No. 138/2026, 36–49
ISSN 2657-6988 (online)
ISSN 2657-5841 (printed)
DOI: 10.26408/138.04

Submitted: 10.10.2025
Accepted: 11.02.2026
Published: 30.06.2026

STORAGE CHANGES IN THE HEALTH POTENTIAL OF MANUKA AND GOLDENROD HONEY DUE TO THERMAL CONDITIONING

Tomasz Pukszta[1]*, Monika Kunzová[2], Wiktoria Raszeja[3]

[1] Gdynia Maritime University, ul. Morska 81-87, 81-225 Gdynia, Poland,
Faculty of Management and Quality Sciences, Department of Quality Management,
ORCID 0000-0003-4587-4505, e-mail: t.pukszta@wznj.umg.edu.pl

[2] Masaryk University, Kamenice 753/5, 625 00 Brno, Czech Republic,
Faculty of Medicine, Institute of Public Health,
ORCID 0000-0002-7834-428X, e-mail: monika.kunzova@med.muni.cz

[3] Gdynia Maritime University, ul. Morska 81-87, 81-225 Gdynia, Poland,
Faculty of Management and Quality Sciences, Department of Quality Management,
e-mail: wiktoriatczew27@wp.pl

* Corresponding author

Abstract: This study aims to assess the stability of the health potential of manuka and goldenrod honeys during storage. The water content in honeys was determined by refractometry, while the total polyphenol content was determined by the Folin-Ciocalteu method, and the antioxidant activities against the DPPH radical and the ABTS cation were determined. These determinations were made before storage and at 4-week intervals during the 16-week storage of the honeys, at 5°C, 20°C, and 30°C. The results were statistically analyzed using Student's t-test, multivariate analysis of variance (MANOVA), and Tukey's post hoc test. The results showed that manuka honey contained significantly more polyphenolic compounds and had a higher antioxidant capacity than goldenrod honey. Storage-induced changes in health potential occurred more rapidly in goldenrod honey than in manuka honey. The rate of these changes was determined by storage temperature. The slowest rate of decomposition was at 5°C, and the fastest at 30°C. Therefore, it can be concluded, that the most favorable temperature for storing opened honey packages is 5°C.

Keywords: manuka honey, goldenrod honey, health quality, storage temperature, honey storage.

1. INTRODUCTION

Honey is a natural bee product that has been valued for centuries, not only for its flavor but also for its high health benefits stemming from its bioactive compounds, including polyphenols, and its ability to neutralize free radicals, making it a natural antioxidant.

In Poland, the most popular honeys are those made from linden, acacia, buckwheat, rapeseed, and heather [Bąkowska & Janda, 2018].

However, in recent years, manuka honey has become increasingly popular worldwide. It is produced only in New Zealand, in regions where rare *Leptospermum scoparium* shrubs grow. This honey is considered one of the healthiest in the world due to its high methylglyoxal content. Manuka honey exhibits potent antibacterial and antioxidant properties. It also has high antiviral activity, making it a potential adjunct to the treatment of viral infections by inhibiting influenza virus replication. [Czajkowski et al., 2017].

Goldenrod honey, sometimes referred to as "the honey of life", is often compared to manuka honey due to its rich polyphenolic profile. Its flavonoids and ferulic acid contribute to mild diuretic and choleretic effects, supporting detoxification and potentially aiding in the management of urinary tract conditions [Różański et al., 2016].

It also exhibits anti-inflammatory, antispasmodic, and wound-healing properties, which may be beneficial in selected health contexts [Madras-Majewska, 2023].

Nevertheless, while honey can provide meaningful nutritional and functional benefits, it should be viewed as a supportive element within a balanced diet rather than a therapeutic agent. Its biological effects are influenced by composition, dosage, and storage conditions, including temperature, humidity, and light exposure, which may affect crystallization, fermentation, and degradation of bioactive compounds [Moise, 2025].

It is generally accepted that honey should be stored at 20°C. However, opinions on this matter are divided, especially regarding storing honey after the first opening of the package and using it periodically [Şireli & Saylak, 2025].

After opening a package of honey and taking the first serving, consumers store it in a refrigerator or a kitchen cabinet at approximately 20°C. Honey storage conditions affect its health potential, including the content of bioactive components and antioxidant activity.

The increasing popularity of manuka and goldenrod honey and consumers' use of different storage temperatures make it necessary to research the stability of honey's health potential under various thermal conditions.

The study aimed to assess the stability of the health-promoting potential of manuka and goldenrod honey at different storage temperatures.

