Environment and Social Psychology (2025) Volume 10 Issue 4
doi: 10.59429/esp.v10i4.3641

ISSN: 2424-8975 (O)
2424-7979 (P)

Review Article

Coumarins in the human–nature nexus: Exploring their environmental and psychological footprint

Wejdan Al-Shakarchi, Yasser Fakri Mustafa*

Department of Pharmaceutical Chemistry, College of Pharmacy, University of Mosul, Mosul, 41001, Iraq

*** Corresponding author:** Yasser Fakri Mustafa, Dr.yassermustafa@uomosul.edu.iq

ABSTRACT

Coumarins, a diverse family of naturally occurring compounds, offer a remarkable window into the deep and dynamic relationship between humans and the natural world. Found in plants, fungi, and even insects, these benzopyrone derivatives are not only known for their pharmacological versatility but also for their cultural, psychological, and ecological resonance. This review journeys through the multifaceted narrative of coumarins—from their ancient medicinal uses and spiritual significance to their contemporary relevance in environmental sustainability and mental health. Historically used in embalming rituals and herbal remedies, coumarins have been quietly shaping human experience for centuries. Their fragrant presence in essential oils and plant-based incense once framed sacred spaces and contemplative practices, hinting at their subtle but lasting psychological impact. Today, coumarins are gaining renewed interest not only for their anti-inflammatory, antimicrobial, and antioxidant properties but also for their potential role in mood regulation, cognitive enhancement, and neuroprotection. Their influence on monoamine pathways suggests applications in stress relief and emotional well-being—key concerns in the modern, often nature-deprived lifestyle. Environmentally, coumarins act as plant defense agents and ecological messengers, influencing biodiversity, herbivore behavior, and even soil microbiota. Their allelopathic and biocidal properties position them as vital tools in green chemistry and sustainable agriculture. Furthermore, interdisciplinary collaborations now explore coumarins in fields ranging from biomedicine and biotechnology to aromatherapy and environmental psychology. This review highlights coumarins not just as biochemical agents but as symbolic links in the human–nature nexus—agents of healing, communication, and balance. Understanding their roles across ecosystems, cultures, and psychological dimensions is essential for developing sustainable strategies that respect both biodiversity and human well-being. In an era of ecological uncertainty and emotional fragmentation, coumarins offer a fragrant reminder that nature and humanity are deeply, chemically, and spiritually entwined.

Keywords: coumarins; environmental psychology; mood regulation; cognitive function; psychoactive phytochemicals

1. Introduction

Coumarins represent a fascinating class of secondary metabolites, known for their wide-ranging biological activities and long-standing role in traditional medicine. Although they were first isolated and characterized in 1820, the use of coumarins in human societies predates their formal discovery by centuries[1]. These phytochemicals have been deeply embedded in cultural, medicinal, and even spiritual practices, serving as a

ARTICLE INFO
Received: 16 March 2025 | Accepted: 3 April 2025 | Available online: 16 April 2025

CITATION
Al-Shakarchi W, Mustafa YF. Coumarins in the Human–Nature Nexus: Exploring Their Environmental and Psychological Footprint. *Environment and Social Psychology* 2025; 10(4): 3641. doi: 10.59429/esp.v10i4.3641

natural bridge between humans and the environment[2]. This work traces the historical and cultural journey of coumarin-containing plants, exploring how human societies have perceived, utilized, and shared knowledge about them across generation-spanning disciplines from ethnobotany and traditional healing to spiritual rituals and the arts[3]. Beyond their well-documented pharmacological and physiological roles, coumarins also evoke subtle psychological and emotional responses, particularly through their presence in incense and aromatic substances used in contemplative, meditative, or religious contexts[4]. Their influence extends into the realm of environmental psychology, suggesting coumarins may act not only as therapeutic agents but also as mediators of human-nature connections[5].

As the global focus shifts toward sustainable health solutions and eco-conscious living, interest in naturally occurring bioactives like coumarins has surged[6]. Researchers are now investigating new sources of coumarins, including endophytic fungi and plant extracts, with the goal of uncovering novel compounds that align with principles of green chemistry and environmental stewardship[7]. This article also addresses the balance between isolating pure compounds for therapeutic purposes and preserving the ecological and synergistic value of whole plant systems[8]. With growing awareness of both safety concerns and sustainability imperatives, coumarins stand at the crossroads of modern science, traditional wisdom, and the evolving human relationship with nature[9].

