nem, diastaz, prolin ve HMF (Hidroksimetilfurfural) değişimleri ölçülmüştür. Elde edilen veriler sonucunda mekanik titreşimli sıvılaştırma süresi geleneksel sıvılaştırma süresine göre %35 daha kısa olduğu tespit edilmiştir. Her iki yöntem ile yapılan ısıl işlem sonunda baldaki kimyasal değerlerin değişimi Türk Gıda Kodeksine uygun olduğu görülmüştür.

Anahtar Kelimeler: çiçek balı, kristalizasyon, sıvılaştırma metotları, balın özellikleri, mekanik titreşim

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Introduction

Flower honey is a sweet and thick liquid of different colors produced from the nectars contained in the essence of flowers by bees. Honey bees convert into honey by combining with their own enzymes nectars collect of their. The moisture, color and other components of honey depend on the type of flowers, the altitude of the region and climatic conditions. Generally honey contains 10-20% water, 70-80% sugar, vitamins, minerals, proteins and amino acids (Ouchemoukh et al., 2007). While the initial humidity of the nectar that the bees take from the flower and put into the comb is 25-45%, this humidity in the hive is reduced to 16-23% by the bees depending on the climatic conditions of the region and the bee genus.

The event that the sugary substance in honey becomes saturated in terms of dextrose ratio and the dextrose molecules become crystalline is considered crystallization. The liquid honey harvested from the honeycomb turns into a cream-like structure over time and then becomes a solid crystal with the growth and condensation of the crystals. The balance between the two main sugar groups, fructose, and glucose, in combination with honey, causes honey to crystallize quickly or slowly. Other factors affecting crystallization are water content and storage temperature. In general, temperatures of 10°C and below reduce the viscosity of honey, delaying the formation and spreading of crystals. However, the crystallization of honey accelerates if the temperature values fluctuate between 10-20°C. Another factor affecting crystallization is foreign particles in honey. The presence of unwanted substances such as pollen, seed particles, and wax crumbs in honey accelerates crystallization (Yao et al., 2003).

Heating and pasteurization in honey are generally used to prevent the crystal structure of honey to become liquid and to prevent crystallization that will occur over time. The heating process stops the fermentation as a result of killing the micro-organisms in honey, reduces the amount of water it contains, increases its fluidity, and also provides ease of marketing. In general, the heating process is done with a double benmary and air-type ovens, but microwave and infrared radiation and ultrasonic bath methods have also been tried (Hebbar et al., 2003; Sandhu, 1986; Thrasyvoulou, 1994). Bogdanov et al. (2014) stated that the heat transfer bain-marie water pool is the most suitable method. However, due to some inconveniences caused by this method, air-type heaters have started to be used more widely. In addition, microwave and infrared radiation applications for the liquefaction of honey were made by Hebbar et al. (2003), and they stated that the liquefaction time could be shorter than traditional methods. Kabbani et al. (2011) heated it at different temperatures and times at 40 kHz using an ultrasonic bath and showed that the crystal structure of honey deteriorates rapidly in experiments performed at temperatures below 50 °C.

When the heating process applied to honey is not applied correctly and in a controlled manner, the nutritional and quality value of honey (Diastas, invertase, HMF) is lost. If honey is heated at a high temperature or for a very long time, the taste and aroma of honey change, and its color becomes darker. With the loss of the diastase enzyme, fructose is broken down and an increase in the amount of hydroxymethyl furfurol (HMF) occurs. For this reason, the way to be followed by heating honey should be to destroy the microorganisms that will cause fermentation and keep it at the lowest temperature to prevent crystallization and for as little time as possible (Güney, 2010).

Heating affects the color, taste, and texture of honey. Therefore, alternative methods such as filtration, additives, pasteurization, and preheating prevent crystallization in honey. Crystallized honey is generally not consumed in this form. Crystallization must be removed in order to both supply and package honey to the consumer. Before packaging, honey is heated to a maximum temperature of 50 °C, and its crystallization is removed (Güney, 2010).

The time-dependent liquefaction curve of crystallized honey and the total liquefaction time depend on the heating methods, the selected temperature, the type of honey, the storage geometry, and the amount of honey. In conventional heaters (oven, benmary), while the temperature of the heating medium is by natural convection, conduction from the outer surface of the container to the inner surface of the honey and from the inner surface of the honey to the honey by only conduction at the beginning of the heating, natural convection becomes dominant in the liquefaction of honey later on.

The liquefied honey, which is heated and lightened during natural convection, completes its cycle upwards along the heated wall along the solid-liquid (crystallized honey) interface. This flow licks the solid-liquid interface and heat transfer to the solid surface occurs. Following the heat transfer, the liquefied honey flows down the solid-liquid interface. The convection effect of melting honey causes liquefaction in the upper layer of honey to be faster. Thus, while liquefaction continues, the melting shape is curved (Pal & Joshi, 2001). However, towards the end of the liquefied process, as the flow rate of honey will decrease in the middle of the tank, the natural convection effect on the solid surface will decrease and the total liquefaction time will increase due to a small amount of honey (De Lucia & Bejan, 1990). As it is known, prolongation of the liquefaction time will cause undesirable changes in honey. The schematic view of the heat transfer to the honey in the oven and the liquefaction of honey is given in Figure 1.

