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REGULATION OF THE STRUCTURE OF HONEY DURING ITS LONG-TERM STORAGE

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Abstract. The article describes a new method of treating crystallised honey and the characteristics of the obtained liquid honey stored for a long period of at least 1 year. It has been shown that a new method of low-temperature isothermal accelerated processing in a microwave reactor MWR-SPR allows melting crystallised honey to the liquid state. This accelerates its decrystallisation by 250 times compared to the known method that involves heat transfer. The properties of crystals of solid and liquid honey have been investigated and their structures have been compared after rapid low-temperature, isothermal treatment with the help of the microwave technology of ultrahigh frequencies at 50°C, for 60s. The number and size of pollen particle in honey are reduced by 10 times, and the size of glucose and sucrose crystals after processing is 5 times as small. The method of angular distribution of the laser beam has shown that the average size of sugar macromolecules in the treated honey decreases by 2 times as compared with crystallised honey. It has been proved that the suggested low-temperature, isothermal, accelerated treatment in a microwave reactor preserves a high diastase number in Gothe units (10–11), and the content of hydroxymethylfurfural does not exceed 3–6mg/kg honey. The results of X-ray fluorescence spectroscopy have confirmed that the chemical and elemental and oxide composition of honey after treatment is almost unchanged. Analysis of chemical and biological oxygen consumption shows that in the liquid honey samples, after melting by the suggested method, the biochemical activity of honey only reduced twofold, but it is far less than when honey is dissolved by the traditional heat transfer method. All this has a positive effect on stabilising liquid honey after its dissolution and on its stability during long-term (up to 1 year) storage. Based on dissolved, liquid, caramelised honey, a chewing gum has been developed to prevent and treat periodontal disease in dentistry. The chewing gum has been clinically tested and has proved highly effective in 72% of patients with gingivitis, gum disease, and periodontitis.

Keywords: honey, crystals, structure, particle size, diastase number, hydroxymethylfurfural.

Introduction. Formulation of the problem

The materials described in the article relate to food processing, an area of the food science. It includes a number of fields related to dilution and decrystallisation of various solid and pasty products, in particular melting solid crystalline bee honey to a liquid consistency. This honey can be used in dentistry to prevent and treat gingivitis, gum disease, and periodontitis. Natural bee honey, especially May honey, white, and acacia honeys, contains a lot of fructose and can remain liquid for 1–3 years in honeycombs sealed by bees. However, honey extracted from honeycombs has a shelf life of only a few months, depending on the type and variety of honey. This is because honey contains up to 80% or more of fructose and glucose in the ratio about 1:1. The consumer characteristics of honey remain almost unchanged, but its appearance becomes less attractive to consumers who want to see and consume it liquid and transparent. So, using new methods and special conditions to decrystallise honey, prevent its natural crystallisation, and keep it liquid for at least a year is an important problem in the food industry. Scientific activity and discussion of the achievements of ONAFT and the Department of Chemistry of Vasyl Stefanyk

Precarpathian National University (Ivano-Frankivsk) have resulted in joint research and introduction of a new food product, the chewing gum Medivnyk-Honeycomb. It is based on melted liquid caramelised honey and has a number of pronounced therapeutic and prophylactic effects: anti-inflammatory, astringent, anti-infective, antimicrobial, and antibacterial. The research provides for the possibility of creating and introducing new types of chewing gum based on liquid, melted honey, to treat and prevent dental diseases, primarily gingivitis, gum disease, and periodontitis.

Analysis of recent research and publications

Comb honey is a unique, extremely healthy natural product. It contains many useful substances: wax, propolis, bee pollen, and liquid honey as such. These substances have anti-inflammatory and antimicrobial effects, strengthen the body in general, and are widely used in medicine [1]. Honey beekeepers extract from honeycombs has a shelf life of only 1–6 months, depending on its type and variety, on whether it is monofloral or polyfloral. Elite acacia honey contains more than 40% of fructose, so it remains clear for 8–12 months [2], while sunflower honey crystallises in a month after beekeepers collect it. Honey becomes thick, opaque, hard, but no less sweet and useful. This is because honey contains a lot of fructose and especially glucose. The valuable and useful properties of honey are almost unchanged, but its appearance becomes less attractive to a consumer, who prefers seeing liquid, clear honey [2]. According to the biological origin, there is monofloral, polyfloral, honewdew, and mixed honey. There are more than 21 known species of honey (see Table 1). Monofloral honeys are those which bees produce from the nectar of mainly one plant species, such as acacia, heather, lime honey. Polyfloral honeys, such as forest, field, meadow, and honeydew honey, are collected from the flowers of various plants. But all types and varieties of liquid honey after 2–6 months of storage begin to thicken and crystallise, losing some consumer properties and attractiveness, but not their medicinal properties.

The process of honey crystallisation is influenced by various factors. The most important of them is the ratio of glucose and fructose in honey. They vary in the range: fructose 21.7–53.9%, glucose 20.4–44.4%. [3]. In the process of crystallisation, fructose remains liquid, while glucose and sucrose crystals become the centres of crystallisation.

