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The use of oaks in cosmetology

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ABSTRACT
The review discusses the application of oaks (Quercus) in cosmetology, focusing on the chemical and biological properties of their extracts. Oaks, rich in tannins, flavonoids, and other phenolic compounds, exhibit strong anti-inflammatory, antioxidant, and antibacterial activity, making them valuable raw materials in cosmetic production. The article presents the use of extracts from oak bark, leaves, and acorns in skin care products, particularly in anti-aging, toning, and treatments supporting the management of dermatological issues. Potential research directions on other properties of oaks that may find application in natural cosmetics are also discussed.
Keywords: *Quercus robur*; *Quercus petraea*; *Quercus pubescens*; *Quercus rubra*; antioxidant activity.

INTRODUCTION

Among the current trends in the cosmetics market, there is a noticeable demand for natural products, so-called biocosmetics, which are primarily based on high-quality raw materials that are environmentally friendly and safe. These ingredients are derived from plants as well as renewable sources. When developing cleansing products, particular attention is paid to the selection of emollients, emulsifiers, and surfactants. Multifunctional products are enjoying considerable popularity – e.g., cleansing products that also provide a protective effect. Consumers are increasingly expecting not only effective foaming and cleansing properties, but also care and nurturing benefits. Therefore, plant extracts are being used more frequently – as ingredients that not only give cosmetics a natural character but also serve as sources of biologically active substances. An example of a plant-derived raw material that has found application as an active component in intimate hygiene products, skincare products for acne-prone and oily skin, and shampoos for oily hair is oak bark extract [1]. The bark is obtained from 2 species of oak: pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* Ehrh.). These species occur in the temperate zone – in Europe, including Poland, as well as in North America [2].

THE PEDUNCULATE OAK

The pedunculate oak is one of the most important forest-forming tree species in Poland. It also plays a key role in park landscapes, roadside tree lines, and avenue plantings. For centuries, this species has been deeply rooted in the awareness and culture of many countries, including Poland. During the interwar period, the State Council for Nature Conservation conducted an inventory of ancient oaks within the then borders of Poland. A significant number of monumental specimens were found near churches, as well as in palace and manor parks. In later years, numerous further attempts at tree inventories were made. Due to their impressive size, oaks were classified among the most magnificent and oldest specimens. Analysis of the Polish nature monument registries suggests that pedunculate oaks represent the most numerous group of monumental trees – accounting for approx. 28%. Interestingly, among the 12 thickest pedunculate oaks in Poland, none are located in a province considered part of the species' natural distribution range.

Quercus robur is a representative of a massive and long-lived deciduous tree species from the beech family (Fagaceae). It typically reaches a height of 30–40 m, with a trunk diameter (at breast height) of 1.5–3 m, and a lifespan exceeding 700 years. The tree features a domed crown with thick, spreading branches, a short trunk, and dark green, leathery leaves that wither in autumn but often remain on the tree throughout winter [3]. It flowers between late April and May, producing wind-pollinated, unisexual flowers that are yellowish-green; the male flowers are gathered in catkins. The oak begins fruiting at the ages 40–80 years. Its fruits are well-known acorns, which mature in September and October, usually grouped in pairs or triplets on peduncles and seated in semicircular, gray cupules. These serve as a food source for many animal species. The pedunculate oak has been one of the most characteristic trees in the European landscape since ancient times. Quercus is the ancient Roman name for oak, while robur means long-lived, strong, and noble. *Quercus robur* is also known as *Quercus pedunculata* Ehrh., from the Latin pedunculus, meaning "flower stalk" [3].

The pedunculate oak is found across nearly all of Europe (with the exception of Iceland, northern Scotland, Sweden, and

