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Assessment of the Ecological Safety of Honey with the Help of "Factor Area" Models

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Abstract: The man-made load on the environment and the decrease in biodiversity cause a direct negative environmental impact on the existence of honey bees and beekeeping products. The priority directions of the food industry are the use of high-quality environmentally friendly raw materials and the prevention of the ingress and formation of harmful substances in food products, including honey. This implies the need to develop methods for assessing the environmental safety of the studied raw materials and products. The purpose of this study was to implement a mathematical modeling method for studying the environmental safety of honey. Five types of honey were studied: Robinia, rapeseed, linden, buckwheat, and sunflower. Mathematical models were built according to the following parameters: total activity of β-emitting radionuclides; residues of levomycetin (chloramphenicol), nitrofuran (according to AOZ and AMOZ), metronidazole, and pesticides (according to hexachloran); and the content of water-insoluble substances (mechanical impurities) and heavy metals. On the basis of the obtained data and established quality criteria, calculation graphic models were built. Using algebraic methods, they derived new formulas for calculating quality coefficients. Multivariate analysis and programming methods were used to evaluate honey using mathematical modeling. The most and least ecologically dangerous contaminants and their share of influence for different types of honey were determined based on the complex of research on negative factors. The proposed mathematical models can be implemented for practical use in specialized laboratories as a tool for determining the environmental safety of honey of various botanical origins.

Keywords: quality; β-emitting radionuclides; chloramphenicol; nitrofuran; metronidazole; mechanical impurities; pesticides; heavy metals; environment; food product; graphic model

1. Introduction

The sustainable development of beekeeping is directly related to the health of *Apis mellifera* L. Bees are important pollinators, and their activity ensures the biodiversity and stability of ecosystems. However, at this point, bees face a number of threats that could lead to their extinction. The use of pesticides, especially neonicotinoids, is one of the main threats to bees [1]. These chemicals can cause acute poisoning, affect the nervous system of bees, and disrupt their ability to navigate, feed, and reproduce [2]. When the bee population decreases, the development of many agricultural and other flower crops is suspended, and their diversity and resistance to changes in agro-technological and climatic conditions decrease, which can affect the resource security of the state. Considering that the situation is aggravated by the war in Ukraine, such risks can be quite significant. Honey is the primary product of beekeeping and is highly valued for its wide range of biologically active substances, including vitamins (especially B-group), minerals (iron, magnesium, potassium, calcium), organic acids, enzymes, and antioxidants [3]. This richness in components gives honey unique functional properties [4], including immunomodulatory [5], antibacterial [6], anti-inflammatory [7], antioxidant [8], and digestive-enhancing [9] effects. However, bees may collect nectar in environments contaminated with pesticides and other anthropogenic pollutants, leading to the presence of toxins in honey. Honey quality control includes checking for residues of pesticides, antibiotics, and other harmful substances that can adversely affect the health of bee colonies [10]. Clean and safe products not only preserve the health of bees but also help to restore the ecosystems where they live and perform their important role of plant pollination [11]. Moreover, the sustainable development of the honey industry provides long-term economic stability for beekeepers. Quality control ensures competitiveness on the international market, prevents losses from counterfeiting, and supports fair trade [12,13]. This allows producers to receive a fair price for their products and invest in the development of their farms. Research related to honey quality opens up new opportunities for innovation in beekeeping. The development of new methods for assessing and improving product quality stimulates the introduction of technological advancements, which in turn enhances production efficiency and reduces costs. This contributes to the formation of a sustainable industry capable of adapting to the challenges it faces.

Specific conditions at honey collection sites can significantly affect the levels of contaminants. In Ukraine, radioactive contamination after the Chornobyl disaster affected, among other things, beekeeping products, which became a prerequisite for monitoring honey and other bee products for radionuclides to prevent the latter from getting into nutriment. Currently, the environment, agroecosystems, and nutrition systems are negatively affected by the hostilities caused by Russian aggression [14,15], which increases the risk of food contamination. At present, about 20% of agricultural land in Ukraine is contaminated by heavy metals, and 12% is contaminated by radionuclides. Despite the general decrease in the content of harmful substances in the environment, the current ecological situation in some geographic regions remains unfavorable for the production of safe beekeeping products. Because of this, constant control of beekeeping products is needed with the view of contamination by harmful substances [16–18]. Contamination of honey, in most cases, occurs in the external environment and is mainly associated with technological violations. The highest content of heavy metals, lead, and cadmium is observed in propolis, honeycombs, and copper. It was established [16] that the content of heavy metals in the body of bees depends on the intensity of environmental pollution and the level of pollution in soils, plants, water, air, and beekeeping products, which gives reason to use honey as a bioindicator of heavy metal contamination of the environment.