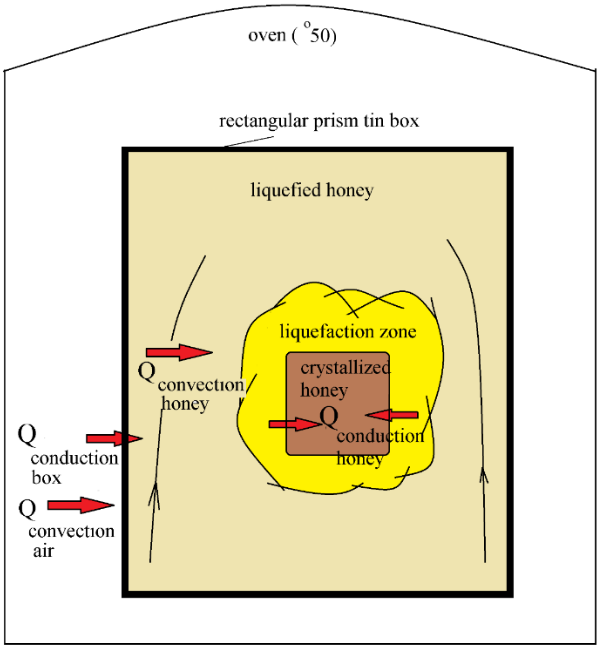

Figure 1. Schematic View of Liquefaction of Honey in the Container

In this experimental study, it was aimed to shorten the liquefaction time of crystallized honey stored in the tin can (18 dm^3) and thus eliminate the deterioration in food values caused by the long liquefaction time of conventional air-type liquefiers. For this purpose, a machine has been designed and manufactured that transforms the natural convection mechanism that occurs in conventional liquefaction processes into forced convection. It has been oscillate made to honey in the tin can at a certain frequency and amplitude during the liquefaction by this machine. The liquefaction of honey by traditional methods has been studied in the literature. With this study, the effects of forced convection on the liquefaction geometry, liquefaction time and food properties of honey have been revealed and an important contribution has been made to the literature.

Material and Method

The flower honey used this experimental study was harvested from Çorum/Mecitözü region. The honey was stored as 24 kg in the two tin cans at dimensions of 236x236x350 mm. The honey nectar of the region consists of highland flowers and sunflowers.

It has been manufactured by designing a mechanical vibrator that can transmit the outdoor temperature more quickly and homogeneously to the center of the honey by converting the natural convection mechanism of the honey to forced convection in order to ensure that the inner heat of the oven is transmitted to the center of the honey.

The experimental setup in which the honey is vibrated is given in Figure 2. The tin placed in the chamber is vibrated mechanically by means of eccentric parts connected to the shaft, which take the rotational power from the electric motor. The speed of the electric motor has been reduced by gear systems and the gear on the shaft that allows vibration movement rotates at 60 rpm and the vibration amplitude is 70 mm.

The amplitude was determined as 70 mm so that the maximum mobility of the liquefied honey does not exceed the distance between the thermocouples.

