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QUALITY OF BEESWAX IN THE CONTEXT OF SUSTAINABLE BEEKEEPING: TECHNOLOGICAL FACTORS OF FORMATION AND ENSURANCE AUTHORS

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Summary: The article examines the influence of wax raw material processing technology on the yield and quality of beeswax. The aim of the study was to identify the optimal method for obtaining a high-quality product and to evaluate the physicochemical and organoleptic characteristics of beeswax depending on the grade of raw material and the processing method. The authors' own research showed that processing first-grade raw material using modern equipment ensures the maximum yield and the highest product quality, while lower-grade raw materials are more efficiently processed using a specialized wax press. The technological processing method affects the moisture content, the presence of mechanical impurities, and the key parameters that determine the purity and consumer properties of beeswax. The results emphasize the importance of improving processing technologies to increase productivity and product quality in beekeeping and are valuable for beekeepers, processing enterprises, and researchers..

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Abstract: Beekeeping has long been an important branch of traditional rural production and a source of valuable products such as honey, beeswax, royal jelly, propolis, pollen, bee venom, and drone brood homogenate, which are widely used in the food, pharmaceutical, and veterinary sectors. Among bee products, beeswax occupies a special place as a complex multicomponent organic substance containing more than 300 compounds, including esters and alcohols of higher fatty acids, free fatty acids, saturated hydrocarbons, minerals, vitamins, and natural aromatic components. Its physicochemical properties determine the possibilities for its application in various industries, particularly in the production of foundation sheets, cosmetic products, and pharmaceuticals. The aim of the study was to determine the effect of processing methods and the grade of raw wax material on the quantitative yield and quality of beeswax. The experiment involved different grades of wax raw material (Grades I, II, and III) and processing methods, including solar and steam wax melters, as well as the modern Kulakov wax press. The physicochemical parameters of the wax (water and mechanical impurity content, iodine value, and saponification value) and organoleptic characteristics were assessed. The results demonstrated that processing technology has a significant impact on both the quantitative yield and quality of beeswax. The highest yield (98.5%) and the purest product were obtained from Grade I wax raw material using a solar wax melter, whereas processing Grade II and III raw materials with the modern Kulakov wax press ensured high yields (92.6–95.3%) along with improved physicochemical indicators. Wax obtained using the wax press was characterized by higher iodine and saponification values, indicating superior quality and compliance with established standards. The obtained data allow recommending the use of mechanized methods for processing wax raw materials at apiaries in order to increase product yield and improve physicochemical and organoleptic characteristics. The results have practical significance for wax producers, contribute to the optimization of technological processes, and enhance the competitiveness of products in both domestic and international markets.

Keywords: beekeeping, beeswax, raw material processing, product quality, physicochemical parameters, animal-derived products, production technologies.

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Тип статті – оригінальна наукова стаття

ЯКІСТЬ БДЖОЛИНОГО ВОСКУ У КОНТЕКСТІ СТАЛОГО БДЖІЛЬНИЦТВА: ТЕХНОЛОГІЧНІ ФАКТОРИ ФОРМУВАННЯ ТА ЗАБЕЗПЕЧЕННЯ

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Резюме: У статті досліджено вплив технології переробки воскової сировини на вихід і якість бджолиного воску. Метою роботи було визначити оптимальний спосіб отримання продукту високої якості та оцінити фізико-хімічні та органолептичні характеристики воску залежно від сорту сировини і методу обробки. Власні дослідження показали, що переробка сировини першого сорту на сучасному обладнанні забезпечує максимальний вихід і найвищу якість продукту, а сировину нижчих сортів ефективніше обробляти на спеціальному воскопресі. Технологічний метод переробки впливає на вміст води, механічних домішок та основні показники, що визначають чистоту і споживчі властивості воску. Результати підкреслюють важливість удосконалення технологій для підвищення продуктивності та якості продукції бджільництва і є цінними для пасічників, підприємств переробки та науковців.