Rivera-Mondragón et al. (2023) [19] show that the physicochemical characteristics and pollen composition of honey differ among different harvests of a single year at the same site. The results also highlight one of the challenges faced by producers in some tropical areas, as honey harvested at the start of the rainy season had a higher water content.

Sidashova et al. (2018) determined that the negative impact of pathogenic or excessive microflora is a threat to the safety and quality of honey, which requires further research [20]. They confirmed that the probiotic supplement has different effects on honey and on the bee colony at both the microlevel (honey) and the macrolevel (the sanitary conditions of the hive interior, the bees' behavior, their health, and the products obtained).

The authors in [21] found that the content of lead (Pb) in all honeys exceeded the established norms by 1.8–2.1 times, with the largest amount being in centrifuged honey, whereas the acceptable amounts of cadmium (Cd), arsenic (As), and 137Cs heavy metals were found there.

An additional threat for beekeeping products is posed by the pesticide load on the environment, constant updating of their preparation forms, as well as their wide use in agricultural activities. It was established that the content of organochlorine pesticides ranged from 0.001 to 0.0041 mg/kg in comb and bee comb, from 0.001 to 0.0045 mg/kg in pure comb, and from 0.001 to 0.0031 mg/kg in honey [22]. The smallest amount of pesticide residues was observed in white Robinia and linden honey, whereas the largest amount was observed in sunflower honey, which is most likely related to the different physiological ability of plants to accumulate organochlorine pesticides, as well as to the constant pesticide load of soils under field crops.

The scientific papers of the international research group COLOSS [23] show that bees can be exposed to pesticides even through contact with dust and spray droplets in the air during flight, movement on contaminated surfaces, and through contaminated nectar, pollen, and water.

The formation of the safety and quality of beekeeping products begins with the choice of the apiary location. The European honey bee is a globally managed pollinator that can serve as a continuous biomonitoring species [24]. Beekeeping products can also serve as a means of monitoring the environment and reflect the composition of contaminants in a particular area. Given that the nectar and pollen collected by bees as their own food are used as a source of honey, bee pollen, and bee pergue, there is a need to monitor their quality along the 'farm to table' chain; there is a need to develop an assessment system for a number of possible eco-toxicants that enter them at the bee–environment and product–hive contact stages

In Ukraine, there is no clear supervision of the sale and use of antibiotic medicines. Antibiotics enter honey through the remains of veterinary drugs used to treat bees for preventive and therapeutic purposes [25]; non-compliance with veterinary and sanitary requirements for keeping bees, in particular, the placement of apiaries near pharmaceutical enterprises, animal farms, landfills, etc. [26]; and due to the antibiotic contamination of water [27].

The production of honey based on sustainable practices and quality control helps preserve bee populations and support natural processes, such as pollination, that are critical to food security and ecosystem preservation. Thus, deeper research into the impact of negative environmental factors on bees and indirectly on beekeeping products and the development of methods to reduce their effect on these types of insects are relevant; the priority areas of the food industry are the use of high-quality environmentally friendly raw materials and the prevention of the ingress and formation of harmful substances in food products, which makes it necessary to develop methods for assessing the safety of the products under research.

The research goal

We aim to evaluate the ecological safety of honey types according to the pollen profile, namely from Robinia, rapeseed, linden, buckwheat, and sunflower, using the experimental base of research on the relevant characteristics of these products and the development of mathematical models of "factor areas".

To achieve this research goal, the following tasks were determined:

We carried out the necessary experimental studies to determine the ecological safety parameters of honey from Robinia, rapeseed, linden, buckwheat, and sunflower.