2. RESEARCH MATERIAL AND METHODS

The research material consisted of packages of MGO 100^{+} manuka honey produced by Manuka Health New Zealand and goldenrod honey supplied by the manufacturer, Dolina Tatr. All the honey was produced in 2024.

The honeys were purchased from online stores, nine jars each. All jars contained raw, unpasteurized honey, which preserved its natural bioactive and enzymatic properties.

The honeys were analyzed for water content, total polyphenol content, and antioxidant activity against the DPPH radical and the ABTS cation radical. After opening a container of honey, some consumers store it in the refrigerator, while others store it in a room at around 20°C, sometimes even 30°C, especially in the summer. The average consumer uses up a jar of honey within 12-16 weeks. With this in mind, the research material was stored at 5°C, 20°C, and 30°C for 16 weeks.

Water content and health-related parameters were determined at 4-week intervals over a 16-week storage period. Reflecting the way honey is stored and handled at home, samples were taken from the same jars for each test.

The water content, expressed as a percentage by weight, corresponding to the determined refractive index or extract, was measured by refractometry in liquid honey.

Approximately 5 g of honey was placed in a test tube, the tube was closed with a cork, and the tube was placed in a water bath at 40°C to decrystallize the honey. Using a glass rod, a few drops of honey were placed on the dry prism of an HI96800 digital refractometer, and the refractive index (n_D^{20}) was read. The water content (by weight), corresponding to the determined refractive index, was then read from tables showing the relationship between the refractive index (refraction), water content (% m/m), and extract in honey [Regulation of the Minister of Agriculture and Rural Development of January 14, 2009].

The content of polyphenolic compounds was determined using the Folin-Ciocalteu method. A 2.5 g sample of product was weighed, and 15 cm^3 of 80% methyl alcohol was added to extract the test product. Extraction was performed for 24 hours at room temperature, protected from light. After the specified time, the extract was centrifuged for 20 minutes at 1130 rpm and then filtered. The filtered extract was transferred to a 25 cm^3 volumetric flask and adjusted to the desired volume with 80% methyl alcohol.

The obtained extract was used to determine the content of polyphenolic compounds and antioxidant activity against the DPPH radical and the ABTS cation radical.

0.1 cm^3 of each extract solution, 6 cm^3 of distilled water, and 0.5 cm^3 of Folin--Ciocalteu's reagent was taken into volumetric flasks (10 cm^3 capacity), mixed well, and left for 3 minutes. A total of 1.5 cm^3 of saturated sodium carbonate solution was then added, the volume was made up to the mark with distilled water, and then it was mixed. The prepared samples were incubated at 40ºC for 30 minutes. The absorbance was then measured at 765 nm.

The results of the determinations were expressed as the amount of gallic acid equivalent in 100 g of dry matter (mg GAE/100 g dw) [Peri & Pompei, 1971; Singleton & Rossi, 1965].

Antioxidant activity was determined as the ability to quench the synthetic DPPH radical and the ABTS cation radical, expressed in μM TE/100 g dw.

The ability to reduce the synthetic DPPH radical was determined by the method of Brand-Williams et al. [Molyneux, 2004].

0.8 cm^3 of DPPH reagent was measured into flasks. 0.2 cm^3 of the extract to be tested was added to the first flask, and a stopwatch was started. After 30 seconds, 0.2 cm^3 of the extract was added to the second flask, and after another 30 seconds, 0.2 cm^3 of the extract was added to the next flask. The absorbance of the solution at 517 nm was measured exactly 10 minutes after the extract was added to the flask.

Calibration of the spectrophotometer was performed using a mixture comprising 0.8 cm^3 of methanol and 0.2 cm^3 of the colored solution to be tested [Molyneux, 2004].

The antioxidant activity against the ABTS cation radical was determined using the method described by Re et al. (1999).

1.0 cm^3 of ABTS reagent was measured into flasks. 0.1 cm^3 of the extract to be tested was added to the first flask, and a stopwatch was started. After 30 seconds, 0.1 cm^3 of the extract was added to the second flask, and after another 30 seconds, 0.1 cm^3 of the extract was added to the next flask. The solution's absorbance at 734 nm was measured exactly 6 minutes after the extract was added to the flask.

Calibration of the spectrophotometer was performed using a mixture containing 1 cm^3 of water and 0.1 cm^3 of the tested colored solution [Re et al., 1999].

The results of the analyzed health potential parameters before honey storage were expressed as the arithmetic mean of 9 replicates per product. The significance of the differences in polyphenol content and antioxidant activity between honeys was determined using the Student's t-test at the 0.05 significance level.

The results of the tests carried out during honey storage were presented as an average of three repetitions for each storage variant and each product.

