Современная наука и инновации.
2023. № 3 (43). С. 141-155.
Modern Science and Innovations.
2023; 3(43):141-155.

*ТЕХНОЛОГИЯ ПРОДОВОЛЬСТВЕННЫХ ПРОДУКТОВ /
TECHNOLOGY OF FOOD PRODUCTS*

Обзорная статья / Review article

УДК 638.163
https://doi.org/10.37493/2307-910X.2023.3.13

Леонид Чеславович Бурак[1]
[Leonid Ch. Burak],
Вероника Владимировна Яблонская[2]
[Veronika V. Yablonskaya],
Сапач Александр Николаевич[3]
[Alexandr N. Sapach]

Влияние современных методов обработки на антиоксидантную активность и антимикробную способность меда (обзор)

The impact of modern techniques treatments for antioxidant activity and antimicrobial ability of honey (review)

[1,3] Общество с ограниченной ответственностью «Белросаква», г. Минск, Республика Беларусь / Belrosakva Limited Liability Company, Minsk, Republic of Belarus
[1]https://orcid.org/0000-0002-6613-439X
[3]https://orcid.org/0000-0002-8579-2689
[2]Совместное общество с ограниченной ответственностью «Ароматик», г. Дзержинск, Республика Беларусь / Aromatik Joint Limited Liability Aromatic, Dzherzhinsk, Republic of Belarus

Автор, ответственный за переписку: Леонид Чеславович Бурак, leonidburak@gmail.com / Corresponding author: Leonid Ch. Burak, leonidburak@gmail.com

Аннотация. *Результаты исследований влияния обработки на антиоксидантные и противомикробные свойства мёда вызывают заинтересованность научного сообщества, поскольку параметры и способ обработки влияет на качественные показатели мёда. Цель статьи – обзор научных исследований результатов воздействия современных методов обработки на антиоксидантную активность и антибактериальные свойства меда. В обзор включены статьи, опубликованные на английском и русском языке за период 2010–2023 гг. В процессе научного поиска были использованы базы данных Scopus, Web of Science, PubMed и Elsevier и электронной библиотеки eLIBRARY. Результаты научных исследований показали, что компоненты, оказывающие влияние на антиоксидантную активность и антимикробные свойства меда, могут изменяться во время обработки, и обработанный мед может иметь низкий уровень антиоксидантной и антибактериальной активности. Термическая обработка и микроволновая обработка меда отрицательно влияют на антиоксидантную и антимикробную активность меда. В отличие от других нетермических методов, обработка высоким давлением и гамма-облучение не влияют на антибактериальную активность и антиоксидантные свойства меда. Ультразвуковая обработка повышает антиоксидантную активность меда. Представленный научный обзор может быть использован для проведения дальнейших научных исследований, а также предприятиями, осуществляющими сбор и переработку меда в выборе оптимальных способов обработки в процессе производства продукции.*

Ключевые слова: мед, термическая обработка, обработка высоким давлением, облучение, микроволновая обработка, ультразвук, антиоксидантная активность, антибактериальные свойства

Для цитирования: *Бурак Л. Ч., Яблонская В. В., Сапач А. Н. Влияние современных методов обработки на антиоксидантную активность и антимикробную способность меда (обзор) // Современная наука и инновации. 2023. № 3 (43). С. 141-155.* *https://doi.org/10.37493/2307-910X.2023.3.13*

Abstract. *The results of studies of the effect of processing on the antioxidant and antimicrobial properties of honey are of interest to the scientific community, since the parameters and method of processing affect the quality of honey. The purpose of the article is to review scientific studies of the results of the impact of modern processing methods on the antioxidant activity and antibacterial properties of honey. The review includes articles published in English and Russian for the period 2010–2023. In the process of scientific research, the Scopus, Web of Science, PubMed and Elsevier databases and the eLIBRARY electronic library were used. The results of scientific studies have shown that components that affect the antioxidant activity and antimicrobial properties of honey can change during processing, and processed honey may have a low level of antioxidant and antibacterial activity. Heat treatment and microwave treatment of honey adversely affect the antioxidant and antimicrobial activity of honey. Unlike other non-thermal methods, high pressure treatment and gamma irradiation do not affect the antibacterial activity and antioxidant properties of honey. Ultrasonic treatment increases the antioxidant activity of honey. The presented scientific review can be used for further scientific research, as well as by enterprises that collect and process honey in choosing the best processing methods in the production process.*

Keywords: honey, heat treatment, high pressure treatment, irradiation, microwave treatment, ultrasound, antioxidant activity, antibacterial properties

For citation: *Burak LCh, Yablonskaya VV, Sapach AN. The impact of modern techniques treatments for antioxidant activity and antimicrobial ability of honey (review). Modern Science and Innovations. 2023;3(43):141-155.* *https://doi.org/10.37493/2307-910X.2023.3.13*

Introduction. For many centuries, honey has been widely used in traditional medicine as an antimicrobial, anti-inflammatory, cardiovascular agent, and also as an adjuvant for the treatment of wounds, tissue regeneration, relief of gastrointestinal disorders, gingivitis and various other pathologies [1-4]. The results of many scientific studies confirm that honey has antimicrobial, antiviral, anti-inflammatory, antioxidant, antimutagenic and antitumor effects. Honey also has beneficial effects on the cardiovascular, nervous, respiratory and gastrointestinal systems and is licensed as a medical product for professional wound care in Europe, Australia, New Zealand. , Hong Kong and USA [5-10]

However, fresh honey extracted from the comb contains pollen, beeswax and other undesirable materials, including microorganisms. According to research data, the microbiological contamination of honey is from 10^{2} to 10^{4} CFU / g, therefore it is necessary to process it [11]

The main method of processing honey is heat treatment, and to use it for medical purposes it is subjected to gamma irradiation [12] . Currently, honey is used clinically both orally and as an ointment in the treatment of wounds, peptic ulcers, gastroenteritis, oncology, ophthalmology, dermatology and oral hygiene [13-14] . One of the main indicators of honey quality is the mass fraction of hydroxymethylfurfural (HMF) and diastase activity. HMF is a furan compound that is formed as an intermediate in the Maillard reaction, due to the direct dehydration of sugars under acidic conditions (caramelization) and heat treatment. According to the Codex Alimentarius of the World Health Organization, the maximum HMF content in honey is 40.00 mg/kg d for blended or processed honey and 80.00 mg/kg for honey from tropical climates, and the diastase activity of honey should be between 3 and 8 Gothe units [15-16] . In the Russian Federation and CIS countries there are more stringent requirements. According to GOST 19792-2017, the mass fraction of HMF, ppm (mg/kg), is not more than 25, and the diastase number, units. Gothe, no less than 8. The negative impact of heat treatment on honey quality parameters has been confirmed by many research authors [17-19]. Processing may also affect the antioxidant and antimicrobial properties of honey. Antioxidants present in honey include phenolic compounds (phenolic acids and flavonoids), ascorbic acid, glucose oxidase, catalase, carotenoid derivatives, organic acids, Maillard reaction products (glucose-lysine, ribose-lysine and fructose-lysine) and amino acids. These compounds have preventive effects against cancer, cardiovascular diseases, inflammatory diseases, neurological degeneration, wound healing, infectious diseases and aging [5,6,20,21] . Honey also has antimicrobial activity, primarily due to its low water activity, high osmotic pressure and low pH. In addition, antimicrobial activity is also attributed to the presence of glucose oxidase, hydrogen peroxide, phenolic compounds and antibacterial peptides [22] . Honey can have an inhibitory effect on the growth of a number of bacteria, fungi, protozoa and viruses. It has antibacterial activity against both gram-positive and gram-negative bacteria, such as Bacillus *anthracis* , *Corynebacterium diphtheriae* , *Haemophilus influenzae* , *Klebsiella pneumoniae* , *Mycobacterium tuberculosis* , *Proteus species* , *Escherichia coli* , *Pseudomonas aeruginosa* , *Salmonella diarrhoea* , *Shigella dysentery* , *Staphylococcus aureus* (*MRSA*) and *Streptococcus faecalis* [3] . Honey also showed antiviral activity against varicella zoster virus (VZV), influenza virus (H1N1 and herpes simplex [23] . Natural honey has also been used in the treatment of COVID-19 by enhancing the immune response, alleviating comorbidities, and acting as an antiviral agent [24-25] . The influence of heat treatment on the quality indicators of honey has been sufficiently studied. At the same time, the influence of thermal and non-thermal processing methods on the antioxidant activity of honey and its antimicrobial properties is of particular interest to the scientific community. Therefore, the purpose of this article is to review scientific studies of the effects of modern processing methods on the antioxidant activity and antibacterial properties of honey.

