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Original Article

QUALITY AND SAFETY ASSESSMENT OF HONEY IMPORTED FROM UKRAINE TO POLAND: PHYSICOCHEMICAL AND RESIDUE ANALYSIS

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Abstract

The aim of the study was to determine whether honey imported to Poland from Ukraine meets the quality standards and whether it is free of residues of plant protection products in accordance with the maximum permissible residue levels (MRLs). Due to the relatively small number of samples analysed (n=20), the results obtained in our study may not be fully representative for Ukrainian honey imported to Poland. Nevertheless, the pollen spectrum of Ukrainian honeys imported to Poland is characteristic for the climatic zone of Eastern and South-Eastern Europe. The majority of honey imported from Ukraine to Poland meet the quality requirements stated in EU regulations. Residues of plant protection products in Ukrainian honey imported to Poland do not exceed the MRLs. Adherence to quality standards and regular monitoring of honey parameters imported from Ukraine to Poland are key to ensuring the high quality and safety of honey on the Polish market.

Keywords: honey, physicochemical properties, pollen analysis, residues of plant protection products, quality standards, Ukraine

INTRODUCTION

Honey production in European Union countries, which accounts for approximately 13% of world production, is regulated by strict sanitary and quality standards (Regulation (EC) No 852/2004 on the hygiene of foodstuffs, Council Directive 2001/110/EC of 20 December 2001 relating to honey). However, the demand for honey in the EU exceeds domestic production has lead to the import of often cheaper products with lower production costs. Because honey has a relatively high price on world markets, especially in relation to sugar, it has always been subject to adulteration with various types of available and cheap syrups (inverters) produced primarily for the food industry and for beekeeping (for winter feeding of bees) (Szczęsna et al., 2021a,b). EU-coordinated action 2021-2022 confirmed that a significant proportion of honey imported into the EU does not comply with the requirements of the EU Honey Directive 2001/110/EC (46% based on 320 samples) (Ždiniaková et al, 2023). According to EU statistics database, honey is one of the ten most adulterated foods, and according to the US Pharmacopeia, honey is the third most adulterated product after milk and olive oil. (Everstine et al., 2024).

Honey can be deliberately adulterated through the feeding of sucrose or glucose-maltose syrups to bees or the mixing of these syrups directly with honey. Another form of honey adulteration is the misrepresentation of its geographical or botanical origin in order to change the consumer’s perception of its quality, and therefore price of the honey. For example, ultrafiltration used by some companies, disguises the true origin and botanical variety of honey by removing pollen grains and the chemical components that give varietal honeys their distinctive organoleptic characteristics. A common practice in some countries is to centrifuge immature honey to increase its yields. The water in honey obtained in this way, with a moisture content of about 50%, is artificially evaporated to a content of about 18%. Honey that has not undergone the natural ripening process in the hive without the participation of the bees is of a lower quality compared to naturally produced honey (Amiry et al., 2017; Se et al., 2019; Tian et al., 2024; Wilczyńska, 2014; Wu et al., 2022; Żak & Wilczyńska, 2017). In addition to organoleptic evaluation and microscopic analysis of pollen and physicochemical parameters, many modern methods are used to determine a honey's botanical and geographical origin and to detect honey adulteration, including qualitative and quantitative composition of sugar (HPLC, GC), HMF (5-hydroxymethylfurfural) content, proline content, enzymatic activity of β-fructofuranosidase, β- and γ-amylase, and determination of so-called "biochemical markers" (phenolic compounds, volatile compounds, organic acids, minerals), stable carbon isotope ratio analysis/mass spectrometry - SCIRA/MS (Oroian, 2013; Milojković Opsenica et al., 2015; Bogdanov, 2016; Oroian et al., 2017; Pascual-Maté et al., 2018; Thrasyvoulou et al., 2018; Hermanns et al., 2019; Almeida-Muradian et al., 2020; Walker et al., 2022). An indicator of honey adulteration with foreign sugars is the presence of oligosaccharides and starch dextrins (Rybak-Chmielewska et al., 2006; Lipiński & Czajkowska, 2012; Walker et al., 2022).

Ukraine, one of the main exporters of honey supplied about 36,6% of total Polish honey imports in 2023 (Semkiw, 2023). Unfortunately, the imported honey is sometimes adulterated and its labelling does not always reflect its real origin, which destabilizes the market and puts Polish beekeepers in a difficult economic situation (Semkiw, 2023; Ždiniaková et al., 2023).

Council Directive 2001/110/EC established quality standards for honey in the European Union to regulate its physicochemical composition, origin and authenticity. In Poland, honey as a food product must meet the requirements set out in the national regulations in line with the EU legislation. The basic legal act in this respect is the Act of 21 December 2000 on the commercial quality of agricultural products (Journal of Laws of 2019, item 2178, as amended), the Regulation of the Minister of Agriculture and Rural Development of 3 October 2003 on the detailed requirements for the commercial quality of honey (Journal of Laws No 181, item 1773, as amended), which introduced the requirements of the Council Directive 2001/110/EU (EU, 2001) in Poland. The second national document is the Polish Standard for honey (PN-88/A77626, 1998), the application of which has been voluntary since 1 September 2014. In turn, the rules for labelling marketed domestically are defined by the Regulation of the Ministry of Agriculture and Rural Development of 23 December 2014, amending the Regulation on the Labeling of Various Types of Foodstuffs (Journal of Laws of 8 January 2015, item 29, as amended).