Анотація: Бджільництво з давніх часів є важливою галуззю народного промислу та джерелом цінної продукції – меду, воску, маточного молочка, прополісу, пилку, бджолиної отрути та гомогенату трутневих личинок, що широко використовуються

у харчовій, фармацевтичній та ветеринарній сферах. Особливе значення серед продуктів бджільництва має віск, складна багатокомпонентна органічна речовина, що містить понад 300 сполук: ефіри і спирти вищих жирних кислот, вільні жирні кислоти, насичені вуглеводні, мінерали, вітаміни та природні ароматичні компоненти. Його фізико-хімічні властивості визначають можливості використання у різних галузях промисловості, зокрема для виробництва вощини, косметичних та фармацевтичних продуктів. Метою дослідження було визначення впливу способу переробки та сорту вихідної воскової сировини на кількісний вихід і якість бджолиного воску. В експерименті використано різні сорти воскової сировини (I, II та III) та методи переробки: сонячну та парову воскотопки, а також сучасний воскопрес Кулакова. Оцінювали фізико-хімічні показники воску (вміст води та механічних домішок, йодне число, число омилення) і органолептичні характеристики. Результати показали, що технологія переробки істотно впливає на кількісний вихід і якість воску. Найвищий вихід (98,5%) і найчистіший продукт отримано з I сорту воскової сировини на сонячній воскотопці, тоді як переробка II та III сорту на сучасному воскопресі Кулакова забезпечила високий вихід (92,6–95,3%) та покращені фізико-хімічні показники. Віск, одержаний на воскопресі, відзначався підвищеним йодним числом та числом омилення, що свідчить про його більш високу якість і відповідність стандартам. Отримані дані дозволяють рекомендувати використання механізованих методів переробки воскової сировини на пасіках для підвищення виходу продукції та покращення її фізико-хімічних і органолептичних характеристик. Результати мають практичне значення для виробників воску, сприяють оптимізації технологічних процесів і підвищенню конкурентоспроможності продукції на внутрішньому та зовнішньому ринках.

Ключові слова: бджільництво, віск бджолиний, переробка сировини, якість продукції, фізико-хімічні показники, продукція тваринного походження, технології.

1. Introduction

The modern agricultural sector is undergoing active transformation under the influence of innovation and scientific and technological progress, with particular emphasis on the development of environmentally safe sources of animal products that contribute to maintaining ecosystem balance (Danilyuk, 2020; Overkovska, 2023). In this context, beekeeping occupies an important position as a highly efficient and strategically significant branch of the agro-industrial complex (Zdyrko & Shulgan, 2022), supplying the population with valuable, environmentally friendly, and biologically active products (Vitvitska & Kozupitsya, 2016; Shulhan, 2023). The main products include honey, beeswax, pollen, propolis, royal jelly, and drone brood homogenate, all of which possess high nutritional, biological, and therapeutic–preventive value (Brodschneider & Crailsheim, 2011). An important ecological function of bees is the pollination of entomophilous plants, which increases crop yield and improves the quality of agricultural products (Turynskyi & Adamchuk, 2015).

The development of the sector is impossible without a deep understanding of the biological principles governing honeybee colony functioning, which determine the effectiveness of modern management and production technologies (Bugera et al., 2018; Grechka et al., 2021; Mishchenko, 2023). Today, beekeeping has a complex production character and is focused not only on honey and wax but also on other valuable products such as propolis, royal jelly, and bee venom (Campos et al., 2008; Mishchenko et al., 2021; Martinello & Mutinelli, 2021).

Due to their biological origin, bee products combine active components derived from plant nectar with enzymatic substances produced by bees (Kowalski & Kowalska, 2016; Kieliszek et al., 2023), which determines their uniqueness and functional value. Bees perform productive, pollination, and bioindication functions, ensuring ecosystem stability and enhancing the productivity of agrocenoses (Mishchenko et al., 2021). They also play an important role in implementing the “One Health” concept, which emphasizes the interconnection between human, animal, and environmental health (Breeze et al., 2011; Davydova et al., 2024).

Among bee products, beeswax occupies a special place as a complex organic substance produced by specialized wax glands of worker bees and used for constructing honeycombs—the primary structural element of the nest (Bogdanov, 2015). This natural product is a valuable raw material for the food, pharmaceutical, cosmetic, and technical industries (Fedak, 2021). Its quality depends on the origin of the wax raw material, biochemical composition, and processing conditions, while deviations from technological parameters may reduce its value and technological suitability (Vyshniak et al., 2019).