Materials and research methods. The object of the study was scientific publications of the results of various honey processing methods and their effect on antioxidant activity and antimicrobial properties. To search for information, Scopus, Web of Science, PubMed and Elibrary databases were used for the period from 2010 to February 2023. The focus was on articles published in scientific peer-reviewed journals with high citation indexes in the last five years. Conference materials and book chapters were not used in the analysis.

Research results and their discussion. Thermal processing of honey uses a wide range of heating temperatures from 30 to 140 °C for a few seconds to several hours, and optimal heating conditions depend on the geographic and botanical origin of the honey [26] . Although modern heat treatment is effective in reducing the microbial load of honey, it has a detrimental effect on antioxidant and antimicrobial activity [17,19,27]. Therefore, in order to preserve and increase shelf life, reduce microbiological contamination, non-thermal processing methods such as high-pressure processing, ultrasonic processing, irradiation and microwave processing have been studied for honey processing. Food irradiation treatment involves exposing food to doses of ionizing radiation ranging from <3 to <10 kGy. The action of free radicals, formed by the interaction of excited electrons within food atoms, and organic food molecules, is the main method of microbial inactivation [6] . During ultrasonic processing, food products are processed using lower ultrasound frequencies of 20–100 kHz at much higher intensities, in the range of 10–1000 W/cm -2, which causes an increase in biocides through cavitation and the formation of free radicals and hydrogen peroxide, in ultimately inactivating microorganisms. Honey is treated with ultrasound to keep it in a liquid state, dissolving existing crystals and slowing down further crystallization [28] . Other non-thermal processing methods being studied at laboratory scale to replace thermal processing include microwave processing and high-pressure processing. During microwave processing, electromagnetic waves of certain frequencies are used to heat the product. The destruction of microbes is mainly achieved through the heat generated. In high pressure processing, foods are subjected to high pressure, approximately 600 MPa, with or without heating [29] . This processing has minimal impact on nutritional and organoleptic qualities.

1. The effect of heat treatment on the antioxidant properties of honey

The antioxidant activity of honey is usually measured in the form of antiradical activity using the 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) scavenging assay (ABTS).), oxygen radical scavenging capacity (ORAC) assay, and iron reducing antioxidant capacity (FRAP) assay. The results of some studies indicate a negative effect of heat treatment on the antioxidant properties of honey (Table 1). For example, Braghini F. et . al . [27] . studied the effect of heat treatment on the antioxidant properties of bee honey. Honey was subjected to heat treatment at temperatures of 52 and 71 ° C for different times from 0.24 to 470 minutes. Significant reductions in antioxidant activity (DPPH and FRAP) were observed following heat treatment of honey, with major changes observed in treatment combinations of 52°C for 470 minutes, 55°C for 170 minutes, and 57°C for 60 minutes.

Table 1. Effect of heat treatment on the total content of phenols and flavonoids in various types of honey [30-32.19].

Origin of honey	Heat treatment conditions	TPC (mg gallic acid/100g honey), average (range)	TFC (mg quercetin/100g honey), average (range)
Thailand (three samples)	Control	78.983 (60.13–95.16)	48.24 (45.14–53.58)
	For 5 min at 90 °C	64.23 (47.21–80.74)	36.67 (31.52–42.69)
Morocco (eight samples)	Control	96.05 (63.44–130.04)	23.70 (17.12–29.32)
	For 30 min at 121 °C	96.78 (67.27–132.61)	20.44 (14.52–25.59)
Poland (four samples)	Control	84.42 (38.29–121.06)	no data
	For 60 min at 90 °C	79.85 (38.47–120.58)	no data
Mexico (four samples)	Control	85.55 (42.08–154.54)	no data
	For 45 min at 40 °C	86.085 (42.92–154.95)	no data
	For 45 min at 50 °C	88.635 (44.71–161.33)	no data
	For 45 min at 60 °C	91.1825 (46.49–167.71)	no data
	For 45 min at 70 °C	90.96 (47.31–164.58)	no data
	For 45 min at 80 °C	90.73 (48.12–161.44)	no data

TPC – total phenolic content; TFC – total flavonoid content, control – samples without treatment.

A decrease in the antioxidant properties of heat-treated honeydew honey was found in a study by Stojković *et al* . Honey, after heat treatment at 65°C for 15 minutes, showed a significant reduction in TPC and TFC (expressed as mg gallic acid per gram). The total phenolic content decreased from 1.493 to 1.361 mg gallic acid/g/honey, and the flavonoid content decreased from 0.846 to 0.710 mg gallic acid/g, which consequently influenced the decrease in DPPH, ABTS and FRAP values after heat treatment [33]. Impact heating samples of monofloral honey at a temperature of 121 °C for 30 minutes was carried out by the authors Elamine, Y., Anjos, O., Estevinho, LM, Lyoussi, B., Aazza, S. & Miguel, MG, who also established a decrease in the total content flavonoids, but a slight increase in antioxidant activity was noted. This may be due to the formation of non-nutritive antioxidants such as Maillard reaction products.

Three types of honey (lotus, thyme and multifloral) were heat treated at 63 °C for 30 min. [18.34] . After treatment, there was a significant reduction in total phenolic content (TPC), expressed as mg tannic acid/kg honey. TFC content in lotus honey decreased from 609 ± 60 to 482 ± 39 mg tannic acid kg $^{-1}$ honey, thyme honey from 538 ± 41 to 447 ± 40 mg tannic acid kg $^{-1}$ honey and multifloral honey from 462 ± 53 to 404 ± 36 mg tannic acid kg $^{-1}$ honey. A study by Chaikham & Prangthip examined the effect of different heat treatment temperatures ranging from 50 to 100 °C with different processing times ranging from 1 to 5 minutes on the phenolic content and antioxidant capacity of longan flower honey. It was found that TPC increased at treatment temperatures of 50 and 70°C with increasing treatment duration, showing maximum TPC recorded in the sample processed at 70°C for 5 minutes, while a significant decrease in TPC was observed in samples processed at 100° C. , and the reduction increased with increasing treatment duration. [35] . Authors Šarić, G. et . al observed an uneven change in the antioxidant properties of honey in 31 samples of acacia honey and eight samples of chestnut honey. undergone heat treatment at 95 °C for 5 minutes. The results showed uneven changes in the antioxidant activity of individual samples. In some samples, heat treatment increased antioxidant activity, in others it decreased. For example, the antioxidant activity of 16 samples of acacia honey decreased by 31.4%. In contrast, the antioxidant activity of 14 acacia honey samples increased by an average of 36.9% (measured by FRAP). In all chestnut honey samples, FRAP values decreased by an average of 13.1% [36] . Study author Kowalski reported changes in the antioxidant activity of honey after heat treatment at 90°C for 60 minutes. Four types of honey (hodew, linden, acacia and buckwheat) were analyzed for changes in TPC and antioxidant activity (ABTS and DPPH activity after heat treatment. A decrease in TPC of thermally treated honeydew honey was found. No significant changes were observed in samples of acacia honey and buckwheat honey. In samples of linden honey, TPC increased in heat-treated honey. The increase in TPC during heat treatment may be due to the extraction of phenolic compounds during heat treatment. Increased radical scavenging activity of ABTS was observed only in buckwheat and linden honey. ABTS radical scavenging activity of honeydew honey was decreased , whereas in the case of acacia honey it did not change. DPPH radical scavenging activity was increased in all heat-treated samples [30] . It should also be noted that in the study of Pimentel-González *et al.* , increasing temperature during heat treatment did not cause a permanent increasing TPC for different honey samples [32] .