In Ukraine, the quality of honey is regulated by a Standard (DSTU 4497:2005, 2005) which defines the rules of its production, physicochemical requirements, microbiological purity and labeling. This document, a key element of quality control, ensures that honey meets established standards and protects consumers from products that do not meet certain criteria. The botanical origin of honey, including its organoleptic characteristics, is a key factor in determining its market value. The studies show that different nectar sources have a significant impact on the physicochemical, sensory and biological properties of this product (Yücel & Sultanogl, 2013; da Silva et al., 2016; Oroian & Ropciuc, 2017; Pereira et al., 2020). The aim of the study was to determine whether honey imported to Poland from Ukraine meets the quality standards and whether it is free of residues of plant protection products in accordance with the maximum permissible residue levels (MRLs) as specified in the current EC Regulation No. 396/2005. Conclusions from these tests may contribute to the improvement of regulations on the quality and origin of honey as well as help Polish beekeepers to compete with imported product.

MATERIAL AND METHODS

Chemicals

Reagents including glycerol, gelatine, sodium hydroxide (0.1 M), sodium acetate trihydrate, potassium hexacyanoferrate(II) trihydrate, zinc acetate dihydrate, sodium carbonate were purchased from Chempur (Piekary Śląskie, Poland). Certified Reference Material Refractive Index & Density CRM were purchased from VWR (United Kingdom). Phadebas Honey Diastase Test tablets were purchased from Magle Life Sciences (Sweden). Acetonitrile, methanol, isopropanol, glacial acetic acid (HPLC purity), formic acid, proline (≥99.5%), ninhydrin (ACS reagent), 2-methoxyethanol (≥99.8%) and hydroxymethylfurfural (≥99.0%) were supplied by Merck (Darmstadt, Germany). Ammonium formate, turanose (≥98.0%), fructose (≥99.0%), glucose (≥99.5%), sucrose (≥99.5%), trehalose (≥99.0%), maltose (≥99.0%) and isomaltose (≥98.0%) were from Sigma-Aldrich (Seelze, Germany). Conductivity standards: 147 µS/cm; 1413 µS/cm (Hamilton, Switzerland) and 0.05028 S/m 0.141116 S/m (LabStand, Poland) were obtained from Alchem, Poland. Pesticide standards (94-99% purity) were purchased from Dr. Ehrenstorfer (Augsburg, Germany). QuEChERS extraction salts were supplied by Agilent Technologies (Santa Clara, CA, USA). All reagents were of analytical grade purity. Ultrapure water from the Milli-Q system (Barnstead, USA) with a resistivity of 18.3 MΩ-cm was used for analysis.

Samples

The laboratory experiments were conducted in 2023 in two accredited Laboratories of the National Institute of Horticultural Research, Poland: Bee Products Quality Testing Laboratory in Puławy and Food Safety Research Department in Skierniewice. Samples of Ukrainian honey were collected in 2023 at border points (Dorohusk - 4 samples, Hrebenne - 4 samples, Koroszczyn - 2 samples, Korczowa - 10 samples) by Border Veterinary Inspectorates under official border control, secured and sent to the Laboratories between 4 June and 14 December 2023. A total of twenty samples of Ukrainian honey were tested. The initial classification of honeys was based on organoleptic assessment, taking into account aroma, taste, colour and manner of crystallisation. The organoleptic evaluation of honey was based on the criteria specified in the Polish Standard (PN-88/ A-77626, 1998). The honey variety was verified by microscopic pollen analysis, carried out in accordance with the guidelines of the International Commission of Bee Botany (Louveaux et al., 1978) and the International Honey Commission (Pascual-Maté et al., 2018; Thrasyvoulou et al., 2018).

The tests for physicochemical parameters were conducted in accordance with the methods described in the Regulation of the Minister of Agriculture and Rural Development of 14 January 2009 (Journal of Laws No. 17, item 94, as amended, 2009). Some of the methods were modified by Szczęsna et al. (2011; 2021a). These methods are in accordance with the standards in force in the European Union, as well as recommended by the International Honey Commission (Bogdanov, 2009) and the Council Directive 2001/110/EC.

Melissopalynological analysis

Pollen analysis consisted of microscopic determination of the percentage of pollen of nectariferous plants in the honey deposit. In each preparation, 300 pollen grains were counted, classifying them by species. When the proportion of one species exceeded 45%, it was considered to be conductive, and the honey was considered varietal. Only pollen of nectariferous plants was taken into account in the calculations (Louveaux et al., 1978). Parameters such as water content, free acid content and pH, electrical conductivity, diastase number (DN), quantitative and qualitative analysis of sugars, 5-hydroxymethylfurfural (HMF), proline content and insoluble matter were determined according to methods developed by the International Honey Commission (Bogdanov et al., 2004).