The chemical composition of beeswax includes more than 300 compounds, of which approximately 111 have been identified. The main components are complex esters (70–75%), free fatty acids (12–15%), and other bioactive substances such as alcohols, resins, pigments, aromatic compounds, cholesterol, and triterpenes (Bogdanov, 2015; Piaskivskyi, 2020). Owing to this composition, beeswax is characterized by plasticity, water resistance, and resistance to microorganisms and chemical agents, which ensures its durability and environmental safety (Kostiuk et al., 2020). The majority of beeswax is used for the production of foundation sheets, a key element determining the stability and productivity of honeybee colonies.

Thus, studying the influence of technological methods for processing wax raw materials on the quality of beeswax represents a relevant area of scientific research aimed at optimizing production processes, preserving the natural properties of the product, and ensuring consistent quality.

2. Materials and Methods

The study was conducted at a private apiary in the Zhytomyr District of the Zhytomyr Region with the aim of determining the effect of wax raw material processing technologies on the quality of beeswax. To achieve this objective, wax raw materials of different grades and their mixtures were selected, enabling a comparative analysis of the physicochemical parameters of the final product depending on the processing technology.

Wax raw materials were classified according to generally accepted criteria:

Grade I: white and yellow combs, transparent, free of honey and bee bread residues;

Grade II: dry dark-brown combs that remain translucent, without honey or bee bread; light-colored combs containing up to 15% bee bread;

Grade III: dark-brown to black opaque combs not affected by wax moths or mold and free of honey; light-colored combs containing a significant amount of bee bread.

Different processing technologies were applied, including a solar wax melter, a steam wax melter, and the Kulakov wax press. After processing, the following quality parameters of beeswax were determined: moisture content, content of mechanical impurities, iodine value, saponification value, and wax yield from the raw material.

Methods for determining quality indicators:

Mechanical impurities: Beeswax was dissolved in a tenfold volume of gasoline in a water bath, filtered through filter paper, rinsed with petroleum ether, dried, and weighed. The difference in mass was used to calculate the content of mechanical impurities.

Moisture content: A 5–10 g sample of beeswax was placed in a porcelain dish, heated in a water bath until transparent, cooled, and weighed. The difference in mass corresponded to the water content.

Iodine value and saponification value were determined titrimetrically according to standard analytical methods.

The results were processed using methods of variation statistics to establish the relationship between processing technology and beeswax quality.

3. Results

During the study, the influence of different wax raw material processing technologies on the quantitative and qualitative characteristics of beeswax was evaluated. Processing was carried out using methods aimed at preserving the physicochemical and biological properties of the wax. The raw materials included light combs of the first grade, trimmings from construction frames and feeders, wax crumbs, cappings, and queen cells.

Processing of first-grade raw material was performed using a solar wax melter, in which the wax was melted at 70–95 °C in a thin layer of material, ensuring uniform melting and minimizing mechanical impurities. The product yield reached 98.5% ($p \leq 0.001$), and the obtained wax was characterized by a light color and homogeneous consistency. Apiary residues contained 43–58% wax and can be used for secondary processing, yielding an additional 20–30% of the product.

Processing of second- and third-grade raw materials was carried out using a steam wax melter and the wet method with the application of the Kulakov wax press. The steam wax melter provided uniform heating of the raw material by steam, while the wet method included soaking, boiling, pressing, and settling stages, which allowed for an increased yield of wax of satisfactory quality. Both dry and wet pressing regimes ensured effective purification and the formation of a dense, homogeneous wax mass.

The dependence of wax yield on the grade of raw material and the processing method is presented in Table 1.

Table 1. Comparative characteristics of wax yield using different processing technologies, g (M ± m, n = 5)

Wax raw material grade	Method of processing wax raw materials		
	Voskopres Kulakova	Steam wax melter	Solar wax melter
I	-	-	98,5±1,23
II	95,3±1,24	63,4±1,31	-
III	92,6±2,43	53,1±1,12	-
mix II-III	94,6±1,01	49,3±1,25	-

The results demonstrate that wax yield decreases with declining raw material quality, and the combined processing of a mixture of second- and third-grade raw materials reduces process efficiency ($p \leq 0.001$). The highest performance indicators were achieved using the Kulakov wax press, which increased product yield by 1.5–2 times compared with the steam wax melter.