Norway), the Caucasus, and Western Asia (including Georgia, Azerbaijan, Armenia, and Turkey). In Poland, it grows throughout the entire country – both in lowlands and in mountainous areas up to 600 m above sea level. Together with sessile oak (*Q.petraea*), it occupies about 7.7% of Poland's total forest area. It is a light-demanding species, sensitive to late spring frosts, thriving in moist, fertile soils with a slightly acidic to neutral pH. It forms oak forests (called dąbrowy), but is also found in mixed oak-pine forests, as well as in fir, spruce, hornbeam, and riparian forests [4]. The bark of *Quercus robur* (*Q. cortex*) is dark gray and, in old trees, can reach a thickness of up to 15 cm, featuring deep and triangular cracks. It is a commonly used herbal raw material, collected in spring from young trees and branches, and then dried in the shade or in dryers at temperatures up to 50°C [3]. The bark differs significantly from wood in both structure and chemical composition. It contains higher levels of lignins, suberins, and polyphenols. It is primarily composed of polysaccharides (cellulose and hemicellulose), pectin substances, and phenolic compound polymers, including lignins, tannins, and esters such as suberin and cutin [5]. Oak bark is especially rich in tannins – polymerized phenolic compounds consisting of glucose ester-linked with catechin derivatives, mainly protocatechuic and gallic acids. These tannins are located in the cell sap and account for 7–20% of the bark's weight [3]. Notably, oak bark contains approx. 38% lignins, 25% cellulose, and 16% extractable compounds, including polyphenols (mainly tannins and phenolic acids), and 9% hemicellulose [6]. In oak wood, polyphenolic compounds have been identified, including: gallic acid, ellagic acid, castalagin, vescalagin, roburin, grandinin, as well as syringaldehyde and coniferyl aldehyde. In contrast, the bark contains gallocatechins, catechins, leucodelphinidins, leucocyanidins, and leucopelargonidins [7].

The content of free monosaccharides in oak bark is about 5% of its mass, with the most abundant being glucose (1.5–3%) and mannose (1.1–1.7%), and the least being galactose (~0.5%). After hydrolysis of cellulose and hemicellulose, the sugars identified (in decreasing order) are: xylose (12.6%), arabinose (4.0%), glucose (3.0%), galactose (1.7%), mannose (0.8%), and rhamnose (0.8%) [6]. Extracts from pedunculate oak bark are particularly known for their healing and disinfecting properties. They also exhibit strong antioxidant and antimicrobial activity, effective against various bacterial and fungal strains. It has been demonstrated that alcoholic extracts of oak bark significantly inhibit the growth of *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Salmonella enterica*, *Escherichia coli*, as well as yeasts such as *Candida glabrata* and *C. albicans* [3].

Chochołowicz et al. conducted a study on the antioxidant activity of extracts from selected parts of the pedunculate oak (*Q. robur* L.), collected at different stages of the vegetation period [8]. The results obtained using various analytical methods suggest that both acorns and leaves of pedunculate oak are valuable sources of antioxidants. The antioxidant activity of the obtained extracts was found to depend on the solvent used. Both acorns and leaves of *Q. robur* proved to be significant sources of polyphenols. The oxidative potential and polyphenol content of the acorns may be lower in July, as this is the period when they are just beginning to mature. By late September, acorns reach full maturity; therefore, samples collected in October contain higher amounts of active compounds. In contrast, the study of oak leaves did not show a clear increasing or decreasing trend in antioxidant potential related to the month of harvest. Among the 3 tested solvents as extractants – concentrated isopropanol, n-propanol, and ethanol – none appeared optimal for the extraction of active compounds from oak leaves and acorns. Mixtures of each of these alcohols with water yielded better results. Therefore, further research on these raw materials may allow for the isolation of valuable antioxidants [8].

THE SESSILE OAK

The sessile oak has a longer leaf stalk and a shorter fruit peduncle compared to the pedunculate oak. It is characterized by a straight trunk that often reaches almost to the top of the tree, as well as thinner, less fissured bark. It naturally regenerates under the canopy, primarily in the form of clusters. Given its high light requirements, it needs toplight exposure for successful growth. It can also be artificially regenerated through planting or seeding.

The habitat and soil requirements of both pedunculate oak and sessile oak have been frequently described by many researchers [9]. In another study, Włoczewski noted that sessile oak is classified as a mesotroph [10], meaning it prefers moderately fertile sites. Sessile oak occurs mainly in temperate warm climates, limited to maritime and transitional climate zones. In Poland, it reaches the northeastern edge of its natural range. It does not occur east of the Węgorzewo–Ełk–Łomża–Bielsk Podlaski–Hajnówka line. Similar to *Q. robur*, it is considered one of the most important deciduous tree species in Polish forests and is primarily found in mixed forests. Its occurrence at the fringes of its natural distribution likely results in a narrowing of the range of habitats and soil types where the species can develop and grow optimally [9,11]. Seed stands of sessile oak are found mainly on podzolic, brown, and gray-brown podzolic soils. Compared to pedunculate oak, sessile oak is characterized by lower requirements regarding soil moisture and fertility. This distinction between the 2 oak species has been noted by numerous researchers, including Włoczewski [10, 11].