Table 1 – Types and varieties of monofloral and polyfloral bee honey

No.	Types and varieties of monofloral and polyfloral bee honey	Characteristics of different varieties of honey during crystallisation
1.	Acacia honey	Clear, slowly crystallises fine-grained lard-like crystals, acquires a milky colour.
2.	Floral honey	Greenish-yellow colour, smells like almonds, has a wonderful taste with bitterness.
3.	Heather honey	Viscous honey, quickly sediments during storage.
4.	Thyme honey	Golden-yellow colour, crystallises into small grains, settles.
5.	Dandelion honey	Light amber to white with a greenish tinge, with a vanilla aroma.
6.	Blackberry honey	Transparent as water, with a pleasant taste.
7.	Chestnut honey	Dark-coloured, has a faint aroma of chestnut flowers and a rather bitter taste. Crystallises slowly, has an oily appearance.
8.	Clover honey	Colourless, clear, pleasant to smell. Crystallises slowly into a solid mass.
9.	Lime (‘white’) honey	Clear, pale yellow or greenish. Has a lime aroma and a very sweet taste. Upon crystallisation acquires a dense fine-grained texture.
10.	Alfalfa honey	Crystallises quickly, acquiring a white colour and the consistency of thick cream. It has a pleasant aroma and a specific taste of bitterness.
11.	Strawberry and raspberry honey	Very light, has a pleasant aroma and excellent taste. Crystallises slowly.
12.	Thistle honey	Very thick, viscous, yellow with a strong smell and unique taste, crystallises quickly.
13.	Sunflower honey	Golden-yellow or light amber in colour, tastes very sweet, a little tart. Crystallises into small grains, sometimes acquires a greenish tinge.
14.	Phacelia honey	Has a delicate aroma and a pleasant delicate taste. Upon crystallisation acquires a doughy consistency.
15.	Rhododendron honey	Light pink or golden yellow. Has a strong rich aroma and excellent taste.
16.	Forest honey (hawthorn, willow, mountain ash, walnut)	From light yellow to dark brown, sweet in taste, with a pleasant aroma. Upon crystallisation, it forms fine and medium sediment.
17.	Meadow honey (dandelion, clover)	Light yellow or brown, pleasant to the taste and very fragrant.
18.	Field honey (vetch, cornflower, chicory, valerian, etc.)	Has a pronounced antimicrobial and anticystitic effect. The shades of colour range from almost colourless to orange-yellow. Tastes sweet, the aroma is delicate and pleasant.
19.	Honeydew honey	Dark, almost black, with a greenish tinge, or dark brown. The aroma is weak, sometimes unpleasant. Sometimes tastes bitter or sour.

The density of glucose crystals is 1.54g/cm^3, and the density of honey varies from 1.45g/cm^3 to 1.40g/cm^3, depending on the water content and type of honey. That is why honey crystallises from top to bottom. At a lower honey density, the formed crystals go down to the bottom as sediment. Honey can be passed through sand filters or special clays. After this, it does not crystallise for a long time because it is free from pollen grains, proteins, and mucilage substances. However, it significantly reduces the diastase number of honey, its biological activity, taste, and quality [4]. Table 1 shows photos and characteristics of the 19 most famous varieties (monofloral and polyfloral) of bee honey in crystallised form.

Crystallisation of honey is a rather complex phenomenon. The process of uncontrolled crystallisation, which occurs during storage of honey, makes honey opaque and solid. The product becomes less attractive to the consumer [5]. This creates problems during packaging and processing of honey [6]. Uneven crystallisation of honey tells on the quality, too: the non-crystallised part of honey will contain more moisture, which makes honey vulnerable to yeast growth [4]. The rate of the appearance and growth of crystals depends on the temperature. Storing honey at temperatures which are very low (-20°C) or close to the ambient (18°C) leads to formation of small crystals and coarse crystals respectively [7].

When honey is stored in a moderate temperature range +(4–10°C) the formation of mixed type crystals is observed. Lower temperatures result in smaller crystals due to the limited mobility of sugar macromolecules [8]. The second factor influencing the crystallisation of honey is the mass fraction of water.

If honey contains 16–20% of water, crystallisation proceeds rapidly, with a larger H_2O amount (21%), honey remains liquid, clear, and almost colourless for a long time (for example, acacia and white honey) [8]. The third factor influencing the process is the presence of crystallisation centres.

Honey contains a number of primary crystals (protocrystals), around which glucose (grape sugar) crystallises. However, to the greatest extent, the size of crystals and their number are determined by the presence of pollen grains of plants. This is one of the important factors in honey crystallisation, because the presence of bee pollen, i.e. pollen collected by a honey bee and glued together by the secretions of its glands, greatly accelerates the crystallisation of honey. By its organoleptic parameters, bee pollen is a powdery, granular mass of solid lumps 8–200μm in size, which bees glue with the secretion of salivary glands and nectar into multicoloured granules 1–3mm in size. The colour of pollen ranges from yellow to purple (depending on the honey plant), the smell is pronounced, has a floral tone. Almost tasteless, gives a specific colour to each variety of honey (Table 1). The approximate composition of pollen: water (8–10%), carbohydrates (20–40%), proteins (25–35%), fats (5–7%). Residual pollen particles in honey (60 to 28000 grains) are the main centres of honey crystallisation, but at the same time strongly influence the value that indicates the biochemical activity of honey, its diastase number. The largest number of pollen grains is contained in phacelia (about 11 thousand) and buckwheat (about 5.5 thousand) honey, the least in acacia and white honey (about 20 grains in 1g) [9].

Reviewing the literature and patents has shown that further research is needed to solve the problem of honey crystallisation and accelerate honey melting when heated (by using alternative nonthermal methods and microwave treatment).

The purpose of the study was finding new technological methods and tools and selecting certain technological conditions (temperature, time) to melt crystallised honey and stabilise its liquid state during its subsequent storage for at least 1 year.