Determination of water content in the wax showed the lowest level in the product obtained using the solar wax melter (0.24% for first-grade raw material, $p \leq 0.001$), whereas wax produced using the steam wax melter and the Kulakov wax press contained up to 0.5% water, which complies with DSTU 4225:2003 “Natural Beeswax” (Table 2).

Table 2. Water content in beeswax depending on the processing method, % (M ± m, n = 5)

Wax raw material grade	Method of processing wax raw materials		
	Voskopres Kulakova	Steam wax melter	Solar wax melter
I	-	-	0,24±0,05
II	0,46±0,07	0,48±0,09	-
III	0,45±0,05	0,47±0,06	-
mix II-III	0,45±0,05	0,49±0,05	-

The subsequent stage of the study focused on determining the effect of wax raw material processing technologies on the content of mechanical impurities in the finished product. This parameter is an important quality criterion for beeswax, as it reflects the degree of product purification and compliance with technological requirements during processing. Beeswax almost always contains various mechanical inclusions that enter the product during technological operations, including wood shavings from frames, propolis particles, and residues from hive walls.

According to the requirements of the national standard, the content of mechanical impurities in beeswax must not exceed 0.5%. In the present study, the level of mechanical impurities did not exceed 0.3%. The lowest content was observed in first-grade drip wax (cappings wax), amounting to 0.09 ± 0.04% ($p \leq 0.001$), which indicates the high efficiency of the purification technologies applied (Table 3).

Table 3. Mass fraction of mechanical impurities in beeswax of different origins, % (M ± m, n = 5)

Wax raw material grade	Method of processing wax raw materials		
	Voskopres Kulakova	Steam wax melter	Solar wax melter
I	-	-	0,09±0,04
II	0,14±0,02	0,15±0,03	-
III	0,17±0,03	0,29±0,02	-
mix II-III	0,16±0,03	0,26±0,03	-

To assess the qualitative characteristics of beeswax obtained from wax raw materials of different grades and processed using various methods, the iodine value and saponification number were determined. These parameters are key indicators of the chemical purity and biological stability of beeswax. The iodine value reflects the content of unsaturated fatty acids (particularly those of the oleic series) and characterizes the degree of unsaturation of the wax components. The saponification number indicates the quantity of esters of higher fatty acids and alcohols, which determine the purity and quality of the product. According to the national standard, the iodine value should range from 7.0 to 15.0 g of iodine per 100 g of wax, and the saponification number should be 89–97. Chemical purity was evaluated based on the iodine value and saponification number. First-grade drip wax (cappings wax) exhibited the highest values (Table 4), indicating optimal preservation of wax structure and enhanced biological stability.

Table 4. Iodine value and saponification number of beeswax depending on the grade of wax raw material and processing method (M ± m, n = 5)

Wax raw material grade	Method of processing wax raw materials					
	Voskopres Kulakova		Steam wax melter		Solar wax melter	
	Saponification number, mg KOH/1 g wax	Iodine value, g/100 g of wax	Saponification number, mg KOH/1 g wax	Iodine value, g/100 g of wax	Saponification number, mg KOH/1 g wax	Iodine value, g/100 g of wax
I	-	-	-	-	98,5±1,56	14,0±2,11
II	95,6±1,11	10,2±0,16	85,8±2,22	9,3±0,17	-	-
III	97,3±1,17	12,3±0,11	69,8±1,21	8,4±0,12	-	-
mix II-III	97,1±1,55	11,6±0,24	71,4±2,11	7,2±0,24	-	-

Thus, the technology used for processing wax raw materials has a direct impact on the yield and quality of the product. The solar wax melter ensures minimal moisture content and high organoleptic quality, whereas the steam wax melter and the Kulakov wax press produce a product with standard moisture levels and consistent quality. At the same time, the wax press allows for nearly a twofold increase in wax yield compared to traditional methods.