- Construction of a mathematical model of quality when applying the "factor areas" hypothesis.
- Calculation of assessment criteria and development of geometric quality models for all researched types of honey.
- Conducting a grapho-analytical analysis of the environmental safety of the researched types of honey based on the results of mathematical modeling.

2. Materials and Methods

The selection of 50 samples of honey for the research was carried out directly from producers (in apiary conditions) in accordance with the State Standard of Ukraine 4497:2005 Natural Honey Technical conditions in 2022 [28]. The obtained honey was identified according to the improved methods of melissopalynology [29,30] and divided into 5 types: Robinia, rapeseed, linden, buckwheat, and sunflower. This research was conducted for 3 groups of honey: the most common botanical varieties of honey according to physico-chemical indicators, original varieties, fall, and polyfloral flower varieties of honey. The first group was distinguished by botanical affiliation according to pollen analysis; the second and third groups were distinguished according to physical and chemical indicators. This product belongs to a certain botanical variety or has a geographical indication; it has a relatively stable composition and established enzymatic activity and flavonoid content; and it can be used in health food formulations as a functional ingredient to increase nutritional value.

To build a mathematical model of quality, safety indicators were previously investigated using standardized methods.

Testing of *the total β-activity* was carried out on the KPK1-01A beta-radiometer using the standard 40 K: 1 Bq of Σβ-activity (corresponds to the content of 35.4 mg of K+) in the conditions of the Physical and Technological Institute of Metals and Alloys of the National Academy of Sciences of Ukraine (Kyiv, Ukraine). The relationship between the specific β-activity of the studied samples and their potassium concentration was assumed to be linear; the natural mixture contains 0.0119% of radioactive potassium isotopes 40 K. *Antibiotic residues* were investigated using BetaStar Advanced test strips and the Raptor integrated analytical platform in the production laboratory of Askania-Pak LLC (Kyiv, Ukraine). *The content of water-insoluble substances* (mechanical impurities) was determined in accordance with DSTU 4497:2005 in the laboratory conditions of the Faculty of Food Technologies and Product Quality Management of the Agro-Industrial Complex of the National Agricultural University of Ukraine (Kyiv, Ukraine). *The content of pesticides* was investigated using hexachlorane by thin-layer chromatography [30], and the concentration of heavy metals was determined using an atomic absorption spectrophotometer SF-115 PK [18] in the conditions of the production laboratory of Ascania-Pak LLC (Kyiv, Ukraine).

On the basis of the obtained data and established quality criteria, calculation graphic models were built [31]. Using algebraic methods and well-known formulas [32], new formulas for calculating quality coefficients were derived. Multivariate analysis and programming methods were used to evaluate honey using mathematical modeling [33,34].

Statistical processing of the results of experimental studies was carried out by the methods of variational analysis with the help of the Microsoft® Office Excel 2016 software application and specialized programs.

Assessment of the safety indicators of the researched types of honey

According to established hygienic standards, the total activity of β-emitting radionuclides in honey should not exceed 50 Bq/kg. The studied indicator did not exceed the indicated norms in the samples, but it varied depending on the type of honey. Thus, buckwheat honey had the lowest value of radionuclides (Table 1), which is 96% below the limit. This indicator was 92%, 90%, 86%, and 76% below the limit for linden, rapeseed, sunflower, and Robinia types of honey, respectively.

Table 1. Control and current averaged values of the safety indicators of the studied types of honey (n = 50).

No.	Characteristics of the Safety of Honey	Control Value	Current Parameters of Honey Types According to the Pollen Profile				
			Robinia	Rapeseed	Linden	Buckwheat	Sunflower
1	Total activity of β-emitting radionuclides, Bq/kg	≤50 [1]	12	7	4	2	5
2	Levomycetin (chloramphenicol), μg/kg	≤0.3 [2]	0.25	0.1	0.15	0.2	0.2
3	Nitrofuran (for AOZ and AMOZ), μg/kg	≤0.6 [2]	0.1	0.1	0.05	0	0.01
4	Metronidazole, μg/kg	≤0.5 [3]	0.02	0.01	0.005	0.01	0.01
5	Content of water-insoluble substances (mechanical impurities), g/100 g	≤0.1 [4]	0.001	0.002	0.002	0.001	0
6	Pesticides (for hexachloran), mg/kg	≤0.005 [2]	0.0001	0.0005	0.0001	0.0005	0.002
7	Heavy metals, mg/kg	≤0.1 [5]	0.05	0.05	0.05	0.01	0.01