The objectives of the study were as follows:

– to study how the size and amount of pollen particles in honey effected on its crystallisation and stability during storage before and after heat treatment under different conditions;

– to compare how heat treatment of crystalline honey by heat exchange and by microwaves effected on the size of sugar macromolecules and on their distribution by size in honey, depending on the technological parameters of the process and on the equipment;

– to study how the parameters of heat treatment of honey under different conditions effected on the value of its diastase number in Gothe's scale, on the oxymethylfurfural content, on the quantitative and qualitative composition of honey and its biochemical activity;

– to try whether dissolved liquid honey could be used to create bioactive honey in periodontology.

Research materials and methods

To study the crystallisation process, standard samples of crystallised natural honey (FOP *Sviy Med*, Kyiv Region, Ukraine) were used. They meets the requirements of DSTU (State Standard of Ukraine) 4497:2005 "Natural honey. Characteristics of polyfloral honey before and after its low-temperature, isothermal, accelerated processing (melting)," presented in Table 2.

During the study, an alternative method of melting crystallised honey was used [11]. The honey was treated with microwaves at a low temperature (40–60°C) and during the minimum processing time (not more than 60 s). The treatment was carried out in a special rotating glass reactor in a microwave isothermal chamber MWR-SPR (microwave reactor for solid-phase reactions, Milestone, Italy; Faculty of Industrial Technology, O. Dubčak University of Trenčín, Púchov, Slovak Republic).

Table 2 – Organoleptic characteristics of honey taken for research before and after heat treatment

No.	Parameter	Requirements of DSTU 4497: 2005	Natural honey, crystallised, polyfloral (June 2019)	Liquid honey, polyfloral, melted after heat treatment in MWR-SPR
1.	Colour	Colourless, white, light yellow, dark yellow.	Light yellow, sunflower-yellow	Dark yellow
2.	Taste	Sweet, tender, pleasant, tart, without off-flavours	Sweet, tender pleasant, without off-flavurs	Sweet, pleasant, without off-flavurs
3.	Aroma	Specific, pleasant, without off-odours	Pleasant, without off-odours	Pleasant, without off-odours
4.	Consistence	Liquid, viscous, dense	Dense, crystalline, with pollen particles	Liquid, without available pollen particles
5.	Crystallisation	From fine to coarse-grained	Coarse-grained	Absent
6.	Signs of fermentation	Not allowed	Not found	Not found
7.	Mechanical impurities	Not allowed	Not found	Not found
8.	Mass fraction of water, not more than, %	18.5–21.0	20.7	19.7
9.	Diastase number (on dry basis), no less than, Gothe units	15–10	13.88	11.0

The structure and properties of crystalline and liquid honey were studied using an MBS-20 light laboratory microscope. The IR spectra of natural honey were recorded using an IR spectrophotometer (FTIR spectrometer) Nicolet iS50. Quantitative changes in the composition of sugars in honey were determined by the size distribution of sugar microparticles using the method of angular distribution of the laser beam (NANODS CILAS), under dynamic and static conditions. The samples of aqueous solution of honey were analysed by the indicators of chemical (CCO) and biological consumption (BCO) of oxygen made in accordance with the methods (DSTU 4175: 2003) of determining CCO and BCO in water.

The diastase number by Gothe's scale (honey bioactivity) and the content of hydroxymethylfurfural were determined according to DSTU 4497: 2005 "Natural honey" (see Table 2). The honey samples were analysed for the content of individual elements by X-ray fluorescence spectroscopy, using the device EDX-7000. The mass fraction of sugars and water in honey was determined with a special refractometer-saccharometer WALCOM REF 107/117.

Results of the research and their discussion

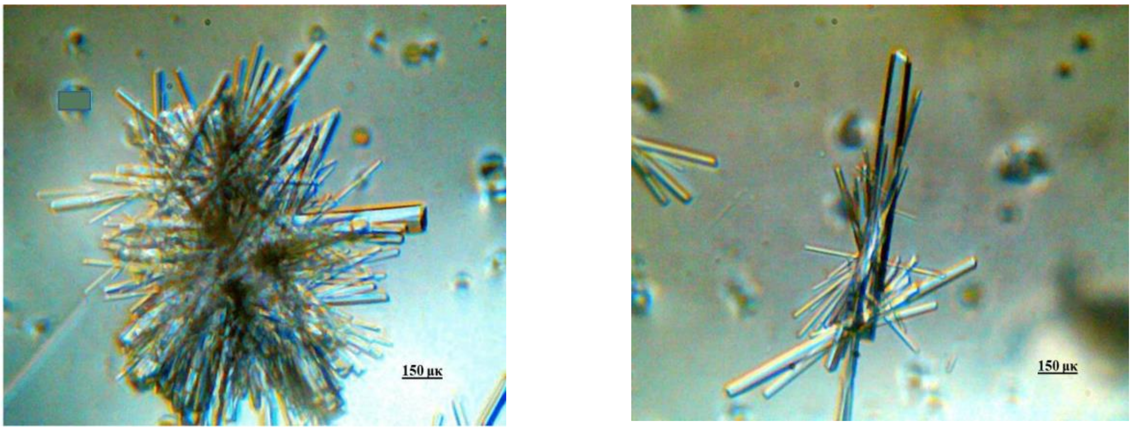
Mostly, crystallised solid honey is melted by means of special equipment, in which heat is transferred from water heated to 70–80°C to crystallised honey through the wall of the tank equipped with stirrers. It is possible to use devices with electric heating for a very long period of 4–12 hours, as described in the literature [10]. Traditional equipment for melting honey allows melting (decrystallisation) of solid honey by heat exchange through the reactor wall, with stirring during electric heating, or by means of a so-called water jacket, to 50–60°C, for 8–12 hours. Pasteurisation of honey is recommended to be carried out at 57–63°C for 60–10 minutes. To destroy the spore forms of microorganisms, it is recommended to heat honey at 63–80°C for 30–40 minutes [10]. Honey is also known to be melted using a device equipped with a microwave oven, but it is not efficient enough [12]. For our research, we used an advanced rotating glass reactor in a microwave isothermal chamber MWR-SPR.