Determination of water content

Water content was determined through the use of the refractometric method. The principle of the method is to measure the refractive index (light refraction) of the honey at 20°C and read the water content (%) corresponding to the value of this index. Analysis were performed by a thermostated Atago RX-5000 digital refractometer (ATAGO CO., LTD., Tokyo, Japan).

Determination of sugars

Such sugars as fructose, glucose, sucrose, trehalose, maltose, turanose and isomaltose were determined by high-performance liquid chromatography with a refractometric detector (HPLC-RI). The principle of the method is based on the identification of individual sugars on the basis of retention times (qualitative analysis), and quantitative determination is carried out with the use of the external standard method based on a comparison of the peak areas of the individual sugars in the standard solution and the peak areas of the same sugars in the honey solution. A Shimadzu HPLC system (SHIMADZU CO., Kyoto, Japan) and PhenoSphere LC column, NH2 80 Å, 250x4.6 mm (Phenomenex Inc., Torrance, CA, USA) were adopted for these analysis.

Determination of 5-hydroxymethylfurfural (HMF)

HMF content was determined through high-performance liquid chromatography with spectrophotometric detection (HPLC-UV) using A Knauer HPLC system (KNAUER GmbH, Berlin, Germany) and Eurospher 100 Å, 5 µm C18 vertex plus column (BGB Analytik Vertrieb GmbH, Lörrach, Germany). The principle of the method is to identify HMF based on retention time (qualitative analysis) and to compare the peak area of HMF in the sample and standard solution (quantitative analysis).

Determination of diastase number

The diastase number was determined with the spectrophotometric method (Phadebas). The principle of the test is to break down a given amount of insoluble blue dyed cross-linked type of starch by the enzyme α-amylase present in the honey, which yields blue water-soluble fragments determined photometrically at 620 nm using spectrophotometer (Spekord 200 Analytik Jena, Jena, Germany).

Determination of pH and free acids

Determination of pH and free acidity was performed with the potentiometric method. The principle of the determination is based on the potentiometric measurement of the honey solution's pH, followed by neutralization of the honey's acidic components with a standard solution of sodium hydroxide. Analysis were performed by DL50 Titrator equipped with a Rondolino autosampler (Mettler-Toledo GmbH, Greifensee, Switzerland).

Determination of proline content

The principle of the method is based on the separation of proline from the honey's other amino acids with the use of isopropanol and the spectrophotometric measurement of its colored ninhydrin complex at a 520 nm performed with a spectrophotometer (Spekord 200 Analytik Jena, Jena, Germany).

Determination of electrical conductivity

Electrical conductivity was determine by conductometric method. The principle of the determination is to measure the conductivity of 1 ml of a 20% (m/m) honey solution on a dry weight basis at 20°C. WTW inoLAB Cond 700 conductometer (WTW,Weilheim, Germany) was used for these analyses.

Determination of insoluble matter

The insoluble matter content was determined with the use of the weight method. The principle of the determination is to separate these substances from the honey by filtering them through a crucible with a pore size of 15-40 µm and the dried residue is weighed after being washed free of soluble material.

Determination of pesticide residues

The analysis of residues of plant protection products was conducted by the QuEChERS modular method with the use of two chromatographic techniques: GC-MS and LC-MS/MS in accordance with PN-EN 15662:2018-06 (Oymen et al., 2022) and the EURL-SRM QuPPe-PO method using LC-MS/MS-based analysis (Anastassiades et al., 2019).

RESULTS

The honey samples analysed were crystallised and ranged in colour from creamy, creamy yellow, to golden. A detailed pollen analysis was performed to determine the pollen content of the honey-growing plants in the Ukrainian honey samples. Based on organoleptic characteristics and pollen analysis, six samples were classified as sunflower honeys (Tab. 1). The pollen analysis of the remaining fourteen samples showed a high total number of pollen grains, which suggests the presence of pollen derived from bee bread. In the case of four samples, although the presence of pollen from bee bread was found, distinct organoleptic characteristics (aroma, flavor, colour and manner of crystallisation) confirmed that these were rapeseed honeys (Tab. 1). Based on the organoleptic characteristics (aroma, flavor, colour and manner of crystallisation), the remaining ten samples were classified as multifloral honeys (Tab. 1 Continued).

To assess the quality of the honey samples from Ukraine, physicochemical analyses were carried out. The results of these analyses are summarised in Tables 2 and 3.

Table 1.