Note: [1]—State Hygienic Norms of Ukraine [35]; [2]—State Standard of Ukraine [28]; [3]—Council Directive of the European Union [36]; [4]—Order of the Ministry of Agrarian Policy and Food of Ukraine [37]; [5]—Commission Regulation (EU) [38].

Residues of veterinary drugs in different concentrations were found in the studied types of honey. Chloramphenicol was mostly contained in honey ranging from 0.1 to 0.25 μg/kg. The highest content was found in the Robinia types of honey. Mechanical impurities are poisoned in honey due to violations of the production technology. The range of this indicator was within the norm in the studied honeys. Water-insoluble substances were absent in the sunflower types of honey. Pesticide residues were determined for types of honey obtained from field crop rotations—rapeseed, buckwheat, and sunflower. Therefore, for sunflower honeys, which were obtained at the end of the season, the pesticide content of hexachloran was the highest (0.002 mg/kg). On the contrary, honeys obtained in the first half of the season—Robinia, rapeseed, and linden—were most susceptible to heavy metal contamination (0.05 mg/kg).

Thus, a different variation in safety indicators for the same or different types of honey is observed within the established norms. This does not show which of the honeys can be considered the most ecologically safe for human consumption. We suggest clarifying the obtained results and their visualizing using the method of mathematical modeling. Existing evaluation methods are characterized by research based on local parameters and organoleptic indicators, which are purely subjective. While the presented method of mathematical modeling makes it possible to carry out a comprehensive assessment according to any number of parameters, it is possible to objectively compare the obtained product characteristics according to normative or recommended quality indicators.

3. Results

Development of a mathematical model of quality

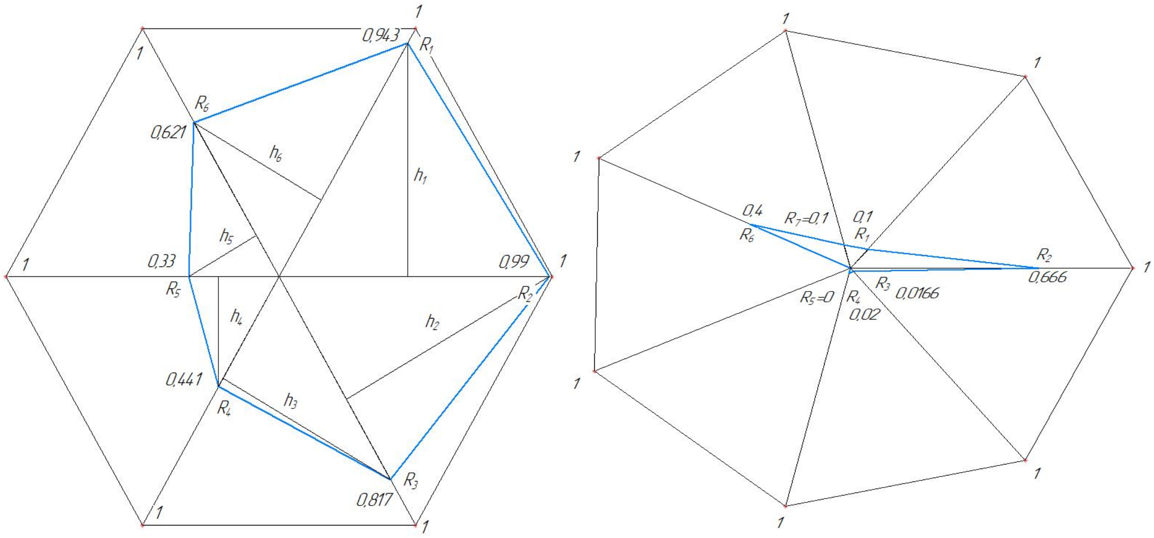
The following hypotheses were used when performing mathematical modeling of the researched types of honey according to the characteristics of ecological safety.