First, it was studied how heat treatment effected on the size and number of pollen particles, which are known to be the centres of honey crystallisation. Fig. 1 shows micrographs of natural bee honey samples (Table 2) after 6 months of storage at 16–21°C recommended by the authors [3]. The honey sample was opaque, partially crystallised, containing pollen particles (Fig. 1a). These samples were compared with samples of the same honey variety after rapid low-temperature, isothermal treatment in a special microwave reactor (Fig. 1b). As can be seen from Fig.1a, the size of pollen particles in honey before treatment ($D_{particl.}$=50–100 microns) was 10–20 times larger than it was after rapid low-temperature treatment in a microwave reactor, when honey becomes transparent and the size of pollen decreases to ($D_{particl.}$=10-20μm). The approximate composition of pollen is: water (8–10%), carbohydrates (20–40%), proteins (25–35%), fats (5–7%) [3].

Additionally, the honey samples were examined under an MBS-20 microscope (x256). The results are shown in Fig. 2. Fig. 2a shows photos of crystals (glucose and sucrose) of crystallised bee honey after 6 months of storage, at 16–21°C ($D_{crys.}$=500–1000μm). In Fig. 2b, you can see the same glucose crystals in honey after low-temperature, isothermal, accelerated treatment of the honey sample in a microwave reactor MWR-SPR and 6 months of storage ($D_{crys.}$=100–200μm). Therefore, as can be seen from the data obtained, after melting crystallised honey, the average size of glucose crystals decreased by 2–5 times.

a) b)

Fig. 1. Natural bee honey (see Table 1) after 6 months of storage, at 16–21°C:
a) – honey sample before heat treatment, the pollen particle size $D_{particl}$=0.05–0.1mm; b) – sample after low-temperature, isothermal, accelerated treatment in a microwave reactor, the pollen particle size $D_{particl}$=0.01–0.02 mm. Microscope MBS-20 (x56)

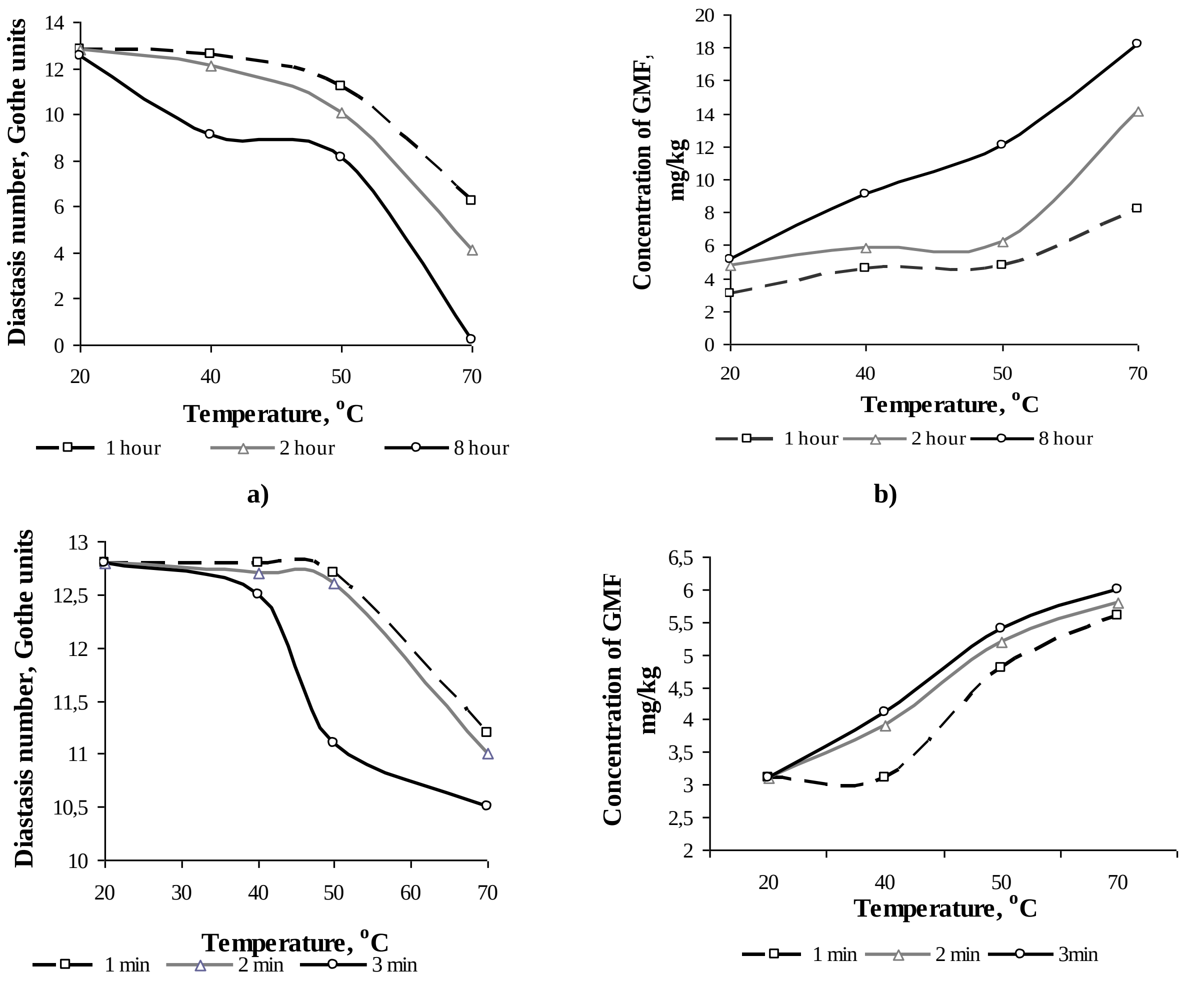


a) b)