4. Discussion

Commercial beeswax is the final product of processing wax raw materials, which include various types of apiary residues – cappings, wax scraps, merwa, and other remnants from comb processing. The yield and physicochemical properties of beeswax depend directly on the quality of this raw material and the chosen processing method (Samoichuk et al., 2021).

Wax raw materials are heterogeneous and contain significant amounts of mechanical and organic impurities; therefore, thorough purification is required before obtaining commercial wax. Mechanical and physicochemical cleaning methods are applied, including settling, filtration, repeated melting, or treatment with hot water and mild alkaline solutions.

Analysis of the results indicates a direct influence of the raw wax grade and the selected processing technology on the physicochemical characteristics and yield of commercial beeswax. In particular, it has been established that maintaining optimal processing conditions allows for the maximal preservation of the wax's natural properties and reduces the content of mechanical impurities and water, which directly affects its quality and suitability for industrial use. These results are consistent with current understanding of the dependence of beeswax quality on the grade of the starting material and the processing technology. It is well known that the quality of beekeeping products is not only an indicator of the technological level of the apiary but also of the overall production culture, as adherence to high-quality standards ensures competitiveness and the safety of food products (Postoenko, V. O., et al., 2019). Beekeeping products, including wax, are used in both the food and pharmaceutical industries, making the control of their purity and physicochemical properties of practical importance (Aghamirlou et al., 2015).

Beeswax is a complex mixture of over 50 organic compounds, predominantly esters, free fatty acids, and carbohydrates. The ratio of these components determines the main properties of wax—melting temperature, hardness, color, gloss, and odor. Specifically, a higher content of saturated fatty acids increases the melting point, while the presence of unsaturated acids affects the iodine value, a measure used to assess the degree of purity and saturation of the wax.

The results of the study confirmed that the technological method of processing the raw material significantly affects both the quantitative yield and qualitative properties of beeswax. The highest yield and the best organoleptic and physicochemical properties were observed in wax obtained using the Kulakov wax press. Its iodine and saponification values exceeded those of wax processed by traditional methods ($p \leq 0.001$), which can be explained by the increased efficiency of the mechanized processing method, ensuring more uniform melting, minimization of losses from impurities, and optimal preservation of the natural composition of wax (Kharchuk & Bodnarchuk, 2022). This pattern aligns with the well-established principles of technological improvement in wax processing, where the use of modern equipment enhances both quality and productivity.

Furthermore, it was demonstrated that processing grade II and III wax raw materials with the Kulakov wax press not only increases wax yield by 1.5–2 times but also reduces the content of mechanical impurities to levels compliant with national standards. This indicates the potential of using modern equipment to improve both the efficiency and environmental safety of production.

The obtained results expand our understanding of optimizing technological processes in beekeeping, particularly regarding the rational use of wax raw materials of different grades, and have significant practical value, as they allow for increased yield and quality of beeswax. Further research should focus on studying microstructural changes in wax under different temperature and pressure regimes, as well as assessing product stability during long-term storage.

5. Conclusions

The conducted research established that the yield and quality of beeswax directly depend on the grade of the starting wax raw material and the processing method. The highest wax yield (98.5%) was obtained when processing grade I raw material using a solar wax melter, which produces a product of the highest quality with minimal water content and mechanical impurities. However, this method is suitable only for high-quality wax raw material, as grade II and III samples yield significantly less wax when processed in this way.

Processing wax raw material using a steam wax melter results in reduced yield and product quality, as confirmed by statistically significant differences ($p \leq 0.001$). The most effective method for processing grade II and III raw materials was the Kulakov wax press, which ensures a wax yield of 92.6–95.3% and allows obtaining a product with lower mechanical impurity content (up to 0.2%) and improved physicochemical properties.

Wax obtained using the Kulakov wax press showed increased iodine and saponification values ($p \leq 0.001$), indicating higher purity, greater content of unsaturated fatty acids, and greater stability of ester compounds compared to wax obtained using the steam wax melter. Thus, the application of the Kulakov wax press under apiary production conditions is the most appropriate, as it not only increases wax yield by 1.5–2 times but also improves quality, ensuring the rational use of wax raw materials of different grades.

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