The first hypothesis is that the obtained characteristics as a whole create appropriate quality spaces, the comparison of which with the minimum permissible regulatory parameters forms the limits of the environmental safety of products.

The evaluation of these characteristics was carried out using dimensionless quantities. The value of any normative indicator is taken as a unit, and the current characteristics are determined from the ratio to this indicator. Thus, it is possible to carry out a mathematical assessment of quality due to certain dependencies between the specified characteristics. Similar methods of converting qualitative characteristics into dimensionless quantities are used for assessing the condition of food products [39–41]. The validity of such an assessment determines *the second hypothesis* with the development of a mathematical model:

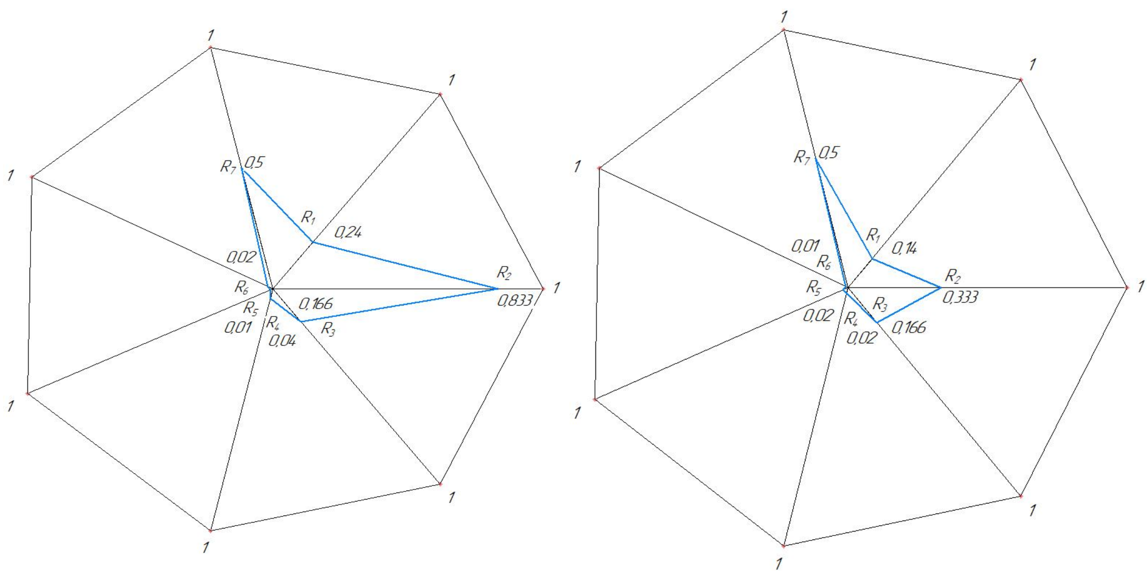
the quality of honey is determined by the values of the ratios between the dimensionless characteristics of the normative and current parameters of honey.

The normative space of quality indicators was displayed in the form of regular polygons. Their central rays make up the values of normative indicators, which are numerically equal to a dimensionless unit. The number of angles or sides of polygons is determined by the number of parameters taken to evaluate a certain type of honey. For each evaluated type of honey, a space was built according to negative parameters for comparison with the normative one according to the determined areas of polygons (Figures 1–3).