Fig. 2. Microphotographs of crystals (glucose and sucrose) of natural bee honey (Table 2) after 6 months of storage at 16–21°C:
a) – crystalline honey (D_{crys}=500–1000μm); b) – honey after low-temperature (50°C), isothermal, accelerated processing in a microwave (60s) and storage for 6 months (D_{crys}=100–200μm); microscope MBS-20 (x256)

In accordance with the requirements of DSTU 4497:2005, the value of the diastase number in Gothe units (bioactivity of honey) and the content of the harmful component hydroxymethylfurfural (HMF) before and after heat treatment have been analysed. The concentration of HMF strongly increases after the classical heat treatment of honey, according to the authors [10]. Fig. 3 (a-d) shows the results of analysis of the diastase number (Fig. 3a) and the content of hydroxymethylfurfural (Fig. 3b) during melting crystallised honey by heating (8 hours) with heat transfer (50°C) from hot water (80°C) on classical heat exchange equipment [10]. For this purpose, the honey samples (Table 2) have been analysed for these indicators (diastase number and HMF content) after rapid isothermal low-temperature (40–60°C) heating (60s) in a microwave reactor MWR-SPR (Fig. 3c and 3d).

The results of the experimental studies (Fig. 3a-d) allow us to conclude that with the classical melting of crystallised honey by electric heating or warm water from 30 to 80°C for 1–8 h, the diastase number (bioactivity) of honey expressed in Gothe units decreases by 2–12 times. As we can see from Fig. 3a, after 8 hours at 80°C, the diastase number decreases to zero, which is much lower than the permissible DSTU limit 10 units by Gothe (Fig.3a). At the same time, the content of toxic hydrosimethylfurfural (Fig. 3b) increases by 3–4 times, reaching 20 mg/kg honey, which significantly exceeds the permissible level of DSTU (10mg/kg). On the other hand, our method of rapid low-temperature, isothermal heat treatment in a microwave reactor involves heating at 40–60°C for only 1–3 minutes and results in a decrease in the diastase number by only 2–3 units to 11 (Fig. 3c). I.e. the duration of treatment is 60–160 times shorter than it is in the traditional method. The hydroxymethylfurfural content only increases 2 times to 6 mg/kg, which is acceptable according to DSTU 4497:2005 (Fig. 3d).



a)

b)

c)

d)

Fig. 3. The content of the hydroxymethylfurfural (HMF) and diastase number before and after heat treatment:

a) – Dependence of the diastase number of honey in Gothe units on the temperature and the heating time during heat transfer from hot water (80°C); b) – Dependence of the hydroxymethylfurfural content on the temperature and the heating time of honey during heat transfer from hot water (80°C); c) – Dependence of the diastase number of honey expressed in Gothe units on the temperature and the heating time under isothermal conditions in a microwave reactor MWR-SPR; d) – Dependence of the hydroxymethylfurfural (HMF) content in honey on the temperature and the heating time under isothermal conditions in a microwave reactor MWR-SPR

The changes in the chemical composition and structure of honey after rapid low-temperature treatment in a microwave MWR-SPR reactor have also been studied. The honey samples were examined by IR spectroscopy on an FTIR spectrometer Nicolet iS50 (Fig. 4). As can be seen from the figure, the IR spectra of the samples of natural honey (Fig. 4, red line) and of honey after rapid low-temperature treatment (Fig. 4, blue line) are almost identical, which makes it possible to speak about the same chemical composition of the samples studied. Therefore, after rapid low-temperature, isothermal treatment of the honey samples by our method, its qualitative composition remains almost unchanged.

Fig. 5 (a and b) shows the size distribution of microparticles (SDMP on NANODS CILAS) of macromolecules of sugars and polysaccharides of natural untreated honey (Fig. 5a) and of honey treated by the rapid low-temperature isothermal method in a microwave reactor MWR-SPb at 50°C for 1 min (Fig. 5b). As can be seen from the figures, the microparticles of honey treated by the rapid low-temperature isothermal method in an MWR-SPR are, on average, 2 times smaller (D_{aver}=6.0μm) than they are in untreated crystallised natural honey (12.0μm, Fig.5.a). Analysis of the mass distribution shows that in the treated liquid honey, there are microparticles of sugars with the size 0.1–0.7 μm, and their content exceeds 50% (Fig. 5b). It is worth noting that such small particles were absent in crystallised honey (D_{aver}=12μm) (Fig. 5a). This confirms our preliminary light microscopy findings that treating honey in a microwave reactor at 50°C for 1min gives a positive result, promotes the melting of honey, and stabilises its liquid state.