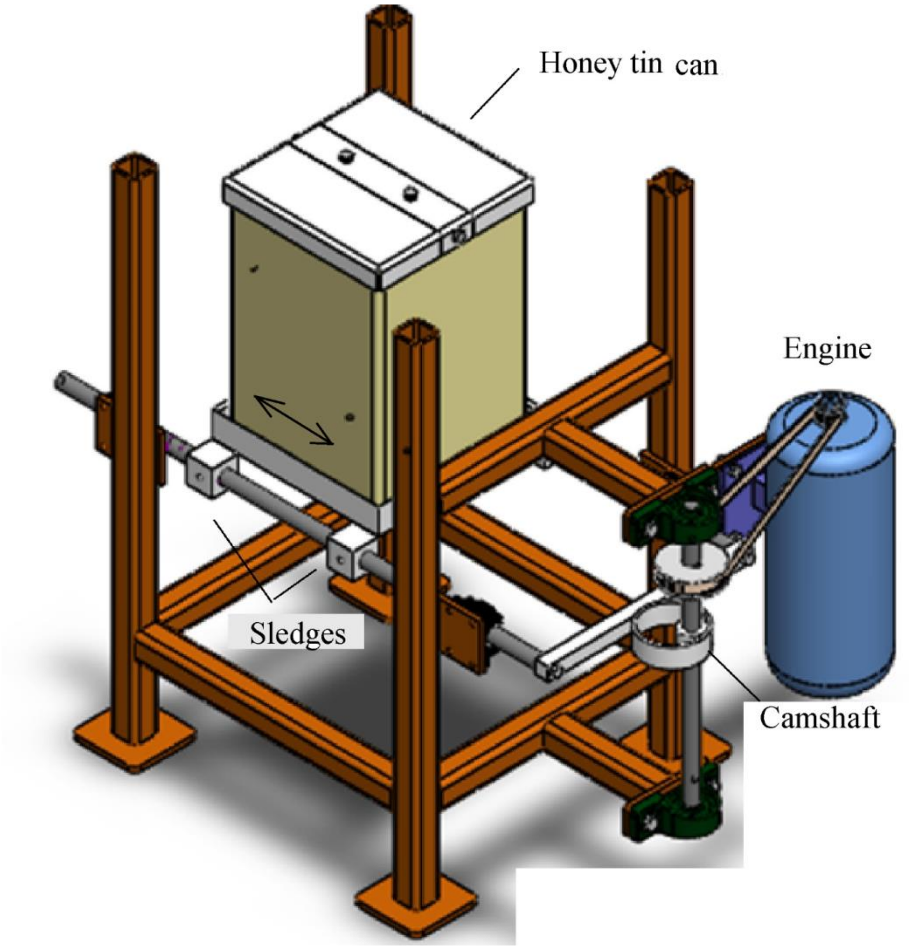

Figure 2. The Experimental Setup of Mechanical Melting (with Vibrator)

Temperature-measuring elements are placed inside the tin can with 20 T-type thermoelements on the x-axis (horizontal) and y-axis (vertical) in a way that does not disturb the heat convection as given in Figure 3.

Thermocouples were placed into the tin can in the form of ladder steps so as not to interfere with natural transport during liquefaction and not to create flow resistances. The movable legs which the thermocouples are attached are made of thin dry wood in order not to conduct heat conduction in the honey and to prevent errors in temperature measurements.

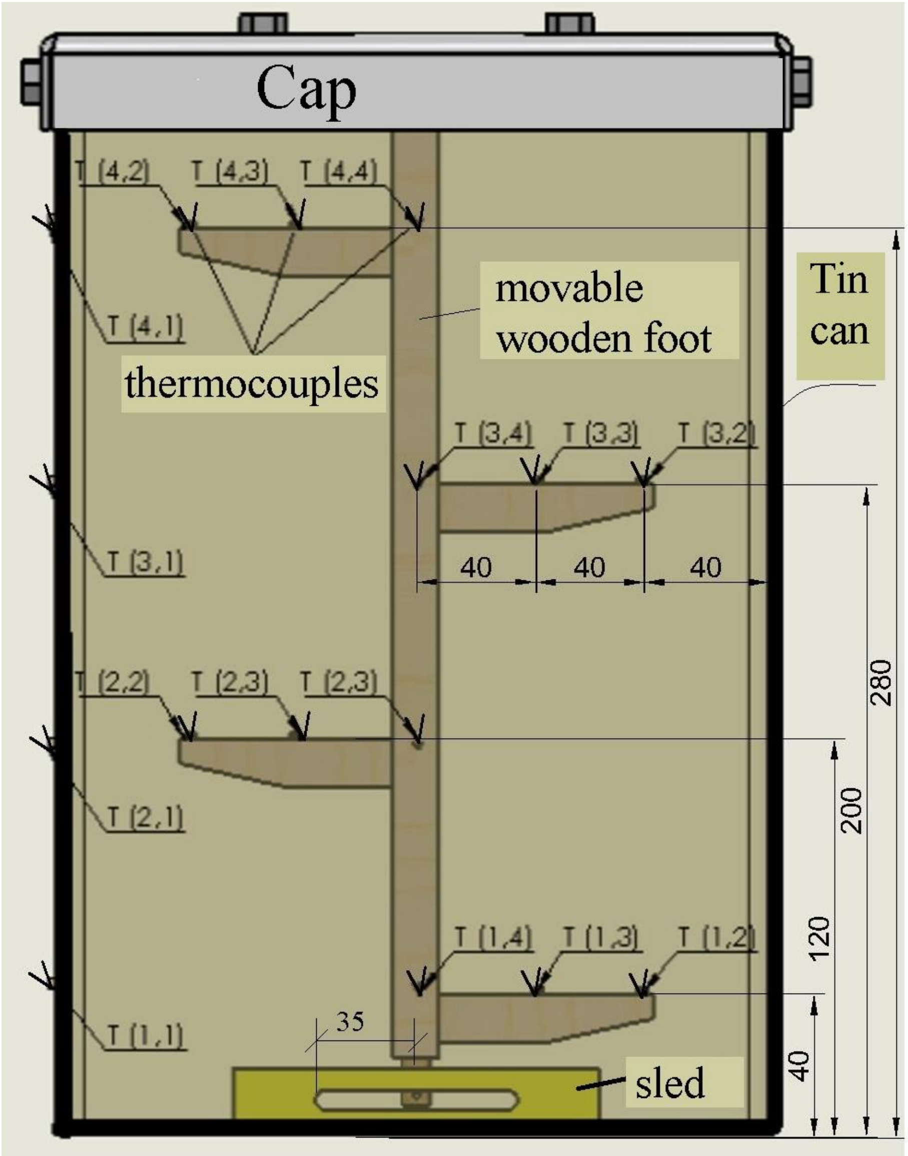

Figure 3. Layout Plan of Thermocouples in the Tin Can

Experiments were carried out in the mechanical liquefaction system placed in the air drying chamber of Ordu Apiculture Research Institute. 18 dm^3 tin can to be used in the 24 kg flower honey experimental setup was placed in a box and crystallized in cold storage. In the traditional liquefaction experiment, the crystallized honey container was liquefied by natural convection in a preheated oven at a constant temperature of 50 °C. This temperature was chosen because it is given in the literature as the highest value at which honey will not deteriorate during liquefaction.