2. The influence of heat treatment on the antibacterial properties of honey.

Heat treatment has a detrimental effect on the antibacterial activity of honey. Stojković, M., Cvetković, D., Savić, A. et al. found that heat treatment at 30, 45 and 60 °C for 1, 5 and 10 minutes reduces the antibacterial activity of honey bees, as evidenced by increased microbiological values contamination. Antibacterial activity was observed against *Escherichia coli* , *Staphylococcus aureus* , *Pseudomonas aeruginosa* and *Bacillus cereus* . [30] . A decrease in the antibacterial activity of thermally treated honey was previously reported by Pimentel-González *et al* . Four different types of honey (acaxochitlán, arenal, huehuetla and tasquillo) were heat treated at 40, 50, 60, 70 and 80 °C for 45 minutes. Antibacterial activity was established as the bacterial growth inhibiting activity of honey solutions at concentrations of 55%, 70% and 85% honey solutions. Antibacterial activity was studied against six bacterial strains, three Gram-positive strains (*Bacillus subtilis* , *Staphylococcus aureus* and *Listeria monocytogenes)* and three G-negative strains (*Escherichia coli* , *Salmonella typhimurium* and *Pseudomonas aeruginosa*). The type and concentration of honey sample had significant differences in inhibitory activity against Gram-positive and Gram-negative bacteria. Heat treatment reduced the inhibitory effect of all honey samples. During heat treatment of honey, increasing the heat treatment temperature reduced the inhibitory effect of honey on the growth of *Salmonella typhimurium* . In contrast, all honey samples showed initial inhibitory activity against *E. coli* increases with increasing heat treatment temperature to 60 °C. Then, a further increase in the heat treatment temperature caused a decrease in the growth-inhibiting activity of honey. In this study, TRS of a honey sample showed a significant effect only on antibacterial activity against *S. Typhimurium* . At the same time, the inhibition of other species of tested bacteria did not correlate with the TPC of the honey sample. These results showed that the effect of heat treatment on the antibacterial activity of honey depends on the type of bacteria [32] .

Bucekova, M., Juricova, V., Di Marco, G. et al. studied the effect of heat treatment of honey on its antibacterial activity against bacterial strains *P. aeruginosa* and *S. aureus* . Completely crystallized samples of raw honey were subjected to heat treatment at 45, 55 and 65 °C until completely liquefied. The antibacterial effectiveness of honey was assessed using the minimum inhibitory concentration (MIC) method, where the MIC is the lowest concentration of honey that inhibits bacterial growth by 99%. Thermal liquefaction at 55 and 65 °C did not affect the overall antibacterial activity of honey against *P. aeruginosa* and *S . aureus* . However, the antibacterial activity of honey liquefied at 45°C showed a significant increase in antibacterial activity. The increased antibacterial activity may be due to increased enzymatic activity of glucose oxidases, which leads to higher accumulation of hydrogen peroxide (H2O2) concentrations observed in honey samples heat-treated at 45 °C. [37] . Moussa, A., Noureddine, D., Saad, A. & Abdelmalek, M. studied the effect of temperature on the antifungal activity of eucalyptus honey by analyzing the minimum inhibitory concentration (MIC) of honey against *Candida albicans* . Honey was heat treated at 40, 60 and 80 °C for 24 hours. Heat treatment significantly reduced the antifungal activity of honey, as indicated by an increase in honey MIC from 40% (v/v) for untreated honey to 42%, 44%, and 45% (v/v) for heat-treated honey at 40°, 60°, and 80°. WITH. [38] .

3. The influence of non-thermal processing methods on the antioxidant activity of honey

The effects of non-thermal processing methods on the antioxidant properties of honey are summarized in Table 2.

Table 2. Effect of non-thermal treatment on the antioxidant activity of various types of honey

Type of non-thermal treatment method	Processing conditions	Changes in antioxidant properties	Link
High pressure processing	200, 400 and 600 MPa for 5, 10 and 15 min	Increase in TRS	[39] .
High pressure processing	600 MPa for 10 min.	Increased DPPH radical scavenging activity	[40] .
High pressure processing	600 MPa for 0, 2, 5, 8, 12 and 15 min.	Increased radical scavenging activity of TPC, ORAC	[41] .
High pressure processing	600 MPa for 10 min.	Increased DPPH radical scavenging activity	[42] .
High pressure processing	600 MPa for 10 min.	Increase in TRS	[43] .
High pressure processing	300, 400 and 500 MPa for 5, 10, 15 and 20 min	Enhance TPC, TFC, DPPH radical scavenging activity and FRAP metal ion scavenging activity	[35] .
Ultrasonic treatment	Frequency 40 Hz, heating power 172 W, at 30, 45 and 60 °C for 1, 5 and 10 min.	Enhanced TPC radical scavenging activity, ABTS, DPPH radical scavenging activity and FRAP metal ion scavenging activity	[33] .
Ultrasonic treatment	Frequency 20 Hz and amplitude 20, 40 and 60% for 5, 10, 15 and 20 min.	Enhance TPC, TFC, DPPH radical scavenging activity and FRAP metal ion scavenging activity	[35]
Ultrasonic treatment	Frequency 20 Hz and amplitude 80% for 30 min.	No significant changes in metal ion reduction activities of TPC, TFC and FRAP. Increased DPPH radical scavenging activity	[31]
Irradiation	10 kGy	There is no significant change in the radical scavenging activity of TPC and DPPH.	[44]
Irradiation	25 kGy	Enhanced radical scavenging activity of TPC, TFC and DPPH	[4 5]
Microwave processing	1.26 W/g sample from 2 to 6 min.	Increased TPC, ABTS radical scavenging activity, and DPPH radical scavenging activity in two honeys while decreasing TPC, ABTS radical scavenging activity, and DPPH radical scavenging activity in one honey. Changes depended on biological origin	[thirty]

3.1. High Pressure Treatment (HPP)

A study by Akhmazillah, MFN & Silva, FVM obtained results on the effect of HPP on the TPC of honey processed at 200, 400 and 600 MPa under ambient temperature conditions for 5, 10 and 15 min. [39] .

An increasing trend in TPC was observed with increasing pressure during treatment. The highest increase of 47.16% was recorded under 600 MPa pressure for 10 minutes of treatment. In the same study, honey was also treated with a pressure of 600 MPa at 50, 60 and 70 °C for 5, 10 and 15 min. An increase in temperature did not have a significant effect on the TPC content. Treatment of honey with HPP appears to cause the release of phenolic compounds present in the pollen remaining in the honey, which resulted in an increase in the TPC of HPP-treated honey [40].