Fig. 6 show the results of analysing samples of aqueous solution of honey by chemical (CCO) and biological (BCO) consumption of oxygen (according to DSTU 4175: 2003). These parameters determine the percentage of chemically and biologically bound oxygen in water and aqueous solutions and are described in standards used to assess the biochemical activity of honey. The experimental data obtained confirm that the biochemical properties of honey after microwave treatment in the MWR-SPR (histograms in Fig. 6b) are slightly reduced. And honey treated at higher temperatures and for longer times by heat transfer from a heating element (caramelised honey, Fig. 6 (a,b)) has much worse biochemical properties. However, it should be noted that honey does not completely lose its healing biochemical properties during heat treatment, and in some cases caramelised honey obtained at higher temperatures and after longer microwave treatment acquires new bioactive antiperiodontic properties.

Fig. 7 shows the results of X-ray fluorescence spectroscopy of ordinary honey samples, of those after rapid low-temperature isothermal treatment in an MWR-SPR (50°C, 1 min), and of caramelised honey treated by heat transfer (at 60°C for 10min). Analysis of the oxide composition of the chemical elements in the samples studied has confirmed that the qualitative content of elements in honey after processing in a microwave reactor is almost the same as in raw honey, but it differs in the quantitative composition, especially after caramelisation of honey in the traditional way [14].

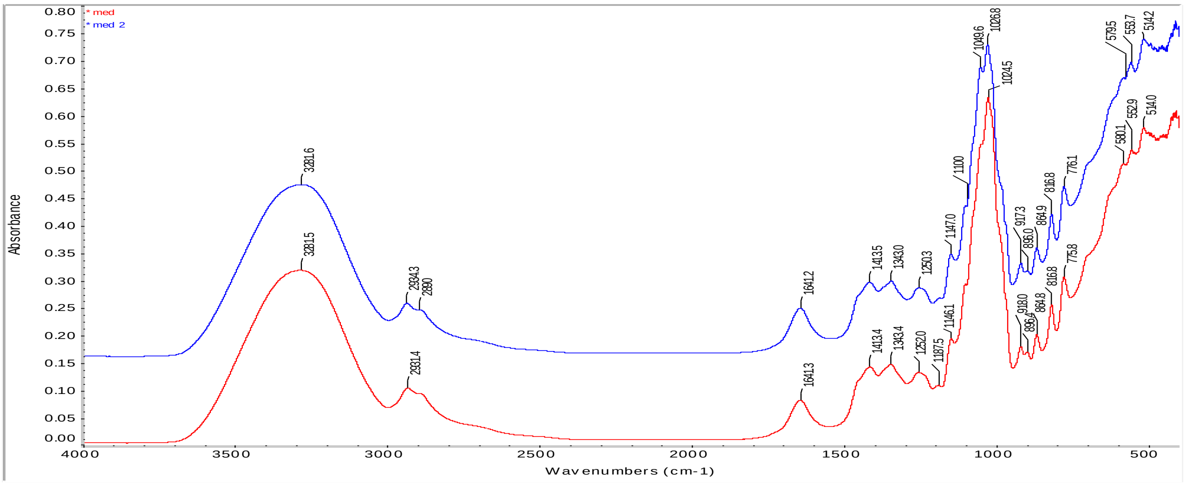
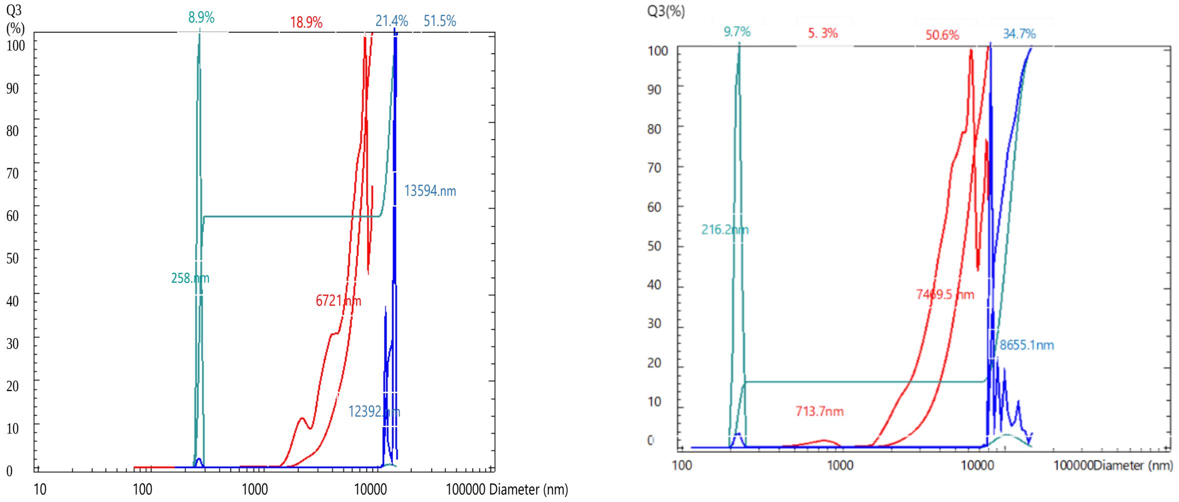
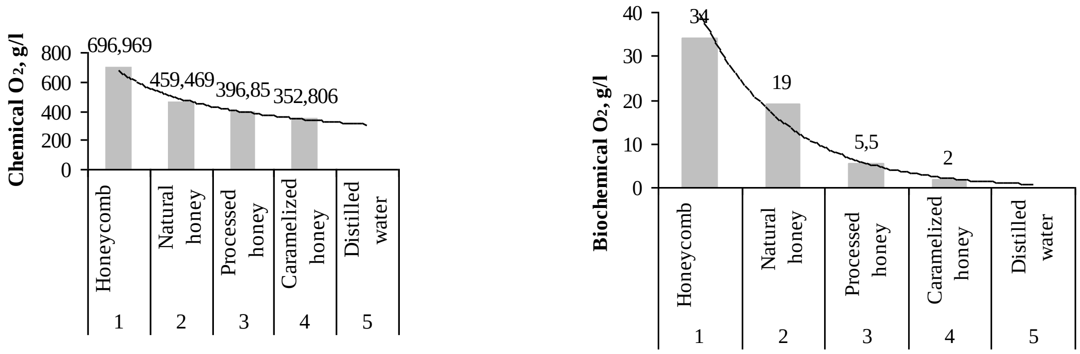