The most important bioactive compounds in sessile oak are tannins and polyphenolic compounds. Among the tannins, both hydrolyzable tannins (including ellagitannins and gallotannins) and non-hydrolyzable tannins (polymeric catechins) can be distinguished. These substances exhibit an astringent effect by forming stable bonds with the proteins of mucous membranes, thereby reducing water permeability. An infusion made from sessile oak bark is commonly used, among other purposes, in the care of oily and thinning hair. It is especially suitable as a rinse for dark hair [11, 12]. As previously mentioned, oak bark is a rich source of tannins (up to 20%), flavonoids (including quercetin – Figure 1), triterpenes, phenolic acids such as ellagic and gallic acids (Fig. 1), catechins, pectin, quercitol – $C_6H_7(OH)_5$ – phenolic resins, and phytoncides [13, 14]. The presence of these active compounds provides oak bark extracts with a broad spectrum of biological activity. They exhibit astringent, antibacterial, anti-inflammatory, antiviral, antifungal, and antioxidant effects [15]. In cosmetics, the most commonly used forms are aqueous-ethanolic and aqueous extracts of oak bark [1]. Sikora et al. conducted a study aimed at developing cleansing formulations containing oak bark extract obtained under supercritical CO2 conditions, which served as a sebostatic and antibacterial component. The study showed that adding a hydrophobic oak bark extract obtained via supercritical CO2 extraction in concentrations of 0.1–0.5% to cleansing products did not affect their foaming or cleansing properties, but it increased their viscosity. The results made it possible to develop products that significantly reduce skin oiliness, which may be suitable for cleansing formulations for combination and oily skin types. Moreover, the diversity of active compounds found in oak bark enables the use of the studied extracts in natural surfactant-based cleansing cosmetic formulations. These can produce mild yet effective products with anti-inflammatory, astringent, and antioxidant properties [1]. In her research, Drożdż demonstrated that a comprehensive characterization of oak bark – as a non-wood forest product – with respect to its antioxidant properties requires the use of a variety of analytical methods. Given the presence of significant amounts of polyphenolic compounds with health-promoting effects, forest plants may serve as components of a healthy diet, as well as ingredients in pharmaceuticals and nutraceuticals [3].