2. Historical context of coumarin research

In ancient Egypt, coumarin-containing substances were valued for their aromatic properties and reportedly used in the preservation of bodies during mummification rituals, particularly in royal burials. These early applications reflect a profound, empirically grounded understanding of natural compounds that were rooted in the traditions, observations, and shared wisdom of early civilizations[10]. Over the centuries, human societies have drawn from the natural world to improve well-being, exploring and refining the use of botanicals, minerals, and other naturally occurring substances[11]. These bioactive agents were integrated into daily life with minimal processing, guided by a deep respect for nature's inherent properties and the belief in its capacity to support health and longevity[12]. Coumarin, a naturally occurring compound found in various plants, exemplifies this enduring relationship between humans and nature. Beyond its pleasant scent, coumarin represents a broader spectrum of interactions—chemical, ecological, and even cultural—that connect living systems[13]. Today, as scientific and societal interest in natural products resurges, coumarin continues to stand out not only for its functional roles in ecosystems and pharmacology but also as a symbol of the intricate and timeless dialogue between humanity and the environment[14].

3. Chemical structure and properties of coumarins

Numerous scientific investigations have highlighted the beneficial properties of natural fragrances, many of which owe their effects to coumarin-based molecules. Among the most iconic examples is the essential oil of oranges—one of Sicily’s most celebrated aromatic exports—which contains coumarins as part of its complex chemical makeup[15]. But what makes these scents, so beloved by humans, rich in structurally diverse and intricate molecules? Interestingly, in nature, simpler molecular structures are typically more abundant, while more complex ones occur less frequently. Yet in the realm of fragrance, complexity reigns. This paradox can be partially explained by the fact that life—at every level—is built upon interactions between molecules with strong intermolecular forces. These forces influence how molecules organize themselves into stable, yet dynamic structures capable of carrying biological and sensory information[16]. The presence of structurally diverse compounds allows for nuanced olfactory experiences, with coumarins often acting as key contributors due to their aroma-enhancing and skin-compatible properties[17].

Coumarins are a broad and chemically intriguing subclass of benzopyrones, naturally found in a wide range of plant species. To date, over 1,300 naturally occurring coumarins have been identified. They are generally classified into monomeric coumarins, dimeric forms, and more specialized types such as furocoumarins, benzocoumarins, and pyranocoumarins[18]. These compounds are distributed across various plant families, including Aceraceae, Fabaceae, Rutaceae, Moraceae, and Polygonaceae. Common natural sources include the tonka bean (*Dipteryx odorata*), *Melilotus officinalis*, *Angelica archangelica*, and *Mentha aquatica*. Interestingly, coumarins are not exclusive to higher plants—they also occur in algae, fungi, and some insects like fireflies and butterflies[19]. Recent studies have revealed that endophytic fungi, particularly species like *Phaeoacremonium viticola* and *Diaporthe* from *Juniperus communis*, are promising alternative sources of bioactive coumarins, further expanding their ecological and biotechnological significance[20].

4. Natural sources of coumarins

Certain coumarin pathways, once considered a byproduct with limited value in extracting plant-derived coumarins, have recently gained renewed scientific attention. Recent improvements in methods and detailed studies of species involved in oxidation reactions have created new opportunities for producing specific coumarin derivatives[21]. These developments are paving the way for replacing traditional chemical synthesis and complex biotransformation routes with more sustainable, economically viable strategies that are also environmentally friendly[22]. One notable example is coumalicin, a naturally occurring antifluorogenic coumarin isolated from endophytic fungi. In addition to its unique structure, coumalicin also serves as a building block in making acetylenic quinolone alkaloids[23]. In the same way, gliocladin C, which is a substance that can kill insect larvae, also comes from endophytic fungi—organisms that live in a close relationship with plants[24].