Fauzi, NA, Farid, MM & Silva, FVM reported a significant increase (30%) in antioxidant activity (DPPH) of HPP-treated honey at 200, 400 and 600 MPa at near ambient temperature, 25 to 35° C for 10 minutes. Similar results of an increase in the TPC content and antioxidant activity of honey after treatment with HPP were obtained in a study by Leyva-Daniel et . al . Honey was treated at 600 MPa for 0, 2, 5, 8, 12 and 15 min. After a 15-minute treatment at 600 MPa, there was a 6.2% increase in TPC content and a 30% increase in antioxidant activity in honey treated at 600 MPa for 2 minutes [41] .

Razali , M.F., Fauzi, N., Sulaiman, A. & Rahman, A. investigated the effect of HPP treatment at 200 and 600 MPa for 5 and 10 minutes on the antioxidant activity (DPPH) of stingless bee honey. A decrease in antioxidant activity was observed in honey treated with a pressure of 200 MPa for 5 and 10 minutes. In comparison, a 3% increase in antioxidant activity was reported in HPP-treated honey at 600 MPa for 10 min. Another study by these authors reported a significant increase in TPC content from 22.93 to 33.70 mg gallic acid g^{-1} when honey was treated with HPP 600 MPa at room temperature for 10 minutes [42-43] .

Chaikham & Prangthip studied the effect of HPP on honey treated at 300, 400 and 500 MPa for 5, 10, 15 and 20 minutes. At all pressure levels, the antioxidant properties of honey were positively correlated with processing time. The maximum increase in TPC, TFC and antioxidant activity (DPPH and FRAP) was observed in honey subjected to a pressure of 500 MPa at 25 °C for 20 min. [4 4] .

3.2. Ultrasonic treatment

Stojković, M. et . al . The study reported an increase in TPC, ABTS, DPPH and FRAP values in sonicated honey. The honey was sonicated using an ultrasonic bath at 40 kHz. Ultrasonic treatment carried out at 30, 45 and 60 °C for 1, 5 and 10 min led to an increase in TPC, ABTS, DPPH and FRAP. Moreover, TPC and TFC increased with increasing temperature during ultrasonic treatment. Ultrasonication promotes a more complete extraction of bioactive compounds, which may be the reason for the improved antioxidant properties of ultrasonicated honey [30] .

The authors Chaikham & Prangthip studied the effect of ultrasonic treatment with a frequency of 20 Hz and amplitude of 20%, 40% and 60% for 5, 10, 15 and 20 minutes on flower honey. Increases in TPC, TFC and antioxidant activity were observed for all treatment combinations. The maximum increase in TPC, TFC and antioxidant activity was observed at a frequency of 20 Hz, amplitude 60% for 20 min. [35] . However, Chaikham *et al* . found no significant changes in TPC, TFC or antioxidant activity in honey samples treated at 80% amplitude for 30 minutes. In this study, honey samples were sonicated at a combination of 20 Hz frequency and 40% and 80% amplitude levels for 30 minutes. It was observed that sonication at 40% amplitude increased the TPC, TFC, DPPH and FRAP values of all types of honey tested [31].

3.3. Gamma radiation treatment

Saxena, S. et . al . studied the effect of gamma radiation with a dose of 10 kGy on the antioxidant properties of honey and found no significant changes in TPC and antioxidant activity (DPPH). However, Hussein, SZ, Yusoff, KM, Makpol, S. & Yusof, YAM reported an increase in antioxidant activity (DPPH) and antioxidant capacity (TPC and TFC) of honey irradiated with 25 kGy gamma radiation. According to the conclusions of the study authors, irradiation causes radiolysis of water with the formation of hydrogen electrons, hydroxyl radicals and hydrogen atoms. These radicals can liberate some phenolic compounds from the glycosidic components, increasing the amount of phenolic compounds [44-45]

3.4. Microwave processing

Author Kowalski, S. studied the effect of microwave processing of honey on the antioxidant activity of various types (linden, buckwheat, acacia and honeydew) honey. Microwave treatment was carried out in a multimode microwave reactor at a constant power level of 1.26 W $g^{-1.}$ per sample for 2 to 6 minutes. The effect of microwave treatment on antioxidant activity depended on the types of honey samples. A decrease in antioxidant activity was observed in honeydew honey, while it increased in linden and buckwheat honey. Microwave treatment did not have a significant effect on the antioxidant properties of acacia honey. The increased antioxidant activity of microwave-processed honey may result from more complete extraction of phenolics, since microwave energy can increase the availability of phenolics by preventing polyphenol binding [30].

4. The influence of non-thermal processing methods on the antimicrobial properties of honey.

As a result of the analysis of the results of scientific research, it was found that non-thermal processing methods, such as high pressure, gamma radiation, ultrasonic treatment and microwave exposure have different effects on the antibacterial activity of honey. Process parameters and exposure time play an important role in the processing process. The results of the effect of processing on the antimicrobial properties of honey are summarized in Table 3.

Table 3. Effect of non-thermal treatment on the antimicrobial activity of honey

Non-thermal treatment method	Process parameters	Controlled microorganisms	Results of the effect of treatment on antimicrobial activity	Source
High pressure processing	100, 200, 500 and 800 MPa for 15, 60 and 120 min	Gram-positive strain - *Staphylococcus aureus*	Antibacterial activity increased	[46] .
Ultrasonic treatment	Frequency 40 Hz, heating power 172 W, at 30, 45 and 60 °C for 1, 5 and 10 min.	Gram-negative strain - *Escherichia coli, Pseudomonas aeruginosa, Bacillus cereus* and gram-positive strain - *Staphylococcus aureus*	Antibacterial activity increased	[3 3] .
Irradiation treatment	doses from 1 to 15 kGy; dose rate 6.5 kGy h^{-1}	Gram-negative strains - *Salmonella Typhimurium, Bordetella bronchiseptica, Escherichia coli, Pseudomonas fluorescens.* And gram-positive *Bacillus subtilis, Staphylococcus aureus*	Antibacterial activity did not change.	[44] .
Irradiation treatment	Doses of 25 and 50 kGy at a dose rate of 2 kGy h^{-1}	Gram-positive strain - *Staphylococcus aureus*	Antibacterial activity remained unchanged.	[47] .
Irradiation treatment	Dose 10, 20 and 30 kGy	Gram-negative strain - *Pseudomonas aeruginosa* and gram-positive strain - *Staphylococcus aureus*	Antibacterial activity remained unchanged.	[48] .
Microwave processing	800, 400 and 80 W for 10, 30, 50, 60, 120 and 180 s.	Gram-negative strain - *Pseudomonas aeruginosa* and gram-positive strain - *Staphylococcus aureus*	Antibacterial activity reduced	[4 9] [50] .

Conclusion. A review and analysis of the results of scientific research showed that the influence of thermal and non-thermal methods of processing honey on its antioxidant and antibacterial properties largely depends on the biological origin of honey. Heat treatment has a detrimental effect on the antioxidant and antimicrobial activity of honey. The results of some studies have shown an increase in antioxidant activity, which may be due to the formation of non-nutritive antioxidants such as Maillard reaction products, as well as the leaching of phenolic compounds from pollen remaining in honey, which occurs at higher temperatures during heat treatment. The formation of HMF as a product of the Maillard reaction is of particular importance, since HMF is an indicator of honey quality throughout the world. Most of the studied samples showed a decrease in the antioxidant capacity of honey after heat treatment.