Results of pollen analysis of honey imported to Poland from Ukraine (%)

No	1	2	3	4	5	6	7	8	9	10
Types of nectariferous pollen	**Percentage of pollen in honey (%)**									
	sunflower						**rapeseed**			
Helianthus typ - sunflower type	54.7	48.9	75.5	79.4	64.9	50.1	0.5	1.2	1.3	0.5
Brassicaceae - brassicas	26.5	35.4	12.0	5.8	21.1	20.0	92.5	88.2	90.3	89.2
Fagopyrum - buckwheat	2.7	2.1	1.1	6.5	2.3	9.5	-	0.1	0.1	0.3
Echium - viper	2.3	0.3	0.4	-	0.1	-	-	-	0.2	0.1
Cirsium typ - thistle type	1.9	0.6	0.7	1.0	0.7	4.2	0.1	0.1	0.1	0.1
Robinia - acacia	1.4	1.0	0.7	0.8	1.4	1.5	0.4	1.7	1.9	2.2
Centaurea jacea - cornflower	1.2	0.4	-	0.4	-	0.3	-	-	-	-
Phacelia - phacelia	1.2	1.8	1.1	0.5	0.2	-	0.3	0.3	-	-
Tilia - linden	0.9	1.3	-	0.6	-	0.3	-	0.1	0.2	0.1
Anthriscus typ - chervil type	0.8	0.6	0.3	0.8	0.2	0.3	0.7	0.1		0.4
Prunus typ - plum type	0.8	0.4	0.1	0,5	1.2	4.1	1.0	3.1	1.4	1.7
Centaurea scabiosa - greater knapweed	0.7	-	-	-	-	-	-	-	-	-
Taraxacum typ - dandelion type	0.6	0.7	0.1	0.5	0.1	1.9	-	0.1	-	-
Parthenocissus - grapevine	0.6	0.1	0.1	0.3	0.2	-	-	-	-	-
Malvaceae - mallow family	0.4	0.1	0.1	-	-	0,1	-	-	-	-
Trifolium typ - clover type	0.3	0.3	-	0,1	-	-	-	-	-	-
Lamiaceae- labiate	0.3	-	-	-	-	-	-	-	-	-
Salix - willow	0.3	1.5	-	0.4	1.1	2.5	0.7	2.1	1.7	2.9
Achillea typ - yarrow type	0.3	-	-	-	-	-	-	-	-	-
Convolvulus - bindweed	0.2	-	0.3	-	-	0.1	-	-	-	-
Onagraceae - evening primrose family	0.2	0.1	-	0.1	-		-	-	-	-
Cucurbita - pumpkin	0.1	0.1	-	-	-	0.1	0.1	-	-	-
Acer - maple	-	-	0.1	0.4	0.4	1.5	1.5	1.9	0.4	0.4
Amorpha - amorpha	-	1.0	4.9	-	2.2	2.8	-	0.2	0.9	0.4
Sophora - styphnolobium	-	0.7	-	-	2.2	-	-	-	-	-
Aesculus - buckeye	-	0.1	0.3	-	0.4	-	0.3	0.1	0.3	0.2
Lonicera - honeysuckle	-	0.1	-	-	0.1	-	0.1	-	-	0.1
Heracleum typ - hogweed type	-	-	-	-	0.1	-	-	-	-	-
Vicia - horsebean	-	0.3	0.1	-	-	-	0.1	0.1	0.1	-
Onobrychis - onobrychis vicifolia	-	-	0.1	-	-	-	-	-	-	-
Solidago typ - goldenrod type	-	-	-	0.4	-	-	-	-	-	0.1
Melilotus - cranesbill	-	0.1	0.5	-	-	-	-	-	-	-
Lotus - birdsfoot trefoil	-	0.1	-	0.6	-	-	0.2	-	-	0.2
Rhamnaceae - buckthorn family	-	-	0.5	-	-	-	0.4	-	0.2	0.2
Thymus typ - thyme type	-	-	-	-	0.1	-	-	-	-	-
Others	1.4	1.0	0.8	0.9	0.8	0.8	0.7	0.4	0.6	0.7

Table 1.

Results of pollen analysis of honey imported to Poland from Ukraine (%) Continued