Coumarin production in plants usually comes from the phenylpropanoid pathway, which often combines elements from the chorismate and malonate pathways, along with the shikimate and malonamate pathways. A crucial beginning in this process is the joining of tiglyl-CoA and malonyl-CoA. A key starting point in this metabolic network is the condensation of tiglyl-CoA and malonyl-CoA[25]. Crucially, plant development stages like germination do not confine coumarin production—it becomes particularly active under stress conditions like mechanical wounding or environmental pressure. When faced with stress, plants turn on their defense systems, creating a series of secondary metabolites, which include smelly compounds and phenolic coumarin derivatives[26]. These phenolic forms, made by adding hydroxyl groups to phenylpropanoids, are often present in the plant's outer waxy layer. Their exceptionally low vapor pressure facilitates strong adhesion to leaf surfaces, enhancing direct interaction with herbivores. This adhesion allows the plant to release toxic and repellent chemicals that serve as a natural deterrent. In tobacco plants, the release of phenolic coumarins is found to be 100 times higher than that of glucosidic compounds, highlighting their important role in protecting the plant[27].

5. Biological activities of coumarins

Recently, growing concern over the adverse effects associated with conventional anti-inflammatory medications has intensified the search for safer alternatives. In this context, coumarins have emerged as promising bioactive compounds due to their broad pharmacological potential[28]. Beyond their well-documented anti-inflammatory activity[29], coumarins have demonstrated significant antitumor[30,31], antioxidant[32,33], antibacterial[34,35], and antiviral properties[36,37]. Computational studies using various computer-based methods also show that they can help with brain-related issues, pain relief, and inflammation[38,39]. Coumarins also exhibit strong antifungal[40] and cardioprotective effects, making them valuable candidates in the management of cardiovascular conditions[41]. Additionally, their therapeutic potential extends to liver health, particularly in addressing non-alcoholic fatty liver disease[42]. Mechanistically, they partially suppress key mediators such as prostaglandins and leukotrienes, notably inhibiting leukotriene synthesis. Some derivatives have also shown potential as modulators of GABA-A receptors, adding to their neuroinflammatory relevance[43].

In simpler terms, studies done in the lab have shown that simple coumarin derivatives can help reduce harmful hydroxyl radicals, which is important for fighting oxidative stress—a key factor in diseases like Alzheimer's[44]. Additionally, their small size and presence in foods and medicinal plants make coumarins appealing options for creating new drugs, especially for diseases that involve inflammation or tumors[45]. Of particular interest is their application in oral cancer therapy, where inflammation and chronic disease progression often intersect[46]. When used together with existing treatments, low-toxicity coumarin derivatives might work better and cause fewer side effects. These combinations, particularly those with compounds that are sensitive to biological changes and last a long time while fighting cell growth, could help solve problems like drug resistance and side effects that often happen with single treatments. These insights position coumarins as valuable candidates in the evolving landscape of integrative and precision medicine[47–49].

5.1. Antioxidant properties

Coumarins play essential roles in plant physiology and survival. Among their many functions, the antioxidant capacity stands out as a crucial mechanism for maintaining cellular integrity, particularly under stress conditions such as oxidative damage. Historically, the value of medicinal plants—rich in bioactive compounds like coumarins—was well recognized, even before the advent of modern pharmaceuticals[50]. Today, this ancient wisdom is echoed in the chemical diversity of coumarins found across various plant species, tissues, and developmental stages, shaped by both genetic and environmental factors. These compounds, whether freely secreted or stored within plant structures, exist in numerous forms, including open-chain and furanocoumarins with varying side chain lengths and substitutions[51]. This structural variability allows them to perform a wide range of protective and adaptive functions. Coumarins are not just leftover substances; they play an important role in helping the plant survive by protecting it from damage, diseases, and insects, and they can also help communicate in ecological relationships[52].

At the molecular level, the α-pyrone ring structure in coumarins is known for its strong ability to fight off damage from free radicals, which can help protect against certain diseases. The presence of groups like hydroxyl, methoxyl, acyl, or geranyl can significantly enhance this ability, making the molecule more effective at neutralizing reactive oxygen species[53]. In plant cells, coumarins play a key role in many processes, such as controlling cell division, helping cells develop, and protecting cell membranes. Also, their ability to change shape lets them work with different enzymes and cell materials, helping to support flexible defense actions and stability inside the cells[54]. Basically, the antioxidant qualities of coumarins give plants an edge in survival and may also help other living things that gain from their protective benefits—it's a lasting benefit from nature's clever chemistry[55].