Among non-thermal processing methods, gamma irradiation has minimal or no effect on the antioxidant and antibacterial properties of honey. Microwave treatment, which was carried out with different powers from 1.2 to 16 W/g with a treatment duration of 10–180 s. had a negative impact on the antioxidant and antimicrobial properties of honey, as heat is generated during the processing process. Although the processing time was short compared to conventional heat treatment, it negatively affected the quality of the honey by reducing the antioxidant and antimicrobial activity of the honey.

During microwave processing, the change in antioxidant activity is influenced by the biological origin of honey. The use of ultrasonic processing of honey with a frequency of 20 Hz, amplitude from 20% to 80% and processing time from 5 to 30 minutes helps to increase the antioxidant activity of honey by increasing the content of phenols and flavonoids. However, it should be noted that during ultrasonic processing the temperature of honey increases, which can have a negative impact on honey quality parameters such as HMF content and diastase activity. Treatment of HPP at pressures from 200 to 600 MPa helps to increase the antioxidant properties of honey.

It has been established that gamma irradiation helps preserve the antioxidant activity and antibacterial properties of honey. The main disadvantage of this processing method is the high cost of processing and special requirements for the irradiation process. For this reason, this processing method is most suitable for sterilizing honey used for medical purposes.

The presented scientific review can be used for further scientific research, as well as for enterprises collecting and processing honey in choosing the optimal processing methods during the production process.

ЛИТЕРАТУРА

1. Макарова Н. В., Игнатова Д. Ф. Изучение возможности использования разных видов меда в качестве антиоксиданта // Инновации и продовольственная безопасность. 2019. № 4 (26). С. 24–30. DOI: 10.31677/2311-0651-2019-26-4-24-30. EDN CANGCC.
2. Akaba D, Atemkeng TF, Malep Mayama BB, Moutila IL, Achu M, Fokou E, Pieme CA, Djam CA. Evaluation of Burns Wound Healing Properties of Different Varieties of Honey from Cameroun. Journal of Applied Life Sciences International. 2023;26(2):1–7 https://doi.org/10.9734/jalsi/2023/v26i2598
3. Ilia G, Simulescu V, Merghes P, Varan N. The health benefits of honey as an energy source with antioxidant, antibacterial and antiseptic effects. Science & Sports. 2021;36(4):272-e1. https://doi.org/10.1016/j.scispo.2020.10.005
4. Rabby MII, Hossain F, Islam MA, Islam A, Akhi IJ, Akter F. Impact of supplemental vitamins and natural honey for treatment of covid-19: A review. Brazilian Journal of Pharmaceutical Sciences. 2022;58:e20607. https://doi.org/10.1590/s2175-97902022e20607
5. Yu W, Sun F, Xu R et al. Chemical composition and anti-inflammatory activities of Castanopsis honey. Food & Function. 2023;14:250–261. https://doi.org/10.1039/D2FO02233H
6. Zubi ZBH, Alfarisi HAH, Ibrahim MB. Antioxidant protective effect of trihoney against hypercholesterolemia-induced testicular oxidative stress in rabbit model // World Journal of Pharmacy and Pharmaceutical Sciences. 2023;121:336–1348.
7. Saxena S, Gautam S, Maru G, Kawle D, Sharma A. Suppression of error prone pathway is responsible for antimutagenic activity of honey. Food and Chemical Toxicology. 2012;50:625–633. https://doi.org/10.1016/j.fct.2012.01.003
8. Fukuda M, Kobayashi K, Hirono Y et al. Jungle honey enhances immune function and antitumor activity. Evidence-Based Complementary and Alternative Medicine. 2011:743.
9. Alvarez-Suarez MJ, Giampieri F, Battino M. Honey as a source of dietary antioxidants:

structures, bioavailability and evidence of protective effects against human chronic diseases. Current Medicinal Chemistry. 2017;20: 621–638.

10. Cianciosi D, Forbes-Hernández TY, Afrin S et al. Phenolic compounds in honey and their associated health benefits: A review. Molecules. 2018;23:2322. https://doi.org/10.3390/molecules23092322

11. Sereia MJ, Março PH, Perdoncini MRG, Parpinelli RS, De Lima EG, Anjo FA. Techniques for the evaluation of physicochemical quality and bioactive compounds in honey. In: Honey Analysis (edited by V.D.A.A. Toledo). Croatia: IntechOpen. 2017

12. Zammit Young G.-W, Blundell R. A review on the phytochemical composition and health applications of honey. Heliyon. 2023;9:e12507.

13. Abou El-Soud NH. Honey between traditional uses and recent medicine // Macedonian Journal of Medical Sciences (Archived). 2012;5:205–214.

14. Mele E. Electrospinning of honey and propolis for wound care // Biotechnology and Bioengineering. 2023;120:1229–1240. https://doi.org/10.1002/bit.28341

15. Da Silva PM, Gauche C, Gonzaga LV, Costa ACO, Fett R. Honey: chemical composition, stability and authenticity. Food Chemistry. 2016;196:309–323.

16. Commission CA. Codex Aalimentarius International Food Standards, Standards for Honey. Standards for Honey. Rome: FAO/WHO. 2019.

17. Haouam L, Dailly H, Bruneau E, Tahar A. The quality of honeys influenced by the traditional heating methods. Journal of Microbiology, Biotechnology and Food Sciences. 2019;8:1271–1275. https://doi.org/10.15414/jmbfs.2019.8.6.1276-1280

18. Zarei M, Fazlara A, Tulabifard N. Effect of thermal treatment on physicochemical and antioxidant properties of honey. Heliyon. 2019;5:e01894. https://doi.org/10.1016/j.heliyon.2019.e01894

19. Elamine Y, Anjos O, Estevinho LM, Lyoussi B, Aazza S, Miguel MG. Effect of extreme heat processing on the Moroccan Zantaz' honey antioxidant activities. Journal of Food Science and Technology. 2020;57:3323–3333. https://doi.org/10.1007/s13197-020-04365-x

20. Akaba D, Atemkeng T. F, Malep Mayama B. B, Moutila I. L, Achu M, Fokou E., Pieme C. A, Djam C.A. Evaluation of Burns Wound Healing Properties of Different Varieties of Honey from Cameroun. Journal of Applied Life Sciences International. 2023. Vol. 10;26(2):1–7. https://doi.org/10.9734/jalsi/2023/v26i2598

21. Jalal SM, Amloqel RA, Aljaber SA, Ali Al-Abdulwahed JA, Aldossary RA, Ali Hakami MA. Effect of honey dressing on wound healing among patients with diabetic foot ulcer at Al-Ahsa, Saudi Arabia. International Journal of Nursing Care. 2023;11:33– 41.

22. Miłek M. The antioxidant, antibacterial and anti-biofilm properties of rapeseed creamed honey enriched with selected plant superfoods. Antibiotics. 2023. Vol. 12. P. 235. https://doi.org/10.3390/antibiotics12020235

23. Awad N.-A, Hamad AH. Honey can help in herpes simplex gingivostomatitis in children: prospective randomised double blind placebo controlled clinical trial. American Journal of Otolaryngology. 2018;39;759–763. https://doi.org/10.1016/j.amjoto.2018.09.007

24. Abbas AC, Alwaeli AZ, Abbas EC, Mohamed A. Effect of honey consumed of covid-19 patients over time and changes in concentrations levels of antioxidants and oxidative stress in the patients over time and compare with control group. Annals of the Romanian Society for Cell Biology. 2021;25:8961–8974.