In the second experiment, the crystallized honey container was placed on the mechanical vibrator in the same environment and the liquefaction process was carried out to activate the heat transfer by forced convection with the mechanical vibrator. In both liquefaction methods, temperatures were measured with thermoelements, and when the temperature measured by all thermoelements reached approximately 45°C, the experiments were terminated since the honey became liquid.

Figure 4. Crystallized and Liquefied Honey in Tin Can

A view of from crystallized and liquefied honey is given in Figure 4. HMF, proline, diastase, and moisture values were measured in the laboratory of Ordu Apiculture Research Institute on crystallized and liquefied honey samples to compare the quality of honey.

Results and Discussion

During the liquefaction process with the traditional method (natural convection), the time-dependent local temperature changes in the horizontal (x) and vertical (y) directions (4 different points at 40 mm distances from the horizontal tin side surface and 80 mm intervals vertically) are graphically given in Figure 5.

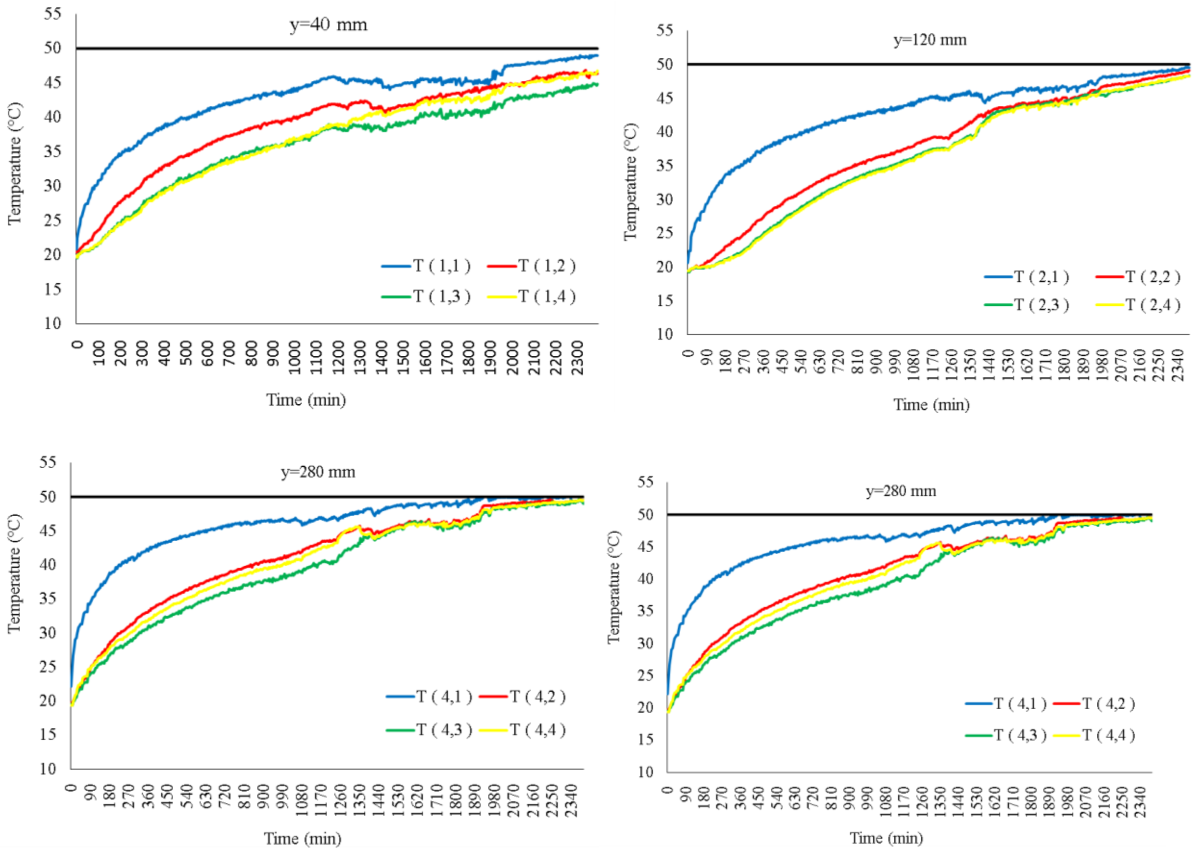

Figure 5. Time-Dependent Temperature Change in the Horizontal (X) Direction at Y distances in Conventional Liquefaction

When the graphs in Figure 5 are examined, the temperatures similarly decrease as you move away from the surface of the container at each height (y=40 mm, 120 mm, 200 mm, 280 mm). When the T(y, 3) point at each altitude reached 39 °C, there was a temperature fluctuation with other points and the temperatures remained approximately constant for a certain period. The reason for this is the initiation of mass movement due to the liquefaction of honey in this direction and the rapid transfer of heat due to the increase in heat convection. While the oven temperature was 50 °C, the inner surface temperature of the container reached an average of 47 °C at the end of liquefaction. The latest liquefaction took place at the T(y,3) point and at different distances in the y direction (40mm, 120 mm, 200 mm, 280 mm) at the T(y,3) point, the time when the temperature of the dissolved honey reached 45 °C and the liquefaction ended was 2390 minutes, respectively. It is 1960 min., 1950 min., 1620 min. It has been determined that the liquefaction process of honey by natural convection is approximately 40 hours under this storage (18 dm^3) condition in air melting systems at 50 °C.