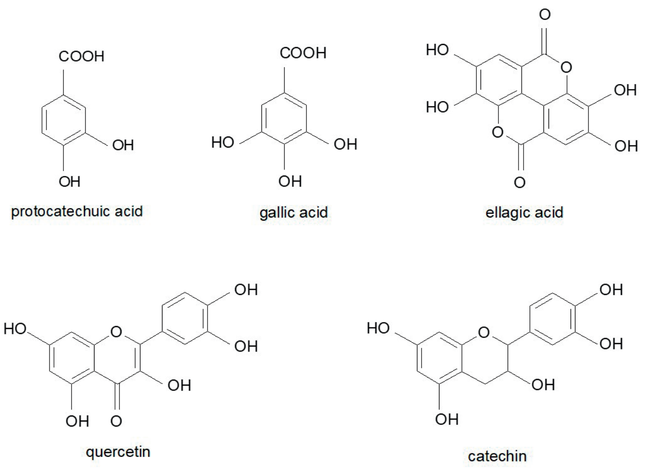

FIGURE 1. The examples of active compounds found in oak extracts

THE DOWNY OAK

The third native oak species in Poland is the downy oak (*Quercus pubescens* Willd.), which is considered an endangered species. It is also classified as endangered in Germany, and as vulnerable in the Czech Republic. This species is both light-demanding and shade-tolerant, prefers calcareous soils, and is drought-resistant. In Poland, it has only one known natural site, located in the forest-steppe reserve in Bielinek on the Oder River. In addition, around 40 non-native species and cultivated varieties of the genus Quercus occur in Poland. The most common among them is the northern red oak (*Q. rubra* L.), which is widely planted not only in parks and along avenues but also in forests [11, 16]. *Quercus pubescens* Willd. is a highly variable species, distinguished into three subspecies. In addition to the widely distributed nominotypical subspecies, subsp. palensis (Palassou) occurs in Spain, while subsp. anatolica is found in the southeastern part of its range. The latter 2 subspecies often occur in shrub form. *Q. pubescens* readily hybridizes with *Q. petraea* and *Q. robur* L. These hybrids are found in Poland and Germany, sometimes even outside the natural range of *Q. pubescens* [16]. As previously mentioned, the only site of downy oak in Poland is located in the Bielinek Reserve on the lower Oder River, where the species has been growing for at least 200 years. It is possible that the downy oak was introduced to Bielinek by humans. It has been described as a "local post-Cistercian anthropophyte". The oak grows primarily on south-facing, sun-exposed slopes. The substrate consists of glacial till and sandy loam of the ground moraine, rich in calcium carbonate (sometimes decalcified at the surface). Brown soils have developed there, with a neutral to alkaline pH. *Quercus pubescens* is a characteristic species of thermophilous oak woods (*Quercetum pubescenti-petraeae*), which form open, forest-shrub communities of relict character. This species is distinguished by the dense pubescence on young twigs, buds, and the undersides of leaves. In Poland, it grows up to 20 m tall and can exceed 200 years in age. It regenerates well, especially in grassland communities, particularly following mast years [16].

THE NORTHERN RED OAK

The northern red oak (*Q. rubra*) is the most numerous non-native deciduous species in Poland, considering both the sites of its introduction and the area it occupies. It occurs both in pure stands and as an admixture in mixed forest stands. As of today, this species grows throughout the lowland areas of the country as well as in the lower mountain regions. It was recognized as the only alien species that has fully acclimated to the habitat conditions present in Polish forest ecosystems [17]. This is most likely due to the fact that Poland's climate is quite similar to the weather conditions found within the natural range of *Q. rubra* in North America, particularly in its northern parts. Despite the long-standing presence of red oak in the forests of Poland, research on its adaptation to environmental conditions has not been conducted frequently. So far, only general patterns of the climate's influence on red oak growing in central Poland have been identified [18]. The homeland of the red oak is the eastern part of North America, and it was introduced to Poland in 1806 [19]. Its presence in various types of plant communities, including those with a natural character, often leads to the species being considered invasive. It is worth noting that negative impacts of red oak on phytocoenoses are observed, especially in ecologically valuable areas. According to the current forest cultivation guidelines from 2012, the elimination of this species is recommended in the reproduction of non-native species. Nevertheless, red oak is currently widespread in the forests of Poland. The species shows a strong tendency for natural regeneration and forming monospecific stands. Currently, red oak occurs on 5% of the area of state forests, where it is the dominant species on 0.5% of the area [20]. The highest concentration of red oak can be found in the following provinces: Silesian (1.04%), Lesser Poland (0.56%), Opole (0.39%), and Lower Silesian (0.28%). In central Poland, the average share of *Q. rubra* in State Forests is around a few tenths of a percent – values range 0.11–0.16%. Only in the Łódź province is this share higher than the national average, reaching 0.23%. Based on a comparison of the current distribution of red oak in Polish forests with data on the distribution of its plantations in the mid-20th century, a hypothesis has been formulated regarding the gradual expansion of red oak's range in Poland [21, 22].

Considering the potential use of raw materials derived from *Q. rubra*, it is important to note that acorn extracts are a valuable source of antioxidants [23]. Compounds from this group have a positive impact on health and are responsible, among other things, for slowing down the skin aging process. Extracts from the red oak's acorns are a particularly rich source of these substances. *Quercus rubra* belongs to the group of plants that contain flavonoids, which are one of the most important classes of natural compounds known for their ability to neutralize free radicals. The antioxidant activity of red oak acorns has long been a subject of interest for researchers across various scientific disciplines. Szynal et al. focused on analyzing the antioxidant properties of extracts obtained from red oak (*Q. rubra*, Fagaceae) acorns collected in October 2023 from 3 distinct locations: the Nowogard Forest District, a site near a busy street in Szczecin, and the vicinity of Lake Goplana in the same city. The conducted analyses revealed that the antioxidant activity of the extracts – prepared using four different low-molecular-weight alcohols – varied significantly depending on the collection site of the plant material. Furthermore, the authors demonstrated that red oak constitutes a valuable source of antioxidant compounds. It was also observed that both the type of solvent used and the extraction time had a substantial impact on the efficiency of bioactive compound recovery. Based on these findings, the researchers highlighted the potential application of red oak extracts in the cosmetics industry, particularly in anti-aging formulations [23].