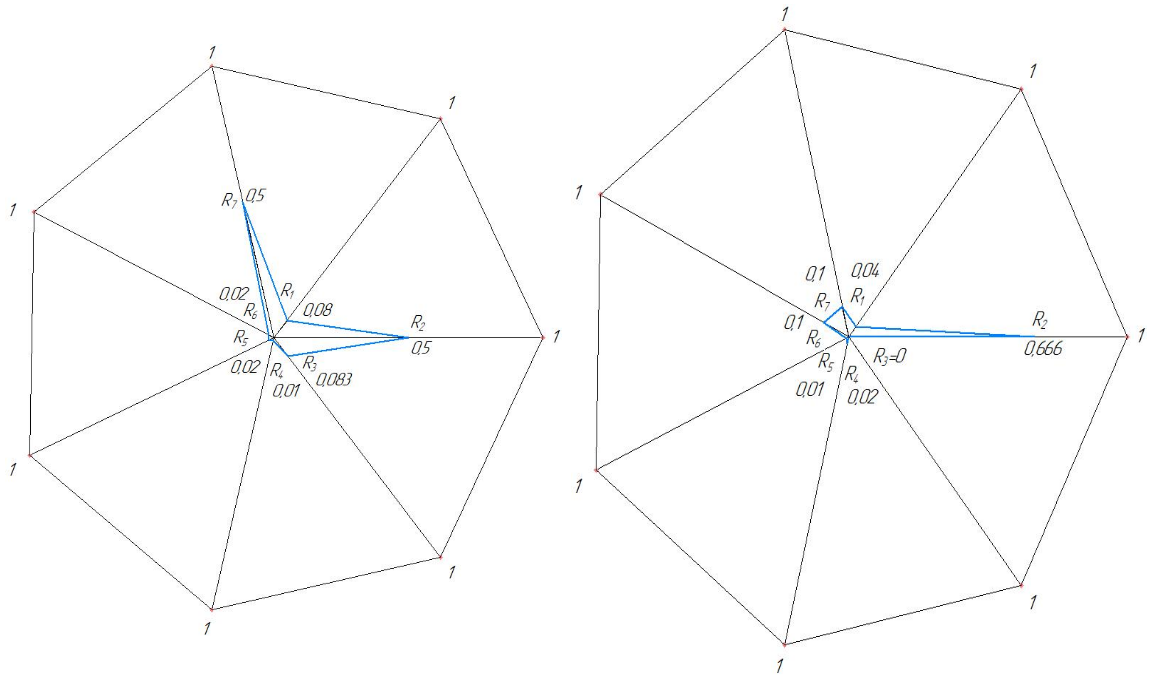
(**a**) (**b**)

Figure 1. Calculation scheme for determining the area of the 6-factor space of negative parameters for evaluating the quality of echinacea variety of honey (**a**); h_1, h_2, h_3, h_4, h_5, h_6 are the heights of the triangles into which the hexagon is divided; R_i is the coefficient of the value of the current parameters, the numbering of which corresponds to the parameters in Table 1; the blue color shows the polygon, which reflects the space according to the evaluated quality parameters of the specified type of honey; estimated graphic model of the 7-factor space of negative parameters for evaluating the quality of sunflower honey variety (**b**).



(**a**) (**b**)

Figure 2. Calculated graphic model of the 7-factor space of negative parameters for evaluating the quality of Robinia (**a**) and rapeseed (**b**) types of honey.



(**a**) (**b**)

Figure 3. Calculated graphic model of the 7-factor space of negative parameters for evaluating the quality of linden (**a**) and buckwheat (**b**) types of honey.

The areas of regular polygons $S_{\text{н}}$ on the displayed calculation graphic models (Figures 1–3) demonstrate the normalized space according to the control parameters during the evaluation of the corresponding type of honey.

To determine these areas ($S_{\text{пр}}$), the generally accepted formula [41] for the area of a polygon was used. To determine these areas ($S_{\text{пр}}$), the generally accepted formula [41] for the area of a polygon was used:

$$S = \frac{ma^2}{4tg\left(\frac{180}{m}\right)}$$

where a = 2$Rsin$(180/m); m is the number of angles or sides of the polygon; a is the size of the side of the polygon; angle α = 180/m.

Then, the sought value of the area of a regular polygon, which determines the normative factor space, is as follows:

$$S = \frac{mR^2 \sin^2(\frac{180}{m})}{tg\left(\frac{180}{m}\right)} = mR^2 \sin(\frac{180}{m}) \cdot \cos(\frac{180}{m}) = 0,5mR^2 \sin(\frac{360}{m}) = 0,5mR^2 \sin \alpha$$

The value of the area S_i, which determines the factor space of negative parameters of the corresponding type of honey, is the area of an irregular polygon; in Figures 1–3, the specified area is outlined in blue.