No	11	12	13	14	15	16	17	18	19	20
Types of nectariferous pollen	**Percentage of pollen in multifloral honeys (%)**									
Helianthus typ - sunflower type	20.2	11.4	15.2	29.3	12.4	6.8	17.3	44.1	24.8	30.5
Brassicaceae -brassicas	53.5	80.0	62.3	42.7	38.0	84.1	57.8	19.4	56.1	41.8
Fagopyrum - buckwheat	0.9	0.3	3.6	9.0	0.2	0.2	2.4		0.5	3.3
Echium - viper	1.1	0.1	0.3	0.1	1.7	-	0.4	3.6	0.3	0.4
Cirsium typ - thistle type	0.9	0.4	0.4	1.4	0.9	0.2	0.6	2.8	1.6	0.4
Robinia - acacia	2.9	1.0	1.8	0.5	0.4	0.5	2.1	3.6	3.4	8.1
Centaurea jacea - cornflower	0.8	0.3	0.4	0.2	0.2	-	0.1	-	0.3	0.1
Phacelia - phacelia	0.6	0.1	0.4	0.1	1.2	0.4	1.2	2.8	0.8	0.7
Tilia - linden	3.6	-	3.3	0.5	-	-	1.2	5.9	0.7	2.7
Anthriscus typ - chervil type	1.9	0.3	0.5	0.8	0.6	0.4	0.4	1.6	1.0	0.6
Prunus typ - plum type	1.9	0.9	3.6	3.1	0.8	1.8	2.7	-	2.1	4.2
Centaurea scabiosa - greater knapweed	-	0.3	-	-	-	0.1	-	0.2	-	-
Taraxacum typ - dandelion type	0.5	0.1	-	0.6	0.4	-	0.1	0.6	0.1	0.4
Parthenocissus - grapevine	0.8	0.4	-	0.6	-	-	0.4	-	-	0.8
Malvaceae - mallow family	-	-	-	-	-	-	0.1	0.2	-	-
Trifolium typ - clover type	0.9	-	-	-	0.4	0.2	0.6	-	0.1	0.1
Lamiaceae - labiate	0.3	-	-	0.1	0.1	-	-	-	-	-
Salix - willow	3.1	-	2.8	3.0	-	0.6	2.1	-	0.4	2.8
Convolvulus - bindweed	-	-	-	0.1	-	-	-	0.2	0.1	0.1
Cucurbita - pumpkin	-	-	-	0.1	0.1	0.1	0.1	0.2	0.1	-
Acer - maple	2.8	2.1	0.8	1.8		2.0	1.8	-	0.9	
Amorpha - amorpha	0.5	-	0.6	0.8	38.2	0.7	1.2	4.9	3.9	1.1
Symphytum - comfrey	0.2	-	-	-	-	0.1	-	-	-	-
Centaurea cyanus - cornflower	0.2	-	0.3	0.3	-	-	0.1	-	0.1	0.6
Frangula - buckthorn	0.2	0.6	0.8	1.8	-	-	-	-	-	-
Citrullus - watermelon	0.2	0.1	-	-	-	-	-	-	-	-
Sophora - styphnolobium	-	0.4	0.4	-	-	0.2	-	-	0.7	-
Aesculus - buckeye	-	-	1.0	0.8	-	0.5	1.6	-	-	0.1
Pisum sativum - pea	-	-	0,3	-	-	-	-	-	-	-
Lonicera - honeysuckle	-	-	0.1	-	0.1	0.1	-	-	-	-
Heracleum typ - hogweed type	-	-	0.1	-	-	-	-	0.2	-	-
Vicia - horsebean	-	-	-	0,.1	0.1	0.1	-	-	-	0.1
Onobrychis - onobrychis vicifolia	-	-	-	0.1	0.1	-	-	0.2	0.1	-
Solidago typ - goldenrod type	-	-	-	0.5	-	-	0.9	0.5	-	-
Geranium - geranium	-	-	-	0.1	-	-	0.3	0.2	0.1	0.1
Melilotus - cranesbill	-	-	-	2,1	-	-	-	-	0.1	-
Lotus - birdsfoot trefoil	-	-	-	0.6	-	-	-	0.5	-	-
Caryophyllaceae - carnation family	-	-	-	-	-	0.1	-	-	-	-
Ribes - flowering currant	-	-	-	-	-	0.1	-	-	-	-
Viola tricolor - pansy	-	-	-	-	-	0.1	0.1	-	-	-
Rhamnaceae - buckthorn family	-	-	-	-	-	-	2.5	0.8	-	-
Rubus typ - raspberry type	-	-	-	-	-	-	-	0.9	-	-
Thymus typ -thyme type	-	-	-	-	-	-	-	0.2	0.1	-
Hedysarum - honeysuckle	-	-	-	-	-	-	-	-	0.4	-
Others	2.3	1.2	1.0	1.0	1.4	0.8	1.5	0.9	0.9	1.0

The analysis of the honey samples from Ukraine showed that the water content ranged from 16.5% to 18.7%, with an average of 17.4%. All the values were below the maximum permissible level of 20%, according to the Regulation of the Minister of Agriculture and Rural Development of 3 October 2003 (Journal of Laws No. 181, item 1773, as amended).

The electrical conductivity of imported honey were low, not exceeding 0.40 mS/cm in any of the honey samples. Such values classify these honeys as nectar honeys, for which, the electrical conductivity should not exceed 0.80 mS/cm. Our own research showed that the free acidity of the samples ranged from 10.1 to 20.5 mval/ kg, averaging 14.6 mval/kg, and pH ranged from 3.81 to 4.11 with an average value of 3.97. The enzyme activity, expressed by the diastase number (DN), in the analysed honey samples from Ukraine ranged from 8.5 to 23.1 Schade, with a mean value of 17.6 Schade. In nineteen of the twenty honey samples tested, the insoluble matter content was within the 0.1% limit. This limit was exceeded in only one sample and was 0.33%. Analysis of the proline content in seven samples of Ukrainian honey showed values ranging from 20.0 to 24.3 mg/100 g, which is lower than the requirements set out in the Polish Standard (PN-88/A-77626, 1998), in which the minimum requirement for this compound was set at

Table 2.