The effect of storage and temperature on polyphenol content and antioxidant activity was determined using multivariate analysis of variance (MANOVA). The significance of differences between means was analyzed using t-tests Tukey. Relationships were considered statistically significant at the $p < 0.05$ level.

The results of the Tukey test are presented in tables, with the middle-class classifications indicated. All calculations were performed using Statistica 13.3 [Łomnicki, 2014].

3. DISCUSSION OF RESULTS

Manuka and goldenrod honeys differed in water content, polyphenol content, and antioxidant activity against the DPPH radical and the ABTS cation radical. The results of these quality parameters are presented in Table 1.

The water content in the honeys ranged from 15.9% m/m to 19.3% m/m. Manuka honey had a significantly higher water content, containing an average of 18.7% m/m of water, while goldenrod honey contained an average of 17.1% m/m. According to the regulations, the water content in honeys cannot exceed 20%, but for heather and baker's honeys, the water content can be up to 23%, and for baker's heather honeys, 25% [https://www.gov.pl/web/ijhars/metody-analityczne-stosowane-w-badaniach-jakosci-handlowej-miodow]. Therefore, it can be concluded that the honeys constituting the research material met the requirements regarding water content.

Table 1. Water and polyphenol contents and antioxidant activity of the honeys tested

Quality Distinctive Feature			Manuka honey	Goldenrod honey
Water content (% m/m)	Min.		18.2	15.9
	Max.		19.3	18.1
	M ± SD		18.7 ± 0.38b	17.1 ± 0.69a
	t-Student		$t_{calc.}$ = 6.3386 $t_{0.05;16}$ = 2.1199	
Polyphenol content (mg GAE/100 g dw)	Min.		155.1	55.8
	Max.		163.7	74.9
	M ± SD		159.6 ± 2.84b	67.6 ± 5.55a
	t-Student		$t_{calc.}$ = 44.2356 $t_{0.05;16}$ = 2.1199	
Antioxidant activity against the DPPH radical	μ M TE/100g dw	Min.	77.7	33.2
		Max.	88.1	41.4
		M ± SD	82.6 ± 3.77b	36.9 ± 3.14a
		t-Student	$t_{calc.}$ = 27.9012 $t_{0.05;16}$ = 2.1199	
Antioxidant activity against the ABTS cation radical	μ M TE/100g dw	Min.	201.3	55.3
		Max.	222.9	70.6
		M ± SD	211.7 ± 7.02b	63.3 ± 5.89a
		t-Student	$t_{calc.}$ = 48.5451 $t_{0.05;16}$ = 2.1199	

n = 9; M – mean value; SD – standard deviation; mean values marked with different lowercase letters in a row differ significantly according to the t-Student test at $\alpha = 0.05$.

Source: own study.

The honeys contained from 55.8 mg GAE/100 g dw to 163.7 mg GAE/100g dw. Manuka honeys had significantly higher polyphenol content, expressed as gallic acid equivalents, containing an average of 159.6 mg GAE/100 g dw, while goldenrod honeys contained an average of 67.6 mg GAE/100 g dw. Comparing the antioxidant activity against the DPPH radical and the ABTS cation radical, it was found that goldenrod honeys showed significantly lower antioxidant activity than manuka honeys (Table 1).

Differences in water content, bioactive components, and antioxidant activity are primarily due to the type and species of plant from which they originate, as well as environmental and climatic conditions. Furthermore, they also depend on the beekeeper's intervention in the honey production process in the hive, as well as the method of honey extraction and storage [Dykiel et al., 2022; Wilczyńska & Żak, 2024].

During honey storage, changes in water content varied by honey type and storage temperature. These changes are presented in Table 2.

Table 2. Changes in water content (% m/m) in manuka and goldenrod honey during storage

Storage time (weeks)	Storage temperature					
	5°C		20°C		30°C	
	Water content	Δ%	Water content	Δ%	Water content	Δ%
	Manuka honey					
0	18.7 ± 0.47Da	---	18.6 ± 0.32Aa	---	18.9 ± 0.40Da	---
4	18.0 ± 0.36CDa	-3.74	18.3 ± 0.31Aa	-1.61	18.5 ± 0.26CDa	-2.12
8	17.5 ± 0.25BCa	-6.42	17.9 ± 0.65Aa	-3.76	17.9 ± 0.40BCa	-5.29
12	16.6 ± 0.26ABa	-11.23	17.2 ± 0.90Aa	-7.53	17.4 ± 0.25ABa	-7.94
16	16.3 ± 0.26Aa	-12.83	16.7 ± 1.04Aa	-10.22	16.8 ± 0.12Aa	-11.10
	Goldenrod honey					
0	17.8 ± 0.49Ca	---	16.8 ± 0.26Ba	---	16.7 ± 0.71Ba	---
4	17.0 ± 0.51BCa	-4.49	16.3 ± 0.45ABa	-2.98	16.0 ± 0.26ABa	-4.19
8	16.6 ± 0.12BCa	-6.74	15.9 ± 0.50ABa	-5.36	15.9 ± 0.29ABa	-4.79
12	16.0 ± 0.47ABa	-10.11	15.2 ± 0.93ABa	-9.52	15.5 ± 0.20ABa	-7.19
16	15.2 ± 0.68Aa	-14.61	14.9 ± 0.78Aa	-11.31	15.1 ± 9.58Aa	-9.58