To determine the mathematical algorithm of this calculation, we used a six-factor geometric model of the quality of echinacea honey (as a basic model for conducting calculations) with negative parameters (Figure 1a).

The sought area was found as the sum of the areas of the triangles that make up the area. Thus, based on Figure 1a, the area S_1 of the first triangle is S_1 = 0.5 · R_1 · R_2 · $sin\alpha$, where α is the angle formed as a result of drawing straight lines built from the center to the vertices of a regular hexagon. R_i denotes the values of the current characteristics of the studied honey (Table 1), which are geometrically drawn through the center of a regular hexagon in the direction of the lines corresponding to the normalized (control) value of each of these parameters. Similarly, we obtained that the area $S_2 = 0.5 \cdot R_2 \cdot R_3 \cdot sin\alpha$; $S_3 = 0.5 \cdot R_3 \cdot R_4 \cdot sin\alpha$; $S_4 = 0.5 \cdot R_4 \cdot R_5 \cdot sin\alpha$; $S_5 = 0.5 \cdot R_5 \cdot R_6 \cdot sin\alpha$; $S_6 = 0.5 \cdot R_6 \cdot R_1 \cdot sin\alpha$. Similarly, the total required area of the septagons for the studied types of honey (Figures 1a, 2 and 3) is as follows:

$$S_{07} = 0.5sin\alpha \cdot [R_1 \cdot R_2 + R_2 \cdot R_3 + R_3 \cdot R_4 + R_4 \cdot R_5 + R_5 \cdot R_6 + R_6R_7 + R_7R_1]$$

4. Discussion

Constructed polygons on the appropriate graphic models allow for assessing the quality of the researched types of honey both visually and analytically using mathematical ratios. The presented assessment criteria show what negative or positive impact this or that product parameter has, as well as how much the researched product variety meets the overall environmental safety and complies with the minimum requirements of quality standards. The latter acts as evaluation criteria. On the basis of the constructed spaces of negative and normative parameters, evaluation was carried out with the help of the following quality indicators. The coefficient of environmental danger $k_{ed} = \frac{S_i}{S_H}$ is the share of negative characteristics in the regulatory space of the evaluation of the products under study. The coefficient of compliance with the minimum quality standards $k_{cs} = \frac{S_H - S_i}{S_H} 100$ shows how close the studied honey variety is to the standard.

An assessment was also made of the individual quality characteristics presented for the investigated types of honey in Table 1. In the assessment process, four indicators were noted that significantly influenced the formation of negative space, namely the content of heavy metals, levomycetin, pesticides, nitrofuran, and the total activity of β-emitting radionuclides, which are presented in the form of the corresponding relative coefficients in Table 2. These coefficients were determined by the formula $k_i = \frac{R_i}{R_H} 100, \%$. On the basis of the developed mathematical graphic models (Figures 1–3), using the created database and quality control parameters (Table 1), the above criteria for assessing the safety of the studied types of honey were calculated, the results of which are shown in Table 2.

Table 2. Quality parameters of the most common botanical types of honey according to safety indicators.

Indicator	Types of Honey According to the Pollen Profile				
	Robinia	**Rapeseed**	**Linden**	**Sunflower**	**Buckwheat**
Negative space amount S_i, μn^2	0.19	0.09	0.05	0.0	0.05
Coefficient of environmental danger, k_{ed}	0.07	0.03	0.02	0.01	0.02
Coefficient of compliance with the minimum quality standards k_{cs}, %	93.23	96.78	98.18	99.42	98.18
Relative to the normative content of heavy metals k_1, %	50	50	50	10	10
Relative to the normative content of levomycetin k_2, %	83.3	33.3	50	66.6	66.6
Relative to the normative content of pesticides k_3, %	2	1	2	40	10
Relative to the normative total activity of β-emitting radionuclides k_4,%	24	24	8	10	4
Relative to the normative content of nitrofuran k_5, %	16.6	16.6	8.3	16.6	0

The presented results of calculations of complex mathematical models make it possible to evaluate the quality of the five studied types of honey according to the eight pieces of criteria of environmental safety.