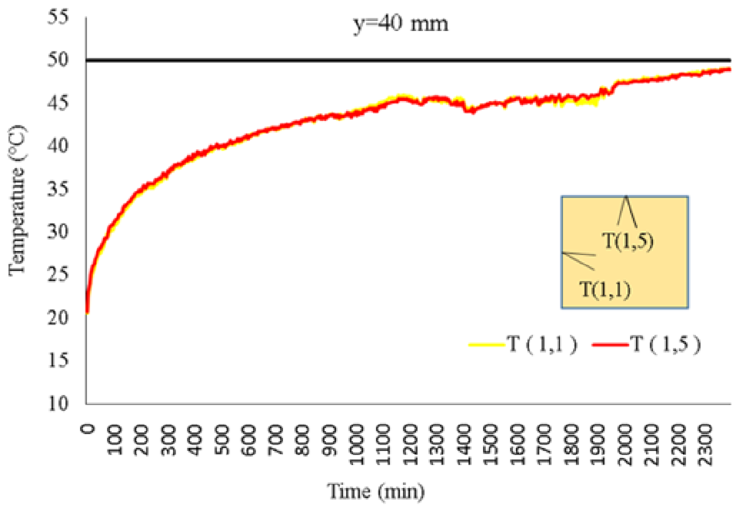

Figure 6. Temperature Change on Both Inner Surfaces of the Container in Conventional Liquefaction

In the graph given in Figure 6, point T(1,1) is in the direction of vibration, and point T(1,5) represents the temperature measurement point on the inner surface of the container at 90° perpendicular to the vibration. It is seen that the temperatures measured on the inner surface of the honey container at the same height are approximately equal during liquefaction. This situation is approximately the same in natural convection for temperature values measured at different altitudes.

In the liquefaction experiment using a mechanical vibrator, the initial liquefaction temperature of crystallized honey was measured in the range of 18-19 °C at all points.

The time-dependent local temperature changes in the horizontal and vertical (x, y) directions during the liquefaction process of honey with a mechanical vibrator are given in Figure 7 as graphics. These graphs show fluctuations in temperature values over time. The main reason for this is the displacement of cold hot regions due to the mobility of liquefied or partially crystallized honey due to forced convection.

When examining the graph in Figure 7, temperature fluctuations were observed when the temperature on the surface of the container was moved away from 40 °C at every height (y=40 mm, 120 mm, 200 mm, 280 mm). This situation started when the temperature of honey in the inner regions reached 37 °C. Due to the mobility of the vessel, the crystallized honey will dissolve and transfer heat by forced convection and indicate the beginning of a turbulent movement.

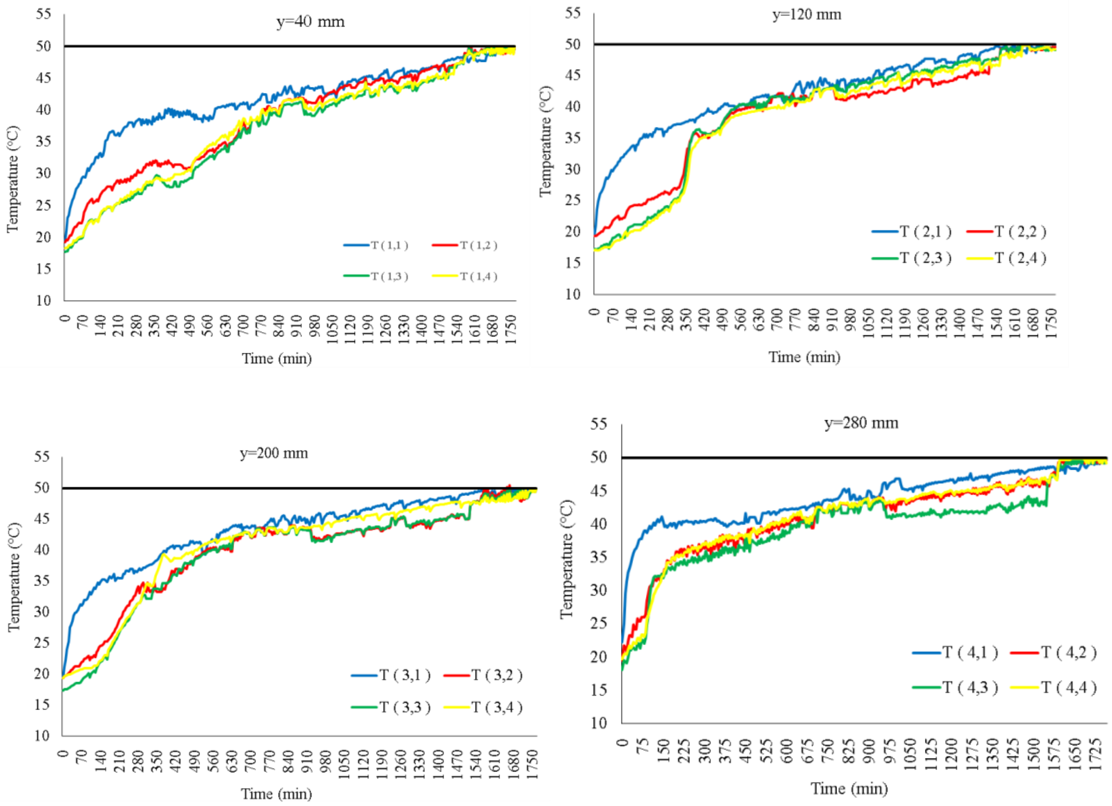

Figure 7. Temperature Change in Horizontal (X) Direction in Y Direction in Liquefaction by Mechanical Vibration