n = 3; values are presented as mean ± standard deviation; Δ% – percentage change compared to the product before storage. Mean values marked with different capital letters in a column within the same honey differ significantly according to Tukey's test at $p < 0.05$. Mean values marked with different lowercase letters in a row within the same honey differ significantly according to Tukey's test at $p < 0.05$.

Source: own study.

After four weeks of storage, the water content decreased in both manuka honey and goldenrod honey. Honeys stored at 5°C experienced a faster rate of change in water content than those stored at other temperatures, while honeys stored at 20°C showed the slowest rate of change. However, these changes proved statistically insignificant. Comparing the rate of water content decrease in the honeys revealed that, regardless of storage temperature, goldenrod honey showed the fastest rate of change.

This trend continued during further storage. After sixteen weeks of storage, a significant reduction in water content was observed in all honeys compared to the honeys before storage. The magnitude of these changes was determined by storage temperature. They occurred most rapidly in honeys stored under refrigeration. This could be due to more favorable conditions for honey crystallization, which occurs more quickly at refrigeration temperatures. However, statistical analysis revealed no significant effect of temperature on changes in water content in honeys. Similarly to the fourth week of honey storage, water content after storage, regardless of temperature, changed more significantly in goldenrod honey than in manuka honey (Table 2).

Polyphenols are chemical compounds classified as secondary metabolites of plants. Their chemical structure is characterized by the presence of at least two hydroxyl groups bound to one or more benzene rings. Depending on the number of these rings and the manner of their connection, polyphenols are divided into various groups, including phenolic acids, flavonoids, stilbenes, and lignans. Of these, the most numerous group is flavonoids, which are derivatives of 2-phenylbenzo-γ-pyrone [Zujko et al., 2018].

Polyphenolic compounds are well known for their potent antioxidant activity, which enables them to scavenge reactive oxygen species and reduce oxidative stress in the human body. Polyphenols contribute to the prevention of cardiovascular and neurodegenerative disorders associated with oxidative damage. They also demonstrate various biological effects, including anticancer, anti-inflammatory, hepatoprotective, and antimicrobial activities. Dietary polyphenols may improve lipid metabolism and glucose homeostasis, preventing metabolic diseases like type 2 diabetes [Tian et al., 2019].

Based on this research, it could be observed that the polyphenol content of manuka honey decreased during storage (Table 3).

After four weeks of storage, the highest polyphenol losses were observed at 30°C, and the lowest in refrigerated conditions. At 30°C, the polyphenol content decreased by approximately 53%, and at 5°C, by approximately 43%. In manuka honey stored at 20°C, polyphenolic compound degradation was approximately 48%.

It can therefore be concluded that storing honey at 5°C slows the degradation of polyphenolic compounds, which determine the product's health-promoting properties.

During further storage of Manuka honey, polyphenol degradation continued. After sixteen weeks of storage, a significant reduction in polyphenol content was observed compared to the honey before storage. The rate of degradation of these compounds was also significantly dependent on storage temperature. In the honey stored at 5°C, the polyphenol content decreased the slowest, reaching approximately 71% at the end of storage. The honey stored at 30°C exhibited the highest rate of degradation, with degradation exceeding 86% (Table 3).

Similar relationships were observed during the storage of goldenrod honey. However, the rate of degradation of polyphenolic compounds in goldenrod honey was found to be higher than in manuka honey. Furthermore, during storage of goldenrod honey, differences in polyphenol content at 20°C and 30°C were statistically insignificant. The differences between 5°C and the other temperatures were significant (Table 3).