25. Soares S, Bornet M, Grosso C et al. Honey as an adjuvant in the treatment of covid-19 infection: A review. Applied Sciences. 2022;12:7800. https://doi.org/10.3390/app12157800

26. Eshete YA, Eshete T. Eshete T. Review on the effect of processing temperature and time duration on commercial honey quality. Madridge Journal of Food Technology. 2019;(4):158–162. https://doi.org/10.18689/mjft-1000124

27. Braghini F, Biluca FC, Gonzaga LV, Vitali L, Costa ACO, Fett R. Effect thermal processing in the honey of Tetragonisca angustula: profile physicochemical, individual phenolic compounds and antioxidant capacity. Journal of Apicultural Research. 2021;60:290–296. https://doi.org/10.1080/00218839.2020.1737362

28. Tiwari BK, Mason TJ. Chapter 6-ultrasound processing of fluid foods. In: Novel Thermal and Non-thermal Technologies for Fluid Foods (edited by PJ Cullen, BK Tiwari, VP Valdramidis). 2018. San Diego: Academic Press. https://doi.org/10.1016/B978-0-12-381470-8.00006-2

29. Gupta R, Balasubramaniam VM. Chapter 5-high-pressure processing of fluid foods.. In: Novel Thermal and Non-thermal Technologies for Fluid Foods (edited by PJ Cullen, BK Tiwari, VP Valdramidis). San Diego: Academic Press. 2012. https://doi.org/10.1016/B978-0-12-381470-8.00005-0

30. Kowalski S. Changes of antioxidant activity and formation of 5-hydroxymethylfurfural in honey during thermal and microwave processing. Food Chemistry;2013:141:1378–1382. https://doi.org/10.1016/j.foodchem.2013.04.025

31. Chaikham P, Kemsawasd V, Apichartsrangkoon A. Effects of conventional and ultrasound treatments on physicochemical properties and antioxidant capacity of floral honeys from northern Thailand. Food Bioscience. 2016;15:19–26. https://doi.org/10.1016/j.fbio.2016.04.002

32. Pimentel-González DJ, Basilio-Cortes UA, Hernández-Fuentes AD, Figueira AC, Quintero-Lira A, Campos-Montiel RG. Effect of thermal processing on antibacterial activity of Multifloral honeys. Journal of Food Process Engineering. 2017;40:e12279. https://doi.org/10.1111/jfpe.12279

33. Stojković M, Cvetković D, Savić A et al. Changes in the physicochemical, antioxidant and antibacterial properties of honeydew honey subjected to heat and ultrasound pretreatments. Journal of Food Science and Technology. 2021;58:2555–2566. https://doi.org/10.1007/s13197-020-04762-2

34. Jahan N, Islam MA, Alam F, Gan SH, Khalil MI. Prolonged heating of honey increases its antioxidant potential but decreases its antimicrobial activity. African Journal of Traditional, Complementary and Alternative Medicines. 2015;12:134–144. https://doi.org/10.4314/ajtcam.v12i4.20

35. Chaikham P, Prangthip P. Alteration of antioxidative properties of longan flower-honey after high pressure, ultra-sonic and thermal processing. Food Bioscience. 2015;10:1– 7. https://doi.org/10.1016/j.fbio.2015.01.002

36. Šarić G, Marković K, Vukicevic D, Lez E, Hruskar M, Vahcić N. Changes of antioxidant activity in honey after heat treatment // Czech Journal of Food Sciences. 2013;31:601– 606. DOI: 10.17221/509/2012-CJFS

37. Bucekova M, Juricova V, Di Marco G et al. Effect of thermal liquefying of crystallised honeys on their antibacterial activities. Food Chemistry. 2018;269:335–341. https://doi.org/10.1016/j.foodchem.2018.07.012

38. Moussa A, Noureddine D, Saad A, Abdelmalek M. Influence of temperature on the inhibitory potency of eucalyptus honey against Candida albicans. Asian Pacific Journal of Tropical Disease. 2012;2:S567–S570. https://doi.org/10.1016/S2222-1808(12)60222-9

39. Akhmazillah MFN, Farid MM, Silva FVM. High pressure processing (hpp) of honey for the improvement of nutritional value. Innovative Food Science & Emerging Technologies. 2013;20:59–63. https://doi.org/10.1016/j.ifset.2013.06.012

40. Fauzi N. A., Farid M. M., Silva F. V. M. High-pressure processing of manuka honey: improvement of antioxidant activity, preservation of colour and flow behaviour // Food and Bioprocess Technology. 2014. Vol. 7. P. 2299–2307. https://doi.org/10.1007/s11947-013-1204-7

41. Leyva-Daniel DE, Escobedo-Avellaneda Z, Villalobos-Castillejos F, Alamilla-Beltrán L, Welti-Chanes J. Effect of high hydrostatic pressure applied to a Mexican honey to increase its microbiological and functional quality. Food and Bioproducts Processing. 2017;102:299–306.

42. Razali MF, Fauzi N, Sulaiman A, Rahman A. Effect of high-pressure processing (hpp) on antioxidant, diastase activity and colour for kelulut (stingless bee) honey. Jurnal Teknologi. 2019;81:91– 98.

43. Razali M, Mohd Fauzi NA, Sulaiman A, Talip BA, Rahman AAF. Effect of high-pressure processing on prebiotic potential of stingless bee (kelulut) honey: tested upon Lactobacillus acidophilus and Lactobacillus brevis // Journal of Food Processing and Preservation. 2019;43:1–10. https://doi.org/10.1111/jfpp.13946

44. Saxena S, Gautam S, Sharma A. Microbial decontamination of honey of Indian origin using gamma radiation and its biochemical and organoleptic properties. Journal of Food Science. 2010;75:M19–M27. https://doi.org/10.1111/j.1750-3841.2009.01405.x

45. Hussein SZ, Yusoff KM, Makpol S, Yusof YAM. Antioxidant capacities and total phenolic contents increase with gamma irradiation in two types of Malaysian honey. Molecules. 2011;16:6378–6395. https://doi.org/10.3390/molecules16086378

46. Al-Habsi NA, Niranjan K. Effect of high hydrostatic pressure on antimicrobial activity and quality of Manuka honey. Food Chemistry. 2012;135:1448–1454. https://doi.org/10.1016/j.foodchem.2012.06.012

47. Yusof N, Ainul Hafiza AH, Zohdi RM, Bakar MZ. A. Development of honey hydrogel dressing for enhanced wound healing // Radiation Physics and Chemistry. 2007;76:1767–1770. https://doi.org/10.1016/j.radphyschem.2007.02.107

48. Horniackova M, Bucekova M, Valachova I, Majtan J. Effect of gamma radiation on the antibacterial and antibiofilm activity of honeydew honey. European Food Research and Technology. 2017;243:81–88. https://doi.org/10.1007/s00217-016-2725-x

49. Bucekova M, Juricova V, Di Marco G et al. Effect of thermal liquefying of crystallised honeys on their antibacterial activities. Food Chemistry. 2018;269:335–341. https://doi.org/10.1016/j.foodchem.2018.07.012

50. Bucekova M, Juricova V, Monton E, Martinotti S, Ranzato E, Majtan J. Microwave processing of honey negatively affects honey antibacterial activity by inactivation of bee-derived glucose oxidase and defensin-1. Food Chemistry. 2018;240:1131–1136. https://doi.org/10.1016/j.foodchem.2017.08.054

REFERENCES

1. Makarova NV, Ignatova DF. Izuchenie vozmozhnosti ispol'zovaniya raznykh vidov meda v kachestve antioksidanta. Innovatsii i prodovol'stvennaya bezopasnost'. 2019;4(26):24–30. DOI: 10.31677/2311-0651-2019-26-4-24-30. EDN CANGCC.