5.2. Antimicrobial effects

Staphylococcus aureus is a prominent pathogen responsible for a wide range of skin-related infections, particularly in cases involving burns, abscesses, surgical wounds, and complications arising from invasive medical procedures. The increasing resistance of this bacterium, particularly methicillin-resistant (MRSA) strains, poses a serious challenge to public health, driving the search for novel therapeutic agents[56]. Recent *in silico* studies have highlighted the potential of coumarin-based compounds to interfere with the bacterial cell division process, suggesting a possible mechanism for their antibacterial action. Several naturally occurring and synthetically modified coumarins have demonstrated notable efficacy against both *Staphylococcus aureus* and its MRSA versions[57]. For instance, a dialkylaminoalkyl-substituted 4-arylcoumarin derivative exhibited impressive anti-MRSA activity with a minimum inhibitory concentration (MIC) as low as 0.5 µg/mL. Similarly, 4,5,6-trifluorobenzo[*d*]thiazole-based coumarins showed potent antibacterial activity, with MIC values ranging from 0.5 to 16 µg/mL[58].

New structural improvements have resulted in the creation of 1,3,4-oxadiazole-linked quinolinone–coumarin hybrids, which also showed strong antimicrobial effects[59]. Notably, coumarin derivatives conjugated with doripenem—a broad-spectrum carbapenem antibiotic—showed enhanced activity against MRSA strains[60]. Among a newly synthesized class of fluoroquinolonyl–coumarin conjugates, one compound demonstrated exceptional efficacy with an MIC of 0.25 µg/mL, along with favorable stability profiles[61]. Beyond synthetic analogues, natural extracts have also shown promise. The root extract of *Maladera affinis*, rich in coumarin content, exhibited strong bactericidal activity against *Staphylococcus aureus*[62]. Also, 4-hydroxycoumarin derivatives with naphthalene parts connected by two-carbon chains showed strong effects, successfully stopping both regular and MRSA strains. Together, these results highlight how coumarins could be used as a base for creating new antibacterial drugs aimed at fighting resistant germs like MRSA phenotypes[63].

5.3. Anti-inflammatory activities

Given the deep evolutionary connection between inflammation and key cellular processes such as oxidative stress and redox signaling, it is not unexpected that many compounds with antioxidant activity—like coumarins—also display significant anti-inflammatory potential. Notable examples include esculetin and esculin, two naturally occurring coumarins that have demonstrated clear anti-inflammatory effects in preclinical studies[64]. The structural features of certain coumarins, such as *ortho*-methoxyl and hydroxyl substitutions at positions 3, 4, and 5, may contribute to their redox-modulating properties, offering mechanisms similar to those observed in flavonoids[65].

Despite these promising observations, much of the current research remains limited to early-stage *in vitro* studies focused on acute inflammatory responses. There is a pressing need for more comprehensive investigations that explore both pro- and antioxidant effects of coumarins under chronic and systemic conditions. Particularly, studies that assess gene expression and potential epigenetic modulation by coumarins would provide valuable insights into their broader biological impact[66]. Furthermore, understanding how coumarins from different sources—whether plant-derived or animal-associated—interact with human cellular pathways may uncover subtle yet important differences in biological response[67].

For these findings to meaningfully translate into clinical relevance, research must follow a rigorous pipeline—from molecular target identification and cellular studies to tissue-level analyses and ultimately, well-designed clinical trials. This translational framework, often described metaphorically as Balmer’s triangle, underscores the importance of connecting molecular mechanisms to real-world therapeutic outcomes[68]. In a broader sense, one might ask: has nature, through millions of years of co-evolution, hidden potent anti-inflammatory agents like coumarins in our food and environment? Or have modern industrial practices and an overemphasis on synthetic "detox" trends obscured their potential? To answer these questions definitively, robust, interdisciplinary, and ethically grounded research is essential.