Table 3. Changes in polyphenol content (mg GAE/100 g dw) in manuka and goldenrod honey during storage

Storage time (weeks)	Storage temperature					
	5°C		20°C		30°C	
	Polyphenol content	Δ%	Polyphenol content	Δ%	Polyphenol content	Δ%
	Manuka honey					
0	159.4 ± 3.69Ea	---	159.9 ± 3.90Ea	---	159.5 ± 1.78Ea	---
4	91.3 ± 5.31Db	-42.72	83.3 ± 3.25 Dab	-47.90	74.6 ± 2.71Da	-53.23
8	75.8 ± 3.91Cb	-52.45	63.7 ± 3.97Ca	-60.16	55.1 ± 3.83Ca	-65.45
12	62.1 ± 6.58Bb	-61.04	51.0 ± 6.76 Bab	-68.11	38.1 ± 4.10Ba	-76.11
16	46.8 ± 3.56Ac	-70.64	32.9 ± 3.25Ab	-79.42	22.1 ± 2.34Aa	-86.14
	Goldenrod honey					
0	65.4 ± 9.55Da	---	69.4 ± 2.92Da	---	68.0 ± 3.38Da	---
4	38.0 ± 2.31Cb	-41.90	29.9 ± 3.04Ca	-56.92	26.2 ± 2.39Ca	-61.47
8	30.6 ± 4.10BCb	-53.21	18.8 ± 1.84Ba	-72.91	16.2 ± 1.12Ba	-76.18
12	19.7 ± 1.55ABb	-69.88	10.3 ± 1.39Aa	-85.16	7.6 ± 1.31Aa	-88.82
16	16.4 ± 1.62Ab	-74.92	8.0 ± 1.50Aa	-88.47	6.1 ± 1.32Aa	-91.03

n = 3; values are presented as mean ± standard deviation; Δ% – percentage change compared to the product before storage. Mean values marked with different capital letters in a column within the same honey differ significantly according to Tukey's test at $p < 0.05$. Mean values marked with different lowercase letters in a row within the same honey differ significantly according to Tukey's test at $p < 0.05$.

Source: own study.

During long-term storage, polyphenolic compounds undergo increased enzymatic or chemical degradation. The extent of these changes is determined by the type of raw material, temperature, pH, water activity, storage time, and oxygen content [Gumul et al., 2005]. This would explain the smaller changes in honey stored at 5°C compared to 20°C or 30°C. The lower storage temperature slowed the progression of these unfavorable changes. It is also worth noting that the honey packages were opened every four weeks. This increased the amount of oxygen after the package was sealed while simultaneously reducing the honey's mass due to sampling for testing.

The antioxidant activity of food products is primarily determined by the content of bioactive compounds, including polyphenols. This can be determined, among other methods, using the synthetic DPPH radical and the ABTS cation radical.

DPPH (1,1-diphenyl-2-picrylhydrazyl) is a stable free radical that is soluble in organic solvents. This method evaluates a substance's ability to reduce DPPH, which results in a color change in the solution. The DPPH method is more sensitive to substances that can rapidly reduce DPPH, which may be beneficial for some antioxidants.

The DPPH assay assesses the capacity of antioxidants to neutralize the stable violet DPPH radical, leading to a color change of the solution from violet to yellow [Koss-Mikołajczyk et al., 2017].

The antioxidant activity of stored manuka and goldenrod honeys against the DPPH radical, expressed in μM TE/100g dw, is presented in Table 4.

Table 4. Changes in antioxidant activity against the DPPH radical (μM TE/100g dw) of manuka and goldenrod honey during storage

Storage time (weeks)	Storage temperature					
	5°C	Δ%	20°C	Δ%	30°C	Δ%
	Manuka honey					
0	81.3 ± 3.77Ca	---	84.5 ± 3.79Ca	---	81.9 ± 4.33Da	---
4	84.5 ± 5.21Ca	3.94	90.7 ± 3.23Cab	7.34	98.4 ± 5.67Cb	20.15
8	65.9 ± 3.19Ba	-18.94	63.5 ± 3.20Ba	-24.85	62.7 ± 6.32Ba	-23.44
12	60.3 ± 5.16ABb	-25.83	53.1 ± 4.39ABab	-37.16	48.2 ± 3.83Aa	-41.15
16	51.2 ± 2.93Ab	-37.02	43.0 ± 5.72Aab	-49.11	35.0 ± 4.01Aa	-57.26
	Goldenrod honey					
0	37.8 ± 3.54Ba	---	36.3 ± 3.56Ca	---	36.6 ± 3.47Ca	---
4	43.0 ± 4.06Ba	13.76	45.6 ± 2.61Da	25.62	51.0 ± 3.27Da	39.34
8	26.1 ± 2.10Aa	-30.95	24.3 ± 3.08Ba	-33.06	21.8 ± 2.40Ba	-40.44
12	22.0 ± 3.93Ab	-41.80	15.2 ± 3.44Aab	-58.13	13.1 ± 2.63Aa	-64.21
16	18.1 ± 1.72Ab	-52.12	12.1 ± 2.08Aa	-66.67	11.2 ± 2.83Aa	-69.40

n = 3; values are presented as mean ± standard deviation; Δ% – percentage change compared to the product before storage. Mean values marked with different capital letters in a column within the same honey differ significantly according to Tukey's test at $p < 0.05$. Mean values marked with different lowercase letters in a row within the same honey differ significantly according to Tukey's test at $p < 0.05$.