Physicochemical parameters of honey from Ukraine (n=20)

Sample number	Physicochemical parameters							
	Water content (%)	**HMF (mg/kg)**	**Proline (mg/kg)**	**DN (Schade)**	**pH**	**Free acidity (mval/kg)**	**Electrical conductivity (mS/cm)**	**Insoluble matter (g/100g)**
1	17.6	11.8	24.1	17.0	3.90	16.1	0.33	0.03
2	17.9	7.0	22.9	11.3	3.99	15.1	0.30	0.06
3	18.1	8.4	20.0	8.5	3.95	12.4	0.22	0.05
4	17.5	10.7	23.6	12.8	4.02	15.0	0.28	0.02
5	17.1	6.4	27.0	14.6	3.96	16.8	0.30	0.02
6	18.5	5.1	30.1	18.0	3.81	14.8	0.22	0.04
7	17.5	6.8	25.1	22.1	4.03	12.1	0.20	0.02
8	17.6	8.5	24.9	17.8	3.92	15.2	0.27	0.01
9	16.7	15.1	23.2	16.1	3.91	14.1	0.31	0.03
10	17.2	10.7	22.7	18.7	4.05	13.1	0.26	0.02
11	17.5	8.3	26.9	23.1	4.10	10.1	0.15	0.03
12	16.5	16.7	25.4	16.7	3.99	15.0	0.28	0.02
13	17.1	16.2	26.2	19.5	3.93	14.2	0.28	0.02
14	18.7	10.0	25.1	21.7	3.94	19.3	0.39	0.03
15	16.6	7.5	24.3	20.3	4.11	10.4	0.16	0.07
16	16.8	15.0	29.4	18.9	3.99	12.9	0.19	0.11
17	17.1	13.0	27.8	19.7	4.01	12.5	0.18	0.02
18	17.5	9.5	26.6	16.5	3.92	15.7	0.30	0.33
19	17.3	12.4	34.1	16.6	3.93	17.2	0.33	0.02
20	17.5	5.9	34.5	21.5	3.86	20.5	0.33	0.04
Average±SD	17.4±0.57	10.3±3.46	26.2±3.54	17.6±3.61	3.97±0.07	14.6±2.57	0.26±0.06	0.05±0.07
Min	16.5	5.1	20.0	8.5	3.81	10.1	0.15	0.01
Max	18.7	16.7	34.5	23.1	4.11	20.5	0.39	0.33

SD - standard deviation, min - minimum, max - maximum

Table 3.

Sugar composition of honey imported to Poland from Ukraine (n=20) (g/100 g)

Sample number	Parameter, unit								
	fructose	glucose	sucrose	turanose	maltose	trehalose	F/G	Sum F+G	Total sugar content
1	40.1	37.1	nd*	0.9	1.2	0.6	1.08	77.2	79.9
2	39.8	35.9	nd*	1.3	1.7	0.8	1.11	75.7	79.5
3	40.0	35.9	nd*	1.1	1.8	0.6	1.11	75.9	79.4
4	40.1	35.8	nd*	1.4	1.6	1.0	1.12	75.8	79.8
5	39.2	36.4	nd*	1.1	1.5	0.8	1.08	75.6	79.0
6	40.5	34.3	<0.5**	1.3	2.2	0.7	1.18	74.8	79.0
7	39.3	37.4	nd*	1.4	1.4	0.8	1.05	76.7	80.3
8	41.0	35.4	nd*	1.2	1.4	0.6	1.16	76.4	79.6
9	43.2	33.0	nd*	1.2	1.4	0.6	1.31	76.2	79.4
10	39.7	36.4	nd*	1.4	1.3	1.0	1.09	76.1	79.8
11	38.9	36.3	nd*	1.5	1.3	1.1	1.07	75.2	79.1
12	40.4	35.1	nd*	1.4	1.4	0.9	1.15	75.5	79.2
13	40.5	35.5	nd*	1.3	1.4	0.7	1.14	76.0	79.4
14	41.9	32.7	nd*	1.3	1.2	0.8	1.28	74.6	77.9
15	38.2	37.1	nd*	1.5	1.2	1.1	1.03	75.3	79.1
16	39.5	34.6	nd*	2.0	1.8	1.3	1.14	74.1	79.2
17	38.3	34.0	nd*	2.0	1.7	1.3	1.13	72.3	77.3
18	39.7	35.1	nd*	0.8	1.6	0.6	1.13	74.8	77.8
19	39.8	36.7	nd*	1.3	1.4	0.7	1.08	76.5	79.9
20	39.8	36.2	nd*	0.9	1.4	0.5	1.10	76.0	78.8
Average±SD	40.0±1.11	35.5±1.27	-	1.3±0.30	1.5±0.24	0.8±0.23	1.13±0.07	75.5±1.05	79.2±0.73
Min	38.2	32.7		0.8	1.2	0.5	1.03	72.3	77.3
Max	43.2	37.4		2.0	2.2	1.3	1.31	77.2	80.3