Marc et al. focused their study on the powder obtained from red oak acorns. They presented the potential use of this powder in the production of a chocolate-like product that does not contain substances stimulating the nervous system. The research showed that red oak acorns are a rich source of phenolic compounds with strong antioxidant properties. As a result, they perform numerous physiological, biochemical, and biological functions. The high content of secondary metabolites can provide protection against microbiological contamination and also inhibit the growth of Gram-positive bacteria (*Bacillus cereus*) [24].

According to current literature, sessile oak is richer in aromatic compounds, while pedunculate oak contains higher levels of tannins [25]. Additionally, pedunculate oak contains compounds such as terpenes or bartogenic acid in dimeric forms. In contrast, sessile oak contains other types of terpenes, such as quercotriterpenosides, which belong to glycosidic terpenes [26, 27, 28, 29].

Buche et al. using various methods for determining antioxidant activity demonstrated significant activity of aqueous extracts from the wood of 3 oak species: pedunculate oak, sessile oak, and downy oak. The free radical scavenging abilities, measured using the DPPH and ABTS methods, were comparable across all species, amounting to 72% for the DPPH method and 95% for the ABTS method. However, the ferric and cupric ion-reducing capacities – almost twice as high for the former – were the greatest for pedunculate oak, followed by downy oak, and were the lowest for sessile oak. Antioxidant activity was correlated with the polyphenol content in the oak wood [25]. The aqueous extract from downy oak proved to be an interesting intermediate product derived from a rarely exploited oak species. It exhibits strong antioxidant activity due to its richness in phenolic compounds such as lignans and ellagitannins. Moreover, it showed moderate anti-elastase activity of about 50–60%, which was inhibited at a concentration of 250 μg/mL, alongside very strong anti-collagenase activity, inhibited at extremely low concentrations of 0.4 μg/mL and 0.04 μg/mL [25]. Considering both enzymes, sessile oak was less effective, while downy oak showed slightly higher activity than sessile oak. Additionally, oak extracts are rich in various groups of compounds, namely: low-polarity ellagitannin derivatives, high-molecular-weight ellagitannins (which are the main concentrated substances in the raw extract), phenolic glucosides, lignans, and triterpenoid derivatives [30].

Plainfossé et al. [31] indicated that the crude extract from the leaves of *Q.s pubescens* (Fagaceae) exhibits highly valuable anti-aging properties. This extract was selected for further studies, which led to the development of an innovative anti-aging agent and its practical cosmetic formulation. The study also confirmed the significant anti-aging activity of the crude *Q. pubescens* leaf extract. An interesting aspect of the work by Plainfossé et al. was the detailed presentation – based on research on this oak species – of the research and development process used to create a new cosmetic ingredient [31].

The literature review conducted by Burlacu et al. [32] encompassed findings on the biological activity of oak extracts and the compounds isolated from them. Most studies on bioactivity focused on antimicrobial, antioxidant, and anticancer effects. It is worth noting that Quercus extracts are a valuable source of phytonutrients, primarily polyphenols. The overall conclusion of the reviewed literature was that these extracts could be utilized for their potential antioxidant, antimicrobial, and anticancer properties. They may also find applications in various research fields such as medicine, pharmacy, and nutraceuticals, as well as in improving the sensory quality of wine. A significant portion of the pharmacological effects triggered by Quercus species may be attributed to their high content of phenolic compounds, particularly tannins, and their antioxidant potential. Pharmacological studies have been conducted mainly *in vitro* and, to a lesser extent, *in vivo*, while clinical trials remain limited. As a result, further clinical research is necessary to confirm *in vitro* and *in vivo* findings and support the rational use of these extracts, e.g., in phytotherapy. Therefore, more studies should focus directly on *in vivo* experiments. Additional research is also needed to explore the relationship between chemical composition and bioactivity and to clarify the mechanisms of action. Even though oak-derived products are generally considered safe, more toxicological data are required. The vast areas of oak forests, large quantities of forest waste (such as bark and leaves) generated during wood processing, high availability, and drought resistance make Quercus species an important source of bioactive compounds.

Extracts from various oak species are currently used in cosmetics, particularly as active ingredients for skin care. It is important to note that these active substances are mainly derived from bark or wood extracts. As of today, once developed, an ingredient must undergo all standard tests, including assessments of quality, efficacy, shelf life, and safety/tolerance (such as skin and eye irritation, cytotoxicity). This process is often referred to as the development chain and is a necessary prerequisite before a product can be introduced to the market. Only after thorough testing can the use of such an ingredient or ingredients be considered in the final formulation of a finished product. Many researchers integrate toxicological evaluation directly into the research and development process of cosmetic ingredients. In doing so, they aim to avoid unexpected findings at the end of the process that could lead to restrictions – or even the discontinuation – of the ingredient's use due to concerns over its toxicity [33].