2. Akaba D, Atemkeng TF, Malep Mayama BB, Moutila IL, Achu M, Fokou E, Pieme CA, Djam CA. Evaluation of Burns Wound Healing Properties of Different Varieties of Honey from Cameroun. Journal of Applied Life Sciences International. 2023;26(2):1–7 https://doi.org/10.9734/jalsi/2023/v26i2598

3. Ilia G, Simulescu V, Merghes P, Varan N. The health benefits of honey as an energy source with antioxidant, antibacterial and antiseptic effects. Science & Sports. 2021;36(4):272-e1. https://doi.org/10.1016/j.scispo.2020.10.005

4. Rabby MII, Hossain F, Islam MA, Islam A, Akhi IJ, Akter F. Impact of supplemental vitamins and natural honey for treatment of covid-19: A review. Brazilian Journal of Pharmaceutical Sciences. 2022;58:e20607. https://doi.org/10.1590/s2175-97902022e20607

5. Yu W, Sun F, Xu R et al. Chemical composition and anti-inflammatory activities of Castanopsis honey. Food & Function. 2023;14:250–261. https://doi.org/10.1039/D2FO02233H

6. Zubi ZBH, Alfarisi HAH, Ibrahim MB. Antioxidant protective effect of trihoney against hypercholesterolemia-induced testicular oxidative stress in rabbit model // World Journal of Pharmacy and Pharmaceutical Sciences. 2023;121:336–1348.

7. Saxena S, Gautam S, Maru G, Kawle D, Sharma A. Suppression of error prone pathway is responsible for antimutagenic activity of honey. Food and Chemical Toxicology. 2012;50:625–633. https://doi.org/10.1016/j.fct.2012.01.003

8. Fukuda M, Kobayashi K, Hirono Y et al. Jungle honey enhances immune function and antitumor activity. Evidence-Based Complementary and Alternative Medicine. 2011:743.

9. Alvarez-Suarez MJ, Giampieri F, Battino M. Honey as a source of dietary antioxidants: structures, bioavailability and evidence of protective effects against human chronic diseases. Current Medicinal Chemistry. 2017;20: 621–638.

10. Cianciosi D, Forbes-Hernández TY, Afrin S et al. Phenolic compounds in honey and their associated health benefits: A review. Molecules. 2018;23:2322. https://doi.org/10.3390/molecules23092322

11. Sereia MJ, Março PH, Perdoncini MRG, Parpinelli RS, De Lima EG, Anjo FA. Techniques for the evaluation of physicochemical quality and bioactive compounds in honey. In: Honey Analysis (edited by V.D.A.A. Toledo). Croatia: IntechOpen. 2017

12. Zammit Young G.-W, Blundell R. A review on the phytochemical composition and health applications of honey. Heliyon. 2023;9:e12507.

13. Abou El-Soud NH. Honey between traditional uses and recent medicine // Macedonian Journal of Medical Sciences (Archived). 2012;5:205–214.

14. Mele E. Electrospinning of honey and propolis for wound care // Biotechnology and Bioengineering. 2023;120:1229–1240. https://doi.org/10.1002/bit.28341

15. Da Silva PM, Gauche C, Gonzaga LV, Costa ACO, Fett R. Honey: chemical composition, stability and authenticity. Food Chemistry. 2016;196:309–323.

16. Commission CA. Codex Aalimentarius International Food Standards, Standards for Honey. Standards for Honey. Rome: FAO/WHO. 2019.

17. Haouam L, Dailly H, Bruneau E, Tahar A. The quality of honeys influenced by the traditional heating methods. Journal of Microbiology, Biotechnology and Food Sciences. 2019;8:1271–1275. https://doi.org/10.15414/jmbfs.2019.8.6.1276-1280

18. Zarei M, Fazlara A, Tulabifard N. Effect of thermal treatment on physicochemical and antioxidant properties of honey. Heliyon. 2019;5:e01894. https://doi.org/10.1016/j.heliyon.2019.e01894

19. Elamine Y, Anjos O, Estevinho LM, Lyoussi B, Aazza S, Miguel MG. Effect of extreme heat processing on the Moroccan Zantaz' honey antioxidant activities. Journal of Food Science and Technology. 2020;57:3323–3333. https://doi.org/10.1007/s13197-020-04365-x

20. Akaba D, Atemkeng T. F, Malep Mayama B. B, Moutila I. L, Achu M, Fokou E., Pieme C. A, Djam C.A. Evaluation of Burns Wound Healing Properties of Different Varieties of Honey from Cameroun. Journal of Applied Life Sciences International. 2023. Vol. 10;26(2):1–7. https://doi.org/10.9734/jalsi/2023/v26i2598

21. Jalal SM, Amloqel RA, Aljaber SA, Ali Al-Abdulwahed JA, Aldossary RA, Ali Hakami MA. Effect of honey dressing on wound healing among patients with diabetic foot ulcer at Al-Ahsa, Saudi Arabia. International Journal of Nursing Care. 2023;11:33– 41.

22. Miłek M. The antioxidant, antibacterial and anti-biofilm properties of rapeseed creamed honey enriched with selected plant superfoods. Antibiotics. 2023. Vol. 12. P. 235. https://doi.org/10.3390/antibiotics12020235

23. Awad N.-A, Hamad AH. Honey can help in herpes simplex gingivostomatitis in children: prospective randomised double blind placebo controlled clinical trial. American Journal of Otolaryngology. 2018;39;759–763. https://doi.org/10.1016/j.amjoto.2018.09.007

24. Abbas AC, Alwaeli AZ, Abbas EC, Mohamed A. Effect of honey consumed of covid-19 patients over time and changes in concentrations levels of antioxidants and oxidative stress in the patients over time and compare with control group. Annals of the Romanian Society for Cell Biology. 2021;25:8961–8974.

25. Soares S, Bornet M, Grosso C et al. Honey as an adjuvant in the treatment of covid-19 infection: A review. Applied Sciences. 2022;12:7800. https://doi.org/10.3390/app12157800

26. Eshete YA, Eshete T. Eshete T. Review on the effect of processing temperature and time duration on commercial honey quality. Madridge Journal of Food Technology. 2019;(4):158–162. https://doi.org/10.18689/mjft-1000124

27. Braghini F, Biluca FC, Gonzaga LV, Vitali L, Costa ACO, Fett R. Effect thermal processing in the honey of Tetragonisca angustula: profile physicochemical, individual phenolic compounds and antioxidant capacity. Journal of Apicultural Research. 2021;60:290–296. https://doi.org/10.1080/00218839.2020.1737362

28. Tiwari BK, Mason TJ. Chapter 6-ultrasound processing of fluid foods. In: Novel Thermal and Non-thermal Technologies for Fluid Foods (edited by PJ Cullen, BK Tiwari, VP Valdramidis). 2018. San Diego: Academic Press. https://doi.org/10.1016/B978-0-12-381470-8.00006-2

29. Gupta R, Balasubramaniam VM. Chapter 5-high-pressure processing of fluid foods.. In:

Novel Thermal and Non-thermal Technologies for Fluid Foods (edited by PJ Cullen, BK Tiwari, VP Valdramidis). San Diego: Academic Press. 2012. https://doi.org/10.1016/B978-0-12-381470-8.00005-0

30. Kowalski S. Changes of antioxidant activity and formation of 5-hydroxymethylfurfural in honey during thermal and microwave processing. Food Chemistry;2013:141:1378–1382. https://doi.org/10.1016/j.foodchem.2013.04.025

31. Chaikham P, Kemsawasd V, Apichartsrangkoon A. Effects of conventional and ultrasound treatments on physicochemical properties and antioxidant capacity of floral honeys from northern Thailand. Food Bioscience. 2016;15:19–26. https://doi.org/10.1016/j.fbio.2016.04.002