SD - standard deviation, min - minimum, max - maximum, F/G- the ratio of fructose to glucose
* limit of detection 0.2 g/100 g±0.1 g/100 g, ** limit of quantification 0.5 g/100 g±0.3 g/100 g

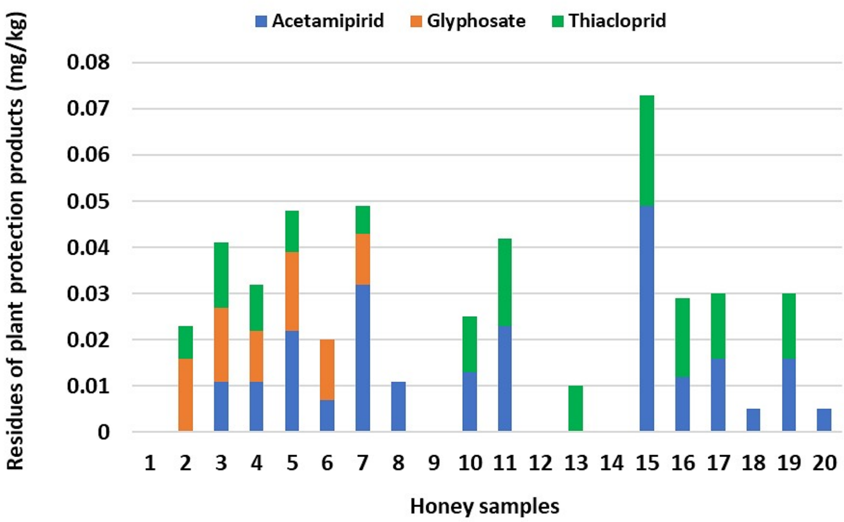

Fig. 1. Residues of plant protection products in honey imported to Poland from Ukraine (mg/kg).

25 mg/100 g. The average content of simple sugars, i.e. fructose and glucose, was 75.5 g/100 g, ranging from 72.3 to 77.2 g/100 g. The ratio of fructose to glucose averaged 1.13, ranging from 1.03 to 1.31. Sucrose was not detected in the samples tested (below the detection limit of the method of 0.2 g/100 g), the maximum permissible content of which is 5 g/100 g according to the applicable Regulation. In addition, disaccharides such as turanose (1.3 g/100 g on average), maltose (1.5 g/100 g on average) and trehalose (0.8 g/100 g on average), which are typical of nectar honey, were found. Trisaccharides characteristic of honeydew honey, such as melecytose, erlose, maltotriose and raffinose, were not found in the samples.

As part of the study on the presence of residue plant protection products in honey, a complex analysis of as many as 549 different residues was conducted. In three honey samples from Ukraine, these substances were not detected at concentrations above their limits of quantification (LQ), taking into account a 50% uncertainty. Acetamiprid was found in twelve samples, thiacloprid in eleven samples and glyphosate in six samples (Fig. 1). In all case, the concentrations detected were below the maximum residue limits (MRLs) set in Regulation EC No 396/2005, as amended.

DISCUSSION

The presence of pollen from bee bread can significantly affect the interpretation of pollen analysis results, which is particularly important for the botanical classification of honey. As a result, the nectar percentage composition of these honeys differed from that obtained from the pollen analysis results. There are notable differences between Ukrainian honey and local Polish honey. Honey from Ukraine is characterized by the predominance of pollen from sunflower (*Helianthus annus*) and Cruciferous plants (Brassicaceae), which is consistent with the climate of Eastern and Southeastern Europe (Kołacz et al., 2023). In Poland, nectarferous species such as robinia acacia (*Robinia pseudoacacia*), linden (*Tilia* spp.) and rapeseed (*Brassica napus*) account for a larger share of honey production, which may influence differences in chemical composition (Szczęsna et al., 2011; Waś et al., 2011).

These results were compared with the requirements specified in the Regulation of the Minister of Agriculture and Rural Development of 3 October 2003 concerning detailed requirements for the commercial quality of honey (Journal of Laws No. 181, item 1773, as amended), as well as with the Polish Standard (PN-88/A-77626, 1998) and the Ukrainian Standard (DSTU 4497:2005, 2005). Natural honey must meet certain quality standards, including for water content, electrical conductivity, free acidity, enzymatic activity (LD), sugar composition and hydroxymethylfurfural (HMF) content. Similar results for the water content of natural honeys have been reported in publications by Almeida-Muradian et al. (2020) and Sedláčková et al. (2022) and slightly lower values by Moldakhmetova et al. (2023). Electrical conductivity is an important indicator of honey quality and helps in its classification, which is crucial to ensuring its authenticity and quality on the market. Similar conductivity results were found in a study on sunflower honey from Vojvodina, Serbia (Živkov Baloš et al., 2023). The free acidity of honey is the result of the presence of organic acids, esters, lactones and inorganic ions (da Silva et al., 2016).