Source: own study.

The analysis of antioxidant activity assays showed that the DPPH-reducing capacity of manuka and goldenrod honeys stored at 5°C, 20°C, and 30°C increased after the first four weeks. This capacity decreased with further storage. After sixteen weeks, it was significantly lower than before storage.

The degree of reduction in the antioxidant capacity of honeys against the DPPH radical depended on the storage temperature. After storage, honeys stored at 5°C had a higher capacity to reduce DPPH free radicals than honeys stored at 20°C and 30°C. This indicates that storage at 5°C enhances the preservation of honey' antioxidant properties. Room temperature and elevated temperatures of 30°C may lead to a more rapid decline in antioxidant activity (Table 4).

ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonate)) is a chemical compound used to evaluate antioxidant capacity, considering the content of hydrophobic and hydrophilic antioxidants in a product. The higher the ABTS reduction capacity, the better the antioxidant properties. This cation radical is soluble in both water and organic solvents, making it more versatile.

The ABTS method, which is more sensitive to other types of antioxidants, is better suited for assessing the antioxidant activity of complex mixtures.

It is used to determine the ability of antioxidants to neutralize the blue cation radical generated from ABTS by sodium persulfate, as evidenced by a decrease in the solution's absorbance [Koss-Mikołajczyk et al., 2017].

Similarly, the ability to reduce the free radical DPPH increased after 4 weeks of storage at 5°C, 20°C, and 30°C, whereas the ability to reduce the cation radical ABTS increased only at 30°C. This antioxidant activity also decreased with further storage. However, this decreases varied with storage temperature. The antioxidant activity decreased the least in manuka and goldenrod honeys stored at 5°C and most significantly at 30°C. It was also found that the antioxidant activity, expressed as μM TE/100g dw, decreased more rapidly in goldenrod honey than in manuka honey (Table 5).

Changes in the antioxidant activity of honeys can result from various reactions. The oxidation of polyphenols can occur during the storage of these products. Partially oxidized polyphenols are characterized by an increased ability to bind free radicals compared to unoxidized polyphenols. These properties result from a greater ability to release the hydrogen atom of the hydroxyl group on the aromatic ring and/or the aromatic rings' increased ability to hold unpaired electrons through delocalization within the π shell. However, as polyphenol oxidation progresses, these abilities disappear [Ocieczek et al., 2023]. These reactions may have contributed to the increased antioxidant activity of honeys after 4 weeks of storage, followed by a decrease thereafter.

The end products of the Maillard reaction may also contribute to changes in the antioxidant activity of honeys during storage. The chemical composition of honeys determines the occurrence of these reactions.

Table 5. Changes in antioxidant activity towards the ABTS cation radical (μM TE/100 g dw) of manuka and goldenrod honey during storage

Storage time (weeks)	Storage temperature					
	5°C	Δ%	20°C	Δ%	30°C	Δ%
	Manuka honey					
0	206.1 ± 5.51Da	---	212.6 ± 9.18Ca	---	216.3 ± 1.41Ca	---
4	224.2 ± 1.76Ea	8.78	263.9 ± 4.24dB	24.13	317.9 ± 3.82Dc	46.97
8	188.4 ± 4.12Cc	-8.59	172.1 ± 8.27Bb	-19.05	136.3 ± 2.12Ba	-36.99
12	137.5 ± 9.67BC	-33.28	106.2 ± 7.28Ab	-50.05	88.2 ± 2.02Aa	-59.22
16	113.6 ± 7.88Ab	-44.88	89.2 ± 3.29Aa	-58.04	82.0 ± 4.41Aa	-62.09
	Goldenrod honey					
0	65.2 ± 6.67Ba	---	61.7 ± 5.20Ba	---	63.1 ± 7.62Ca	---
4	88.1 ± 2.42Ca	35.12	105.5 ± 1.99Cb	70.99	109.4 ± 7.33dB	73.38
8	55.5 ± 2.18Ba	-14.88	72.1 ± 7.97Bb	16.86	45.0 ± 6.82Ba	-28.68
12	28.2 ± 4.08Ab	-56.75	16.3 ± 3.17Aa	-73.58	15.1 ± 3.44Aa	-76.07
16	24.1 ± 1.7 Ab	-63.04	12.9 ± 2.81Aa	-79.09	10.4 ± 3.68Aa	-83.52

n = 3; values are presented as mean ± standard deviation; Δ% – percentage change compared to the product before storage. Mean values marked with different capital letters in a column within the same honey differ significantly according to Tukey's test at $p < 0.05$. Mean values marked with different lowercase letters in a row within the same honey differ significantly according to Tukey's test at $p < 0.05$.