While the oven temperature was 50 °C, the inner surface temperature of the container reached an average of 49 °C at the end of liquefaction. The latest liquefaction took place at the T(y,3) point and at different distances in the y direction (40 mm, 120 mm, 200 mm, 280 mm) at the T(y,3) point, the temperature of the dissolved honey reached 45 °C and the ending of liquefaction time was found to be 1525 mins, 1535 mins, 1545 mins, and 1560 mins, respectively. In air-mechanized melting systems at 50 °C, under this storage (18 dm^3) condition, the liquefaction of honey in the y direction at the T(y,3) point was approximately at the same time and it was determined that it was 26 hour. The experiments were terminated when the honey temperature reached 49 °C at each point.

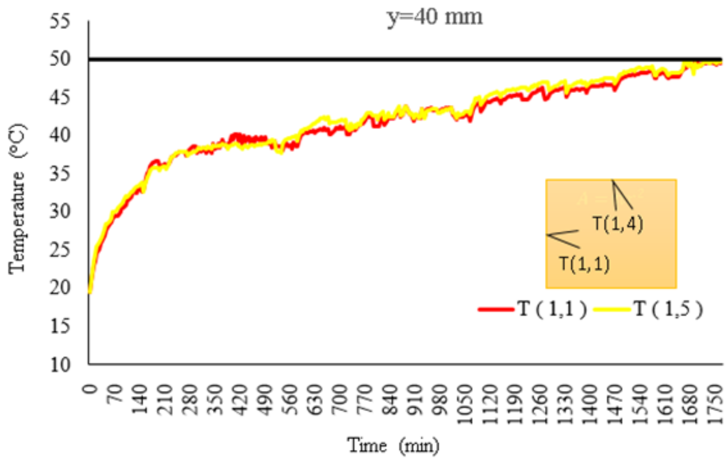

Figure 8. Temperature Change on Both Inner Surfaces of the Container in Liquefaction by Mechanical Vibration

Although the temperatures measured perpendicular to each other on the inner surface of the honey container at the same height are approximately equal to each other during liquefaction, it is seen in Figure 8 that when the honey temperature reaches 40 °C, the temperature on the surface perpendicular to the vibration T(1,5) increases slightly after the 10th hour compared to the temperature at the T(1,1) point.

This situation is similar to the temperature values measured at the T(y,1) points. Temperature fluctuations are higher above 40°C and this fluctuation is much less on both surfaces of the container compared to the inner regions. The comparison curves of horizontal and vertical temperature changes of conventional method (G.Y.) and mechanical vibrator (M.T.) honey liquefaction systems are given in Figure 9-10.

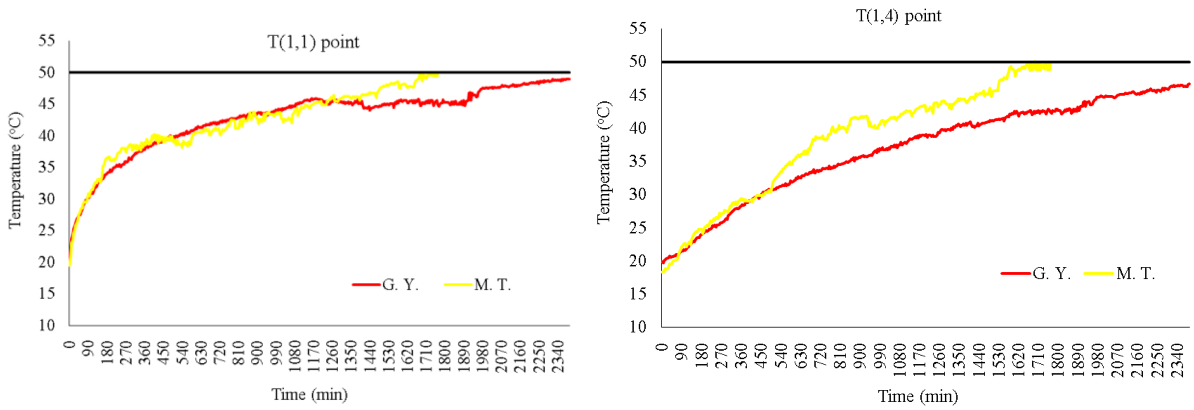

Figure 9. Local Temperature Comparison Graphs for Y=40 mm

While the temperatures were similar in both liquefaction processes up to 44 °C and 1355 mins at the T(1,1) point on the inner surface of the honey container given in Figure 9, a rapid temperature increase was observed in the liquefaction system with mechanical vibrator after this time and the mechanical vibrator was 30% shorter at this point to complete the process. While the temperature separation at the T(1.4) point in the middle of the honey pot took place at a lower temperature and time (31 °C and 500 mins), the mechanical vibrator completed the liquefaction process in a 33% shorter time.