Fig. 4. IR spectra of natural honey (red spectral line) and honey after low-temperature (50°C) treatment (blue spectral line); FTIR spectrometer Nicolet iS50



a) b)

Fig. 5. Mass distribution of honey particles: a) – mass distribution of particles of natural unprocessed honey, average particle diameter D_{aver}=12000nm. (NANODS CILAS); b) – mass distribution of honey particles heat-treated in a microwave reactor MWR-SPR (50°C, 1min.), average particle diameter D_{aver}=6000 nm. (NANODS CILAS)



a)

b)

Fig. 6. Oxygen consumption: a) – chemical oxygen consumption in laboratory samples of different honey types (CCO5), g/l; b – biological oxygen consumption in laboratory samples of different honey types (BCO5), g/l

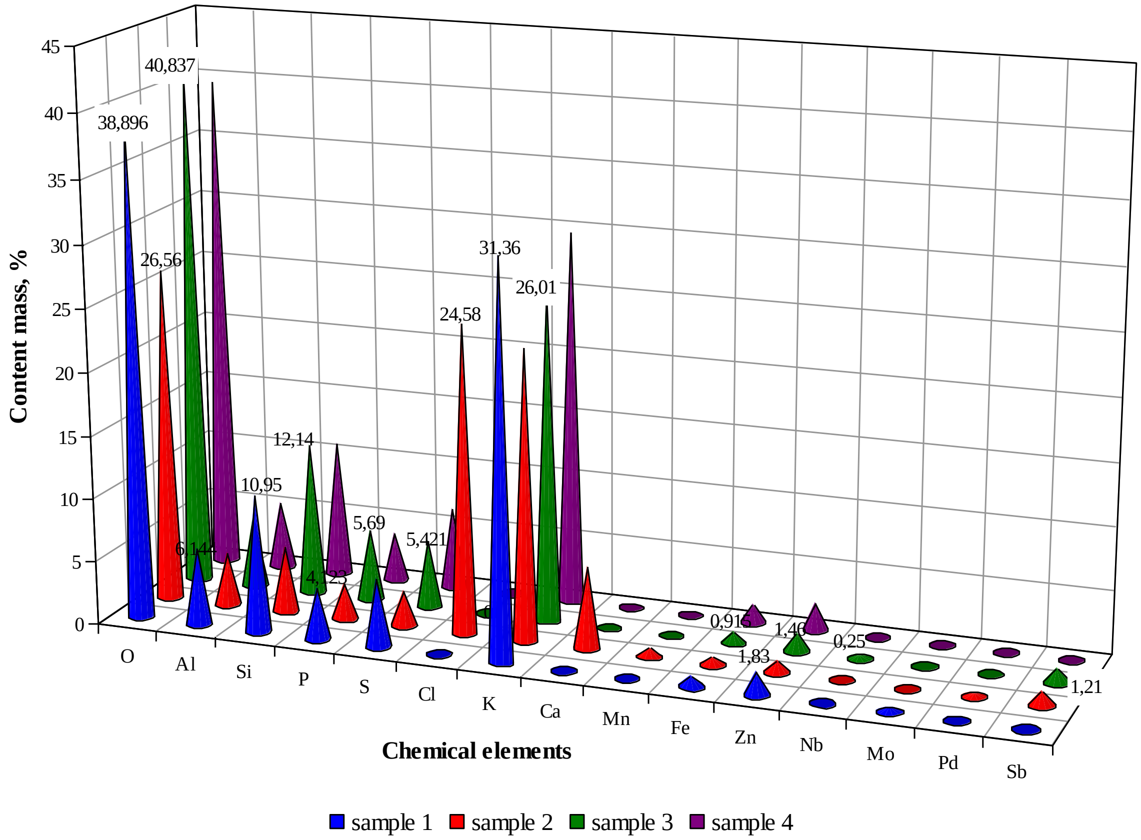


Fig. 7. The content of chemical elements (oxides) according to the results of X-ray fluorescence spectroscopy EDX-7000: Sample 1 – honeycomb honey; Sample 2 – honey heat-treated in a microwave (50°C, 1 min); Sample 3 – liquid honey melted by heat transfer; Sample 4 – honey caramelised at 60°C, 10 min [14]

Experimental studies and the results of decrystallisation of honey have made it possible to create a new food product – a chewing gum with therapeutic and prophylactic properties. For this purpose, samples of liquid, caramelised honey melted in an MWR-SPR were used. On the basis of this honey, new chewing gum *Medivnyk* prototypes with the composition of liquid and caramelised honey in the form of chewing candies have been created. In 2018–2019, this chewing gum was successfully clinically tested at the Research and Training Centre for Molecular Microbiology and Immunology of Mucous Membranes of Uzhgorod National University [14]. Samples of prophylactic chewing gum are recommended for manufacture, as they give a positive therapeutic effect in 72% of patients with gingivitis, gum disease, and periodontitis. The chewing gum *Medivnyk* has a pronounced prophylactic, anti-inflammatory, astringent, anti-infective, antimicrobial, and antibacterial effect, especially on the periodontal tissues of the oral cavity and is effective against other dental diseases. The copyright is protected by an industrial design right [15].