Source: own study.

The main substrates and reagents in the Maillard reaction are sugars, amino acids/proteins, and polyphenols found in honeys. During non-enzymatic browning, bioactive molecules, such as modified proteins and protein-polyphenol complexes, are formed. These are then converted into brown polymeric melanoidins, which can increase or decrease the antioxidant and antibacterial properties of honeys. The Millard reactions and the formation of melanoidins in honey are considered key mechanisms that determine the antibacterial and antioxidant properties of honey [Starowicz et al., 2021].

The natural antioxidant and bacteriostatic components of honeys may aggregate with melanoids during storage, thereby simultaneously losing their antioxidant properties. Therefore, the formation of melanoids during honey storage contributes to the loss of biologically active components. On the other hand, the antioxidant activity of melanoids may compensate for these losses. However, the final effect depends on the initial chemical composition, determined by the origin of the individual honeys

[Wilczyńska, 2012]. Millard reactions may have occurred in the manuka and goldenrod honeys during storage, thereby reducing their antioxidant activity.

Millard reactions occur at room temperature (20°C). The intensity of these reactions increases with increasing storage temperature, e.g., to 30°C [Ocieczek, 2021]. This could explain the different rates of decline in antioxidant activity observed in honeys stored at 5°C, 20°C, and 30°C.

One of the most important changes in stored honey is crystallization, which can occur even at room temperature. However, most consumers consider it a sign of honey adulteration. Crystallization, in addition to changing the appearance and color of honey, also contributes to the stability of biologically active compounds that determine its antioxidant activity. The crystallized portion of honey contains less water, making it less susceptible to reactions that degrade any antioxidant compounds. The rate of crystallization depends on the honey storage temperature, occurring more rapidly at lower temperatures [Krishnan et al., 2021; Özkök & Silici, 2018].

Progressive crystallization was observed in honeys stored at 5°C and 20°C. This process occurred faster in products stored at 5°C, which would explain the slower rate of decline in polyphenolic compound content and antioxidant activity than in honeys stored at 20°C.

The findings indicate that lower storage temperatures are more favorable for preserving the nutritional and antioxidant properties of both types of honey, which is relevant for commercial honey storage and distribution.

4. CONCLUSIONS

- Manuka honey was characterized by a significantly higher content of polyphenolic compounds than goldenrod honey.
- Goldenrod honey showed significantly lower antioxidant activity against the DPPH radical and the ABTS cation radical than manuka honey.
- During storage, manuka and goldenrod honey experienced a decline in their health potential, but this decline was slower in manuka than in goldenrod honey.
- Honey stored at 5°C after opening the package showed a slower rate of deterioration in its health potential than honey stored at 20°C or 30°C.
- The higher stability of the health potential at 5°C justifies considering this temperature as the most favorable for storing manuka and goldenrod honey after opening the package.

The research was financed from financial resources allocated to the UMG departments for research activities under project no. WZNJ/2025/PZ/05.

REFERENCES

Bąkowska, M., & Janda, K. (2018). Właściwości prozdrowotne wybranych miodów. *Pomeranian Journal of Life Sciences, 64*(3), 147-151. https://doi.org/10.21164/pomjlifesci.459

Czajkowski, M., Czajkowska, K., Sokołowska-Wojdyło, M., Matuszewski, M., Połom, W., & Nowicki, R. (2017). Miód manuka i jego zastosowanie w medycynie. *Farmacja Współczesna, 10*, 36-41.

Dykiel, M., Rygiel, E., Krochma-Marczak, B., & Baran, J. (2022). Ocena wybranych parametrów jakościowych miodu. *Herbalism, 8*(1), 140-151. https://doi.org/10.12775/HERB.2022.011

Gumul, D., Korus, J., & Achremowicz, B. (2005). Wpływ procesów przetwórczych na aktywność przeciwutleniającą surowców pochodzenia roślinnego. *Żywność. Nauka. Technologia. Jakość, 45*(4)*,* Supl., 41-48.