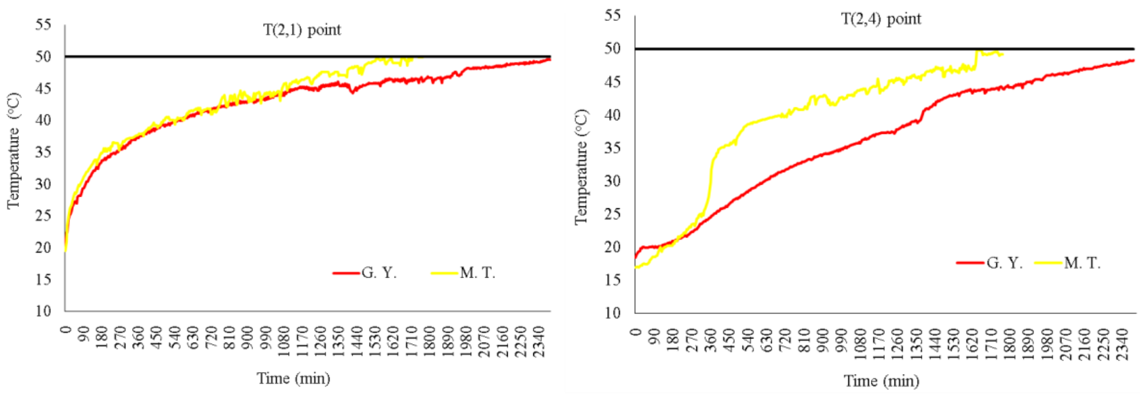

Figure 10. Local Temperature Comparison Graphs for Y=120mm

While the temperatures were similar in both liquefaction processes up to 43 °C and 1095 mins at the T(2,1) point on the inner surface of the honey container given in Figure 10, an increase in temperature was observed in the liquefaction system with mechanical vibrator after this time, and at this point, the mechanical vibrator liquefied in a 32% shorter time to complete the process. While the temperature separation at the T(2,4) point in the middle of the honey pot took place at a lower temperature and time (24 °C and 325 mins), the mechanical vibrator completed the liquefaction process in a 30% shorter time.

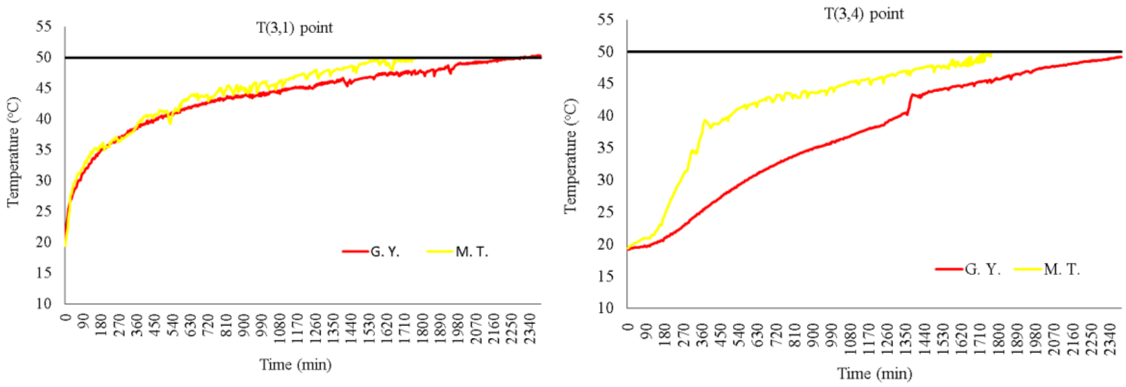

Figure 11. Local Temperature Comparison Graphs for Y=200 mm

While the temperatures were similar in both liquefaction processes up to 41 °C and 570 mins at the T(3.1) point on the inner surface of the honey container given in Figure 11, an increase in temperature was observed in the liquefaction system with mechanical vibrator after this time, and at this point, the mechanical vibrator liquefied in 29% less time to complete the process. While the temperature separation at the T(2,4) point in the middle of the honey pot took place at a lower temperature and time (22 °C and 90 mins), the mechanical vibrator completed the liquefaction process in a 27.7% shorter time at this point.