32. Pimentel-González DJ, Basilio-Cortes UA, Hernández-Fuentes AD, Figueira AC, Quintero-Lira A, Campos-Montiel RG. Effect of thermal processing on antibacterial activity of Multifloral honeys. Journal of Food Process Engineering. 2017;40:e12279. https://doi.org/10.1111/jfpe.12279

33. Stojković M, Cvetković D, Savić A et al. Changes in the physicochemical, antioxidant and antibacterial properties of honeydew honey subjected to heat and ultrasound pretreatments. Journal of Food Science and Technology. 2021;58:2555–2566. https://doi.org/10.1007/s13197-020-04762-2

34. Jahan N, Islam MA, Alam F, Gan SH, Khalil MI. Prolonged heating of honey increases its antioxidant potential but decreases its antimicrobial activity. African Journal of Traditional, Complementary and Alternative Medicines. 2015;12:134–144. https://doi.org/10.4314/ajtcam.v12i4.20

35. Chaikham P, Prangthip P. Alteration of antioxidative properties of longan flower-honey after high pressure, ultra-sonic and thermal processing. Food Bioscience. 2015;10:1– 7. https://doi.org/10.1016/j.fbio.2015.01.002

36. Šarić G, Marković K, Vukicevic D, Lez E, Hruskar M, Vahcić N. Changes of antioxidant activity in honey after heat treatment // Czech Journal of Food Sciences. 2013;31:601– 606. DOI: 10.17221/509/2012-CJFS

37. Bucekova M, Juricova V, Di Marco G et al. Effect of thermal liquefying of crystallised honeys on their antibacterial activities. Food Chemistry. 2018;269:335–341. https://doi.org/10.1016/j.foodchem.2018.07.012

38. Moussa A, Noureddine D, Saad A, Abdelmalek M. Influence of temperature on the inhibitory potency of eucalyptus honey against Candida albicans. Asian Pacific Journal of Tropical Disease. 2012;2:S567–S570. https://doi.org/10.1016/S2222-1808(12)60222-9

39. Akhmazillah MFN, Farid MM, Silva FVM. High pressure processing (hpp) of honey for the improvement of nutritional value. Innovative Food Science & Emerging Technologies. 2013;20:59–63. https://doi.org/10.1016/j.ifset.2013.06.012

40. Fauzi N. A., Farid M. M., Silva F. V. M. High-pressure processing of manuka honey: improvement of antioxidant activity, preservation of colour and flow behaviour // Food and Bioprocess Technology. 2014. Vol. 7. P. 2299–2307. https://doi.org/10.1007/s11947-013-1204-7

41. Leyva-Daniel DE, Escobedo-Avellaneda Z, Villalobos-Castillejos F, Alamilla-Beltrán L, Welti-Chanes J. Effect of high hydrostatic pressure applied to a Mexican honey to increase its microbiological and functional quality. Food and Bioproducts Processing. 2017;102:299–306.

42. Razali MF, Fauzi N, Sulaiman A, Rahman A. Effect of high-pressure processing (hpp) on antioxidant, diastase activity and colour for kelulut (stingless bee) honey. Jurnal Teknologi. 2019;81:91– 98.

43. Razali M, Mohd Fauzi NA, Sulaiman A, Talip BA, Rahman AAF. Effect of high-pressure processing on prebiotic potential of stingless bee (kelulut) honey: tested upon Lactobacillus acidophilus and Lactobacillus brevis // Journal of Food Processing and Preservation. 2019;43:1–10. https://doi.org/10.1111/jfpp.13946

44. Saxena S, Gautam S, Sharma A. Microbial decontamination of honey of Indian origin using gamma radiation and its biochemical and organoleptic properties. Journal of Food Science. 2010;75:M19–M27. https://doi.org/10.1111/j.1750-3841.2009.01405.x

45. Hussein SZ, Yusoff KM, Makpol S, Yusof YAM. Antioxidant capacities and total phenolic

contents increase with gamma irradiation in two types of Malaysian honey. Molecules. 2011;16:6378–6395. https://doi.org/10.3390/molecules16086378

46. Al-Habsi NA, Niranjan K. Effect of high hydrostatic pressure on antimicrobial activity and quality of Manuka honey. Food Chemistry. 2012;135:1448–1454. https://doi.org/10.1016/j.foodchem.2012.06.012

47. Yusof N, Ainul Hafiza AH, Zohdi RM, Bakar MZ. A. Development of honey hydrogel dressing for enhanced wound healing // Radiation Physics and Chemistry. 2007;76:1767–1770. https://doi.org/10.1016/j.radphyschem.2007.02.107

48. Horniackova M, Bucekova M, Valachova I, Majtan J. Effect of gamma radiation on the antibacterial and antibiofilm activity of honeydew honey. European Food Research and Technology. 2017;243:81–88. https://doi.org/10.1007/s00217-016-2725-x

49. Bucekova M, Juricova V, Di Marco G et al. Effect of thermal liquefying of crystallised honeys on their antibacterial activities. Food Chemistry. 2018;269:335–341. https://doi.org/10.1016/j.foodchem.2018.07.012

50. Bucekova M, Juricova V, Monton E, Martinotti S, Ranzato E, Majtan J. Microwave processing of honey negatively affects honey antibacterial activity by inactivation of bee-derived glucose oxidase and defensin-1. Food Chemistry. 2018;240:1131–1136. https://doi.org/10.1016/j.foodchem.2017.08.054

ИНФОРМАЦИЯ ОБ АВТОРАХ

Леонид Чеславович Бурак – кандидат технических наук, директор Общества с ограниченной ответственностью «БЕЛРОСАКВА», ул. Пономаренко, д. 35А, пом. 610, г. Минск, 220015, Республика Беларусь, +375173774151, +375296466525

Вероника Владимировна Яблонская – главный технолог Совместного общества с ограниченной ответственностью «Ароматик», ул. Колхозная, д. 1, г. Джержинск, 222112, Республика Беларусь, +375296303067, v_taiy@mail.ru

Александр Николаевич Сапач – инженер-химик Общества с ограниченной ответственностью «БЕЛРОСАКВА», ул. Пономаренко, д. 35А, пом. 610, г. Минск, 220015, Республика Беларусь, +375173774151, +375297569519, sapabra7@gmail.com

INFORMATION ABOUT THE AUTHORS

Leonid Ch. Burak – Cand. Sci. (Tech.), Manager, BELROSAKVA Limited Liability Company, 35A, 610 room, Ponomarenko st., Minsk, 220015, Republic of Belarus, +375173774151, +375296466525

Veronika V. Yablonskaya – Chief Technologist, Aromatik Joint Limited Liability, 1, st. Kolhoznaya, Dzerjinsk, 222112, Republic of Belarus, +375296303067, v_taiy@mail.ru

Aleksandr N. Sapach – Chemist, BELROSAKVA Limited Liability Company, 35A, 610 room, Ponomarenko st., Minsk, 220015, Republic of Belarus, +375173774151, +375297569519, sapabra7@gmail.com

Вклад авторов: все авторы внесли равный вклад в подготовку публикации.
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Contribution of the authors: the authors contributed equally to this article.
Conflict of interest: the authors declare no conflicts of interests.

Статья поступила в редакцию: 11.07.2023;
одобрена после рецензирования: 15.08.2023;
принята к публикации: 08.09.2023.

The article was submitted: 11.07.2023;
approved after reviewing: 15.08.2023;
accepted for publication: 08.09.2023.