Koss-Mikołajczyk, I., Baranowska, M., Namieśnik, J., & Bartoszek-Pączkowska, A. (2017). Metody oznaczania właściwości przeciwutleniających fitozwiązków w systemach komórkowych z wykorzystaniem zjawiska fluorescencji/luminescencji. *Postępy Higieny i Medycyny Doświadczalnej, 71*, 602-617. https://doi.org/10.5604/01.3001.0010.3841

Krishnan, R., Mohammed, T., Kumar, G. S., & SH, A. (2021). Honey crystallization: Mechanism, evaluation and application. *The Pharma Innovation Journal, 10*(5S), 222-231. https://doi.org/10.22271/tpi.2021.v10.i5Sd.6213

Łomnicki, A. (2014). *Wprowadzenie do statystyki dla przyrodników*. Wydawnictwo Naukowe PWN. https://images.iformat.pl/28FCE894EB/712E84B6-CB21-48F1-B22C-37D59569E4A8.pdf

Madras-Majewska, B. (2023). *Dary z ula.* Podlaski Ośrodek Doradztwa Rolniczego. https://odr.pl/wp-content/uploads/2023/09/Produkty-pszczele_srodek-1.pdf

Metody analityczne stosowane w badaniach jakości handlowej miodów. https://www.gov.pl/web/ijhars/metody-analityczne-stosowane-w-badaniach-jakosci-handlowej-miodow (10.06.2024).

Moise, G. (2025). Evaluation of honey quality: Comparison of the physico-chemical composition initially and after two years of storage. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 25*(1), 667-674.

Molyneux, P. (2004). The use of the stable free radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity. *Songklanakarin Journal of Science and Technology, 26*(2), 211-219.

Ocieczek, A. (2021). *Podstawy przechowalnictwa żywności dla dietetyków*. Wydawnictwo Ars Nova.

Ocieczek, A., Pukszta, T., Żyłka, K., & Kirieieva, N. (2023). The influence of storage conditions on the stability of selected health-promoting properties of tea. *LWT-Food Science and Technology, 184*, 115029. https://doi.org/10.1016/j.lwt.2023.115029

Özkök, D., & Silici, S. (2018). *Effects of crystallization on antioxidant property of honey. Journal of Apitherapy, 3*(2), 24-30. https://doi.org/10.5455/ja.20180607113134

Peri, C., & Pompei, C. (1971). An assay of different phenolic fractions in wine. *American Journal of Enology and Viticulture, 22*, 55-58. https://doii.org/10.5344/ajev.1971.22.2.55

Re, R., Pellegrini, N., Porteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant Activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine, 26*(9-10), 1231-1237. https://doi.org/10.1016/S0891-5849(98)00315-3

Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 14 stycznia 2009 r. *w sprawie metod analiz związanych z dokonywaniem oceny miodu*, Dz.U. 2009, nr 17, poz. 94.

Różański, H., Bobak, Ł., & Trziszka, T. (2016). Znaczenie nawłoci (Solidago) w fitoterapii. *Herbalism, 2*(1), 160-173. https://doi.org/10.12775/HERB.2016.013

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16*, 144-158. https://doi.org/10.5344/ajev.1965.16.3.144

Şireli, H. D., & Saylak, Ü. (2025). The effect of storage temperature on some physicochemical properties of flower honey. *Agrociencia*, January. https://doi.org/10.47163/agrociencia.v59i1.3194

Starowicz, M., Ostaszyk, A., & Zieliński, H. (2021). The relationship between the browning index, total phenolics, color, and antioxidant activity of Polish-Originated Honey Samples. *Foods, 10*, 967. https://doi.org/10.3390/foods10050967

Tian, S., Sun, Y., Chen, Z., Yang, Y., & Wang, Y., (2019). Functional properties of polyphenols in grains and effects of physicochemical processing on polyphenols. *Journal of Food Quality, 2019*, 2793973. https://doi.org/10.1155/2019/2793973

Wilczyńska, A. (2012). *Jakość miodów w aspekcie czynników wpływających na ich właściwości antyoksydacyjne.* Wydawnictwo Akademii Morskiej w Gdyni.

Wilczyńska, A., & Żak, N. (2024). Polyphenols as the main compounds influencing the antioxidant effect of honey – A review. *International Journal of Molecular Sciences, 25*(19), 10606. https://doi.org/10.3390/ijms251910606

Zujko, M. E., Cyuńczyk, M., & Zujko K. (2018). Polifenole jabłek w profilaktyce chorób układu sercowo-naczyniowego. *Postępy Higieny i Medycyny Doświadczalnej, 72*, 740-750. https://doi.org/10.5604/01.3001.0012.2425