In addition to bark or wood extracts, aqueous oak wood extract has also found applications in cosmetology. It could be used to neutralize reactive oxygen species generated during oxidative stress and to prevent the degradation of collagen and elastin during skin aging. Its additional properties may make oak extract a valuable, multifunctional ingredient in anti-aging cosmetic formulations. Further studies on the use of these evaluated cosmetic ingredients would be of interest, particularly through confirming *in vitro* results with tests on cell cultures or skin models, as well as exploring other types of biological activity [25].

Existing studies on oak (*Quercus spp.*) extracts indicate their considerable cosmetological potential resulting from the presence of polyphenolic compounds such as tannins, flavonoids, and phenolic acids. Despite their well-documented antioxidant and anti-inflammatory activity, many aspects related to the efficacy, stability, and influence of these extracts on skin microbiology require further investigation. Most of the current scientific reports on oak extracts are based on *in vitro* studies that evaluate, among others, their antioxidant properties and their ability to inhibit skin-degrading enzymes [25]. However, in order to confirm their effectiveness and safety under real conditions, *in vivo* studies, including animal models and clinical trials involving humans, are necessary. This would make it possible to determine the bioavailability of active compounds, their metabolism within the skin, and potential side effects [34]. Such studies would also allow the assessment of optimal concentration, frequency of application, and long-term effects of preparations on skin condition. Although the scientific literature provides numerous data on the chemical composition of extracts from various oak species, there is still a lack of systematic analyses linking the chemical profile with biological effects [25]. In future research, standardization of extracts should play a key role – determining and maintaining a constant content of major markers such as ellagitannins and condensed tannins. At the same time, it would be worthwhile to develop correlation studies between the content of these markers and indicators of biological activity (e.g., collagen level, elastase activity, or reduction of oxidative stress in skin cells). This would make it possible to build models describing the relationship between chemical composition and biological action, increasing the reliability and reproducibility of results. Even extracts with high biological activity may lose their effectiveness in products if they undergo chemical or physical degradation. For this reason, an important point for future research is the evaluation of the stability of oak extracts in real cosmetic formulations [35]. This concerns resistance to light, temperature, and pH changes, as well as interactions with other product ingredients (e.g., metal ions or peptides). The degradation of polyphenols may lead to changes in color, odor, and a decrease in antioxidant activity. Stability studies will make it possible to determine optimal storage conditions, formulation methods, and minimum concentrations ensuring product effectiveness. In recent years, increasing attention has been paid to the skin microbiome as an essential element in maintaining its health and biological balance. Although the effect of plant extracts on the intestinal microbiota has been relatively well studied [36], there is a lack of studies evaluating their impact on the skin microbiome. In the case of oak extracts, it would be particularly interesting to investigate whether the polyphenols they contain can modulate the composition and activity of commensal skin bacteria, support the protective functions of the epidermal barrier, or prevent colonization by pathogens. The results of such studies could open up new directions for the use of oak extracts as ingredients that support the natural microbial balance of the skin. In the context of sustainable cosmetology, another important direction of research is the evaluation of how raw material extraction and processing methods affect its biological value. Optimization of extraction processes using environmentally friendly solvents and low-temperature methods can increase both the safety and effectiveness of final products [25]. Moreover, the use of wood by-products (e.g., oak bark or sawdust) as a source of bioactive substances fits into the concept of green chemistry and upcycling, making these raw materials attractive for the modern cosmetics industry. Further research on oak extracts should adopt an interdisciplinary approach – combining phytochemistry, toxicology, dermatology, and skin microbiology. The results of such studies may contribute to the development of a new generation of natural cosmetics combining efficacy, safety, and biological harmony with the skin.