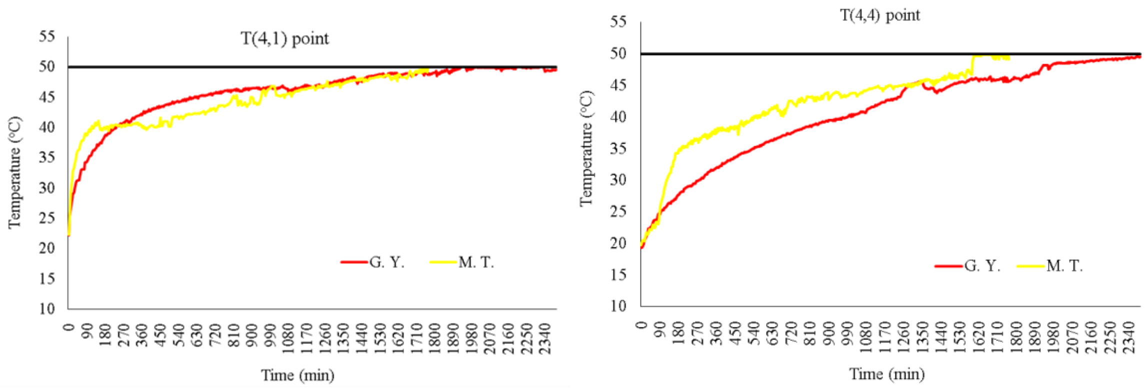

Figure 12. Local Temperature Comparison Graphs for Y=280 mm

While the temperatures were similar in both liquefaction processes up to 40 °C and 260 mins at the T(4,1) point on the inner surface of the honey container given in Figure 12, an increase in temperature was observed in the liquefaction system with mechanical vibrator after this time, and liquefaction took 12% in a shorter time with the mechanical vibrator on the surface of the container to complete the process. While the temperature separation at the T(2,4) point in the middle of the honey pot took place at a lower temperature and time (22 °C and 60 mins), the mechanical vibrator completed the liquefaction process in a 28.3% shorter time.

In the middle of the honey container, when the temperature of honey reaches approximately 49 °C, depending on the height (40 mm, 120 mm, 200 mm, 280 mm), the liquefaction times of honey with the help of conventional liquefaction method and a mechanical vibrator are 1600/2390, 1670/2390, 1730/2395 and 1590/2220 minutes. As expected, in the traditional air honey liquefaction system, the bottom and top of the container liquefied early, while the middle parts liquefied later. However, in the honey liquefaction system with a mechanical vibrator, the height caused by the difficult convection had little effect on the liquefaction time.

Honey Analysis

The analysis results of the samples taken before and after liquefaction from honey liquefied with the help of the traditional liquefaction method and mechanical vibrator are given in Table 1. The humidity (g/100g) value is below the desired value, and as expected, it is about the same as raw honey for both liquefaction processes.

Proline values (304.6) decreased by approximately 1% compared to raw honey in both liquefaction processes. This decrease is negligible. Diastase number decreased by approximately 10% in conventional liquefaction and increased by 10% in mechanical vibratory liquefaction. The number of HMFs increased in both kinds of honey in the heat treatment process. These expected increases are well below the maximum HMF value (40).

Table 1. Food Analysis Results of Crystallized Honey Before and After Liquefaction

Order Number	Name of the Analysis	Honey Notification Value	Raw Honey (Crystallized)	Heat Treated Honey (50 °C) (Traditional liquefaction)	Heat Treated Honey (50 °C) (Mechanical liquefaction)
1	Proline	min. 300	304.6	301.2	300.2
2	Fructose (g/100g)	-	37.7	37.4	37.4
3	Glucose(g/100g)	-	33.9	33.5	33.6
4	Fructose + Glucose(g/100g)	min. 60	71.6	70.9	71
5	Fructose/ Glukoz	0.9-1.4	1.11	1.12	1.11
6	Sucrose (g/100g)	max. 5	nd	nd	nd
7	Maltose(g/100g)	-	1	1.4	0.9
8	Humidity(g/100g)	max. 20	16.99	16.06	16.98
9	Briks	-	81.66	81.3	81.31
10	pH	-	4.06	4.08	3.97
11	Electrical conductivity	max. 0.8	0.258	0.26	0.221
12	Free Acidity (meq/kg)	max. 50	11	11	13
13	Diastase Count	min. 8	9.5	8.8	10.7
14	HMF	max. 40	0.8	1.1	2.4

** nd; not determined*

Conclusion and Suggestions

As a result of time-dependent temperature changes and food analysis of honey liquefied by both methods in a tin can (18 dm^3),

1. The conventional liquefaction of honey in the air oven (natural convection) took 40 hours, while it took 26 hours with the mechanical vibrator (forced convection). Therefore, liquefaction with the mechanical vibrator was realized in a 35% shorter time.
2. Liquefaction with mechanical vibration does not have the effect of spoiling the food properties of honey.
3. Since the machine is not complicated, it is cheap to manufacture and easy to maintain and repair.

Suggestions for future work,

1. Liquefaction studies should be carried out at different ambient temperatures and temperature curves of honey based on time in the x and y directions should be obtained.

2. By changing the vibration amplitude and frequency, the time-dependent liquefaction behavior of honey in the x and y directions should be revealed.
3. The economic analysis of the manufactured system should be done.

Support and Acknowledgements

This study was produced from the master's thesis titled "Mechanical Increasing of the Melting Rate of Crystallized Flower Honey" completed by Turgay Şahin under the supervision of Mithat Akgün (Thesis No. 613655).

Author Contribution

Mithat Akgün prepared the experimental environment and followed the experimental process. Turgay Şahin carried out the data collection and experimental process. The authors co-authored, read, and approved the article.

Ethic

There are no ethical issues with the publication of this article.

Conflict of Interest

The authors state that there is no conflict of interest.

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