Conclusion

As a result of research and detailed study of the suggested method and mode of low-temperature isothermal accelerated treatment of crystallised honey in a microwave reactor, we can draw the following conclusions:

1. The chemical, physicochemical, and structural characteristics of liquid and crystallised (solid) honey depending on its thermochemical processing and duration of storage have been investigated. There are 3 main factors that affect the rate of crystallisation of honey: water content, pollen content, and the ratio of glucose and fructose. It has been shown that low-temperature isothermal rapid treatment in a microwave reactor MWR-SPR at 40°C for 60s allows melt crystalline honey into a liquid state. This is faster than the time for its melting by the classical method using heat transfer from hot water through the reactor wall or by means of electric heating for 4–12 hours. At the same temperature 50°C, the treatment only takes 1 min, i.e. the method suggested by us is by 240–600 times faster.
2. The properties, structure, and qualitative and quantitative composition of the liquid honey obtained have been investigated and compared with those of the original crystalline and liquid honey without treatment. It has been proved that the suggested accelerated treatment in a microwave reactor MWR-SPR at 50°C for 60s retains the high diastase number 10–11 Gothe units. The content of hydroxymethylfurfural did not exceed 3–6mg/kg honey, which meets the DSTU requirements for honey. The sensory characteristic of honey in the liquid state remain for 1 year, while with the traditional method of decrystallisation (melting), these characteristics are much worse, the diastase number decreases to 0–6, and the toxic hydrosimethylfurfural content increases to 12–18mg/kg, which significantly exceeds the permissible norms (DSTU 4497:2005 "Natural honey").
3. The qualitative and quantitative composition of honey after low-temperature isothermal accelerated treatment in an MWR-SPR at 50°C for 60s has been analysed by IR spectroscopy. The analysis has shown no significant qualitative changes compared to untreated honey. Microscopic studies have confirmed a 10-fold reduction in the number and size of pollen particles. The size of glucose and sucrose crystals after this treatment is also reduced by 5 times. At the same time, the analysis of the mass distribution of sugar macromolecules by the method of angular distribution of the laser beam (NANODS CILAS) has shown a 2-fold decrease in the average particle size in the treated honey compared with the crystallised samples. All this contributes to stabilising liquid honey stored for 1 year after melting (decrystallisation).
4. Analysis of CCO and BCO (honey bioactivity) has confirmed that in liquid honey samples after decrystallisation by the proposed method, these values are reduced by half, which is far less than it is with the traditional method of heating by heat transfer. Analysis of the chemical and elemental and oxide composition of honey by X-ray fluorescence spectroscopy has confirmed that the qualitative composition of honey treated by our method is almost unchanged.
5. On the basis of the samples of decrystallised liquid honey obtained by the new technology, a preventive chewing gum has been created for treatment of gingivitis, gum disease, and periodontitis. Chewing gum samples based on the composition of liquid, caramelised honey were clinically tested at the Research and Training Centre for Molecular Microbiology and Immunology of Mucous Membranes (Uzhgorod National University) in 2018–2019. The tests of the product's ability to prevent and treat gingivitis, gum disease, and periodontitis showed a positive result in 72.5% of patients.

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РЕГУЛЮВАННЯ СТРУКТУРИ МЕДУ ПРИ ДОВГОТРИВАЛОМУ ЗБЕРІГАННІ

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Анотація. У статті описано новий спосіб обробки закристалізованого меду та надано характеристику отриманого рідкого меду протягом тривалого терміну зберігання (не менше 1 року). Показано, що за допомогою нового способу низькотемпературної ізотермічної прискореної обробки в мікрохвильовому реакторі MWR-SPR, можна провести розпуск закристалізованого меду до рідкого агрегатного стану, що скорочує час на його розпуск в 250 раз, у порівнянні з відомим методом теплопередачі. Досліджено властивості і порівняно структуру кристалів твердого та рідкого меду після низькотемпературної ізотермічної прискореної обробки за допомогою мікрохвильової технології надвисоких частот при 50°С, за 60с. При цьому кількість і розмір частинок пилку в меді знижується в 10 разів, а розміри кристалів глюкози і сахарози після обробки зменшуються в 5 разів. Методом кутового розподілу лазерного променю показано зменшення середнього розміру макромолекул цукрів в обробленому меді в 2 рази, порівняно з закристалізованим медом. Доведено, що запропонована низькотемпературна ізотермічна прискорена обробка в мікрохвильовому реакторі зберігає високе діастазне число по Готе 10–11, а вміст гідроксиметилфурфуролу не перевищує 3–6мг/кг меду. За результати Х-променевої флуоресцентної спектроскопії підтверджено, що хімічний та елементо-оксидний склад меду після обробки майже не змінюється. Аналізи показників хімічного та біологічного споживання кисню показує, що у зразках рідкого меду, після розпуску запропонованим методом, біохімічна активність зменшуються тільки в два рази, але це значно менше, ніж під час розпуску меду традиційним способом теплопередачі. Усе це позитивно впливає на стабілізацію рідкого меду після його розпуску, на його стабільність при довготривалому (до 1 року) зберіганні. На основі розпущеного рідкого карамелізованого меду розроблено профілактичну жуйку, для запобігання та лікування захворювання тканин пародонту в стоматології.

Ключові слова: мед, кристали, структура, розміри частинки, діастазне число, гідроксиметилфурфурол.

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