Significant variability in free acidity and pH values in the honey samples analysed was observed by both Zhuk et al. (2022) and Moldakhmetova et al. (2023). Free acidity in their study ranged from 19.0 to 34.0 meq/kg and from 13.5 to 58.0 mval/ kg, while pH ranged from 3.88 to 4.26 and from 3.34 to 4.56.

The hydroxymethylfurfural (HMF) content in these samples was low and did not exceed 16.7 mg/kg. These results fully meet the requirements set out in the current Regulation, which requires the diastase number to be not less than 8 Schade and the HMF content not to exceed 40 mg/kg. These results are consistent with the publications data, including the studies by Zhuk et al. (2022) and Moldakhmetova et al.

(2023), confirming that these honeys meet high quality standards.
Similar results were reported by Živkov Baloš et al. (2023), where the majority of honey samples met the standards for this parameter.
The Regulation of the Ministry of Agriculture and Rural Development of 3 October 2003 does not specify requirements for proline content in honey. Similar results for the simple sugars in sunflower honey were obtained by Manolova et al. (2021).
In conclusion, the analysis of the composition of sugars confirms that the honey samples studied meet the normative requirements for their quality (Bogdanov, 2009). According to the current research (Sedláčková et al., 2022; Zhuk et al., 2022; Kołacz et al., 2023; Moldakhmetova et al., 2023), the content of monosaccharides and the ratio of fructose to glucose content are key parameters characterising honey quality. These studies indicate that sucrose content remains below 3.5 g/100 g. The monosaccharide contents (sum of fructose and glucose) and the sucrose content are important criteria in the context of assessing the compliance of honey samples with the quality requirements set in the currently applicable normative documents (Regulation of the Minister of Agriculture and Rural Development of 3 October 2003) concerning detailed requirements for the commercial quality of honey (Journal of Laws No. 181, item 1773, as amended), the Polish Standard (PN-88/A-77626, 1998).
Neonicotinoids, although effective in controlling agricultural pests, can negatively affect bee populations, which are essential to the pollination process of many plants. Such testing is extremely important to ensure food safety and protect consumer health. Even low concentrations of these substances in honey may indicate their widespread use in agriculture, which may require additional regulation. However, Ligor et al. (2020) showed that sunflower honey, as well as two rapeseed honey samples and two acacia honey samples from Poland and Romania, were completely free of the pesticides tested, including neonicotinoids. This suggests that there are regions and agricultural practices to produce honey that is free of these substances (Kołtowski et al., 2021).
All the honey samples contained residues of thiacloprid, acetamiprid and carbendazim (0.0702 mg/kg, 0.0300 mg/kg and 0.0242 mg/kg, respectively), as reported by Kędzierska-Matysek et al. (2022). Imidacloprid predominated in honey samples from Africa and South America, acetamiprid in samples from Asia, and thiacloprid in honey from Europe, according to the data presented by Mitchell et al. (2017). The presence of dicofol was recorded in 38.9% of the samples tested, while acetamiprid and imidacloprid were predominant in honey from Israel, as shown by Eissa et al. (2014) and Bommuraj et al. (2019).
Council Directive 2001/110/EC, as well as Polish Standard for honey (Regulation of the Ministry of Agriculture and Rural Development of 3 October 2003 on detailed requirements for the commercial quality of honey, PN-88/A-77626, 1998) and Ukrainian legal acts (DSTU 4497:2005, 2005) are key to ensuring honey authenticity. Compliance with these standards is important for both consumers and producers, guaranteeing the availability and high quality of the product on the Polish market.
Due to the relatively small number of samples analysed (n=20), the results obtained in our study may not be fully representative for Ukrainian honey imported to Poland. Nevertheless, the pollen spectrum of Ukrainian honeys imported to Poland is characteristic for the climatic zone of Eastern and South-Eastern Europe. Organoleptic features and results of pollen analysis of twenty samples examined indicate that a proportion of the honey imported to Poland from Ukraine is varietal sunflower. In the remaining fourteen samples out of twenty examined, a high total number of pollen grains was found, which indicates that the honey contained pollen from bee bread. For this reason, it was impossible to determine the botanical origin of a large proportion of the honey imported to Poland from Ukraine.
The majority of honey imported to Poland from Ukraine meets the quality requirements binding in the European Union, as specified in the Regulation of the Ministry of Agriculture and Rural Development of 3.10.2003 on detailed requirements concerning the commercial quality of honey (Journal of Laws No 181, item 1773 as

amended). Residues of plant protection products in Ukrainian honey do not exceed the maximum residue levels (MRLs) in honey specified in the current Regulation EC No. 396/2005, as amended. Adherence to quality standards and regular monitoring of honey parameters imported from Ukraine to Poland are key to ensuring the high quality and safety of honey on the Polish market.

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