Given the natural origin of honey, environmental conditions and proper beekeeping practices play a leading role in the formation of quality and safety. The main factors influencing the biosphere on the safety and quality of honey are the accumulation, transfer, and further accumulation of contaminants of various nature through soil, water, and air into nectar, pollen, and wax. The accumulation of plant protection products and other agrochemicals in the soil directly affects the safety of honey. Collecting nectar and pollen near industrial centers contributes to the accumulation of heavy metals and other mechanical pollution. The violation of honey production and processing regulations is a prerequisite for microbiological contamination and the reduction in the quality and biological value of honey.

According to the results of our measurements of the main characteristics of the studied types of honey, the content of heavy metals, levomycetin, pesticides, and nitrofuran and the total activity of β-emitting radionuclides can be noted among the most significant parameters in the spectrum of negative impact. The highest content of heavy metals is observed in linden, Robinia, and rapeseed honey types, with the lowest found in sunflower and buckwheat. The highest content of pesticides is found in sunflower honey, with the lowest found in rapeseed honey. Robinia honey has the highest levomycetin content, and rapeseed honey has the lowest content. The highest total activity of β-emitting radionuclides is characteristic of the Robinia and rapeseed types of honey, and the lowest total activity was found in buckwheat. Robinia, sunflower, and rapeseed types of honey have the highest contents of nitrofuran, whereas this compound is not found in buckwheat honey at all. In general, according to the results of a physical and chemical study, the largest share of negative properties is found in Robinia and sunflower types of honey, and the smallest share is found in buckwheat and linden types of honey. Similar differential studies are used to construct the mineral profile of multifloral honeys from different geographic regions [42].

The question of the composition, functional properties, and safety of honey is an actual trend of research in the fields of technology, food science, and ecology [43,44]. Along with this, the methods of determining the safety and quality of honey are only becoming more complicated and require harmonization in a number of countries. There are no approaches to the comprehensive assessment of honey safety and quality indicators that would simplify the research methodology, make it possible to obtain quick and reliable results in terms of types and quality criteria, and, as a result, promote fair competition in the world honey market. This was openly stated by scientists from different countries around the world at the 48th Apimondia Congress in Santiago, Chile [45–47].

With regard to the obtained results, mathematical modeling of the quality of honey can serve as an additional method of determining the consumer safety of this product based on the sum of the generalized parameters. Sunflower honey has the lowest percentage of negative impact and, accordingly, the minimum coefficient of ecological danger. Along with this, this type of honey is the cheapest and is considered the least valuable by consumers [48]. Robinia honey can show the greatest negative effect and, accordingly, the maximum coefficient of ecological danger. This is explained by its frequent adulteration by unscrupulous sellers [49]. This type of honey is considered the best in terms of nutrition, medicinal, and organoleptic properties [50].

The method of mathematical modeling presented in this article can be considered a conceptual development of the methods of mathematical and physical–mathematical modeling that were shown by the author [51].

5. Conclusions

The application of the mathematical modeling method for the study of the ecological safety of the main types of honey based on indicators of contamination with antibiotic and pesticide residues, radionuclides, heavy metals, and mechanical impurities is scientifically justified. The proposed models can be implemented for practical use in specialized laboratories as a tool for determining the environmental safety of honey of various botanical origins. External factors can also be used as evaluation criteria, when their direct influence on product characteristics has been proven by experimental research, and they are presented in numerous forms. The evaluation characteristics used in the models are not limited in number but must have a clearly positive or negative impact on the change in product quality.

A point assessment based on a complex of such negative factors as the content of heavy metals, levomycetin, pesticides, nitrofuran, and the total activity of β-emitting radionuclides found Robinia and sunflower honey to be among the most ecologically dangerous types of honey, whereas buckwheat and linden types of honey have the smallest share of such environmentally hazardous components.

The smallest share in the total space of negative parameters is observed in sunflower honey, with the largest one being in Robinia honey.

Using the developed method of evaluating the researched varieties of honey by the mathematical modeling of "factor areas", it can be used for any number of parameters, which allows for more accurate results to be obtained. The presented geometric models demonstrate the overall quality of the studied product type and its alignment with normative or recommended characteristics, allowing for the identification of development or regression directions based on individual parameters.

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