Extracts obtained from the bark, leaves, wood, and acorns of oaks (Quercus spp.) are rich in polyphenols, particularly tannins, flavonoids, and phenolic acids. These compounds exhibit valuable biological properties; however, their high chemical activity may, in certain situations, lead to adverse effects. Therefore, the safety of using oak-based preparations requires detailed toxicological evaluation and standardization of the production process [32, 37]. Current research suggests that the topical use of oak extracts at typical cosmetic concentrations is considered safe. Nevertheless, there is still a lack of comprehensive data on chronic toxicity and clinical studies involving humans, which makes it difficult to conclusively evaluation of the risks associated with long-term use. The literature emphasizes the need for *in vivo* studies and the development of standardized limits for tannin and ellagitannin content in cosmetic raw materials [8, 13]. Due to their high tannin content, oak bark extracts may cause local irritation such as excessive dryness, redness, or burning sensations, particularly after frequent use or high concentrations of the product. In rare cases, allergic contact dermatitis has been reported, resulting from hypersensitivity to polyphenols or their derivatives [38, 39]. It is recommended to perform patch tests prior to product commercialization and to include cautionary labeling for individuals with sensitive skin. Membranes and damaged skin astringent preparations should not be applied to large open wounds or mucous membranes without prior safety confirmation. The protein-coagulating effect, characteristic of tannins, may cause excessive tissue dryness or interfere with the natural healing process. However, at moderate concentrations, oak extracts can support the healing of minor abrasions and irritations due to their antibacterial properties [15]. The oral intake of oak preparations is not recommended without medical supervision, as high doses of tannins may cause gastrointestinal disturbances (nausea, vomiting, constipation) and reduce the absorption of certain minerals. There is a lack of data regarding chronic toxicity; therefore, these extracts should primarily be used for external application [5]. The safety of oak extracts largely depends on the quality of the plant material and extraction method. Microbial contamination, solvent residues, pesticides, or heavy metals can pose real risks to consumers. Therefore, quality control of each production batch and compliance with pharmacopeal purity standards are essential [40]. Tannins present in oak extracts can form complexes with proteins, peptides, and metal ions, affecting product stability and the activity of other active ingredients. When formulating cosmetics containing oak extracts, compatibility studies should be conducted to prevent precipitation or loss of biological activity [33]. Due to insufficient data on safety during pregnancy, lactation, and in children, products containing oak extract should not be used in these groups without appropriate toxicological evidence. Individuals with dermatological disorders, atopy, or reactive skin should take care and avoid products with high tannin content [14]. Oak extracts represent a valuable source of natural bioactive substances; however, their safety depends on the quality of raw materials, extraction method, and concentration in formulations. Further toxicological research, dermatological testing, and the implementation of strict quality control standards are recommended, especially for products intended for direct skin contact (Table 1).

TABLE 1. Summary of selected parameters of extracts from various oak species (*Quercus spp.*)

Oak species	Part of the plant used in studies	Main chemical markers	Biological activity	Potential cosmetic applications
Quercus robur L. (English oak)	bark, leaves, acorns	tannins (castalagin, vescalagin, roburins), gallic acid, ellagic acid, catechins, lignins, flavonoids	antioxidant, antibacterial, anti-inflammatory, astringent	oily and acne-prone skin care, tonics, intimate hygiene products, hair care for oily hair
Quercus petraea (Sessile oak)	bark	ellagitannins, gallotannins, quercetin, triterpenes (bartogenic acid), quercotriterpenoids, phenolic acids	astringent, antiseptic, anti-inflammatory, antioxidant	hair shampoos and rinses (for dark hair), cleansing and toning cosmetics
Quercus pubescens Willd. (Downy oak)	leaves, wood	ellagitannins, lignans, phenolic glycosides	antioxidant, anti-aging, anti-wrinkle, rejuvenating	protective and regenerating anti-aging cosmetics
Quercus rubra L. (Northern red oak)	acorns	flavonoids (quercetin, catechins), phenolic acids, polyphenols, tannins	antioxidant, antibacterial, anti-aging	anti-aging and protective cosmetics
Quercus ilex L. (Holm oak)	leaves	polyacylated flavonoid glycosides	antioxidant, protective	natural source of antioxidants in cosmetics
Wood of Quercus spp. (various species)	wood	lignans, ellagitannins, phenolic glycosides	antioxidant, anti-collagenase	anti-wrinkle creams, antioxidant serums

SUMMARY

Consumers are increasingly seeking more eco-friendly and safer cosmetic ingredients. They place significant importance on the actual effectiveness of these ingredients, which means that manufacturers must provide evidence to support the claims made on their product packaging [41, 42]. As a result, cosmetic producers are continuously striving for naturalness and originality, intensifying the use of biotesting to scientifically justify the use of natural cosmetics.

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