6. Coumarins in traditional medicine

The recognition of plants as sources of healing and well-being has long been a foundational concept in traditional medicine systems across the globe. As some of the earliest tools available to humans, medicinal plants have historically been used to prevent and treat illness, forming what is arguably one of the oldest branches of empirical science[69]. For thousands of years, various plant species played a pivotal role in human survival, not only as sources of nourishment but also as therapeutic agents. From these early practices emerged the first structured medicinal systems, initially guided by folk knowledge and later refined by shamans, herbalists, and early physicians[70]. Over time, these evolved into more formalized traditions such as Traditional Chinese Medicine, Ayurveda, and Greco-Arab medicine, which continue to influence modern healthcare paradigms, including allopathic medicine[71].

In many regions, especially in Latin America, the enduring legacy of indigenous medical knowledge remains evident. Native healing practices, deeply rooted in cultural identity and the natural landscape, have made significant yet often underappreciated contributions to the broader field of medicine[72]. Despite occasional skepticism or historical inaccuracies in documentation, these systems represent a rich reservoir of therapeutic insight. An example of the global reach of botanical remedies is the use of a particular four-leafed plant—historically cited in numerous healing traditions[73]. Ancient Chinese physicians during the Tang Dynasty employed it for gastrointestinal disorders and mental calmness. In Ayurvedic medicine, where it is referred to as sugan, it is traditionally used to treat various skin conditions[74]. During the Renaissance, European physicians utilized it as a vermifuge, and Benedictine monks incorporated it into colonial pharmacopeias. In traditional Mexican medicine, its use is practical and culinary—boiled into poultices to heal wounds or added to dishes for its pungent flavor and reputed digestive benefits[75].

6.1. Historical uses

Pliny the Elder, the Roman naturalist and philosopher, documented the use of incense derived from *Commiphora* species—commonly known as myrrh—long before the Black Death of 1347, which would later be attributed to a bacterium from the *Yersiniaceae* family. Though the true nature of microbial infections was unknown at the time, the antiseptic properties of *Commiphora* resin appear to have been intuitively recognized and passed down through generations[76]. Avicenna, the renowned Persian physician and polymath, famously referred to myrrh as “liquid gold,” emphasizing its high value and therapeutic potential[77]. Pliny believed that its resistance to decay contributed to its medicinal efficacy, a notion echoed by Dioscorides, the Greek physician and botanist, who also noted its role in embalming practices in ancient Egypt[78].

Later, as alchemical knowledge spread from the Arab world to Europe—particularly through translations carried out in centers like Toledo—substances such as mercury were believed to possess unique transformative powers, including the ability to dissolve gold. Against this historical and cultural backdrop, the medicinal application of *Commiphora* resin becomes even more significant[79]. Modern phytochemical analysis supports its traditional uses, revealing bioactive compounds with therapeutic potential for treating ulcers, tumors, asthma, and coughs, as well as for their antiseptic and antiviral properties[80].

6.2. Modern applications

Coumarins and their synthetic derivatives have been widely recognized for their antibacterial and antifungal properties. In plants, these compounds play a vital role in defense mechanisms against herbivores[81]. For instance, certain coumarins induced by ultraviolet exposure form a protective chemical barrier that deters insect predation, offering an energetically efficient alternative to more complex defense systems[82]. Beyond their ecological functions, coumarins have found diverse applications in modern industries, particularly in food and pharmaceuticals[83]. Natural and synthetic coumarin derivatives are employed as sweetening agents, ultraviolet light protectors, and antioxidants[84]. Moreover, several coumarins isolated from medicinal plants exhibit significant acetylcholinesterase inhibitory activity, suggesting their potential as therapeutic agents in the treatment of neurodegenerative disorders such as Alzheimer's disease[85].

In the cosmetic and materials sciences, coumarin-based compounds serve as pigments, chemical sensors, and components of organic light-emitting diodes. These applications exploit their unique ultraviolet–visible absorption properties, which arise from extended conjugated π-systems[86]. Additionally, coumarin derivatives have shown promise in biomedical imaging and molecular diagnostics, including techniques like positron emission tomography, single-photon emission computed tomography, and magnetic resonance imaging[87]. Coumarins are also utilized in eco-friendly vegetable tanning processes for leather production, offering a more sustainable alternative to traditional tanning methods due to their carbon-based, biodegradable nature[88]. In summary, the complex chemical ecology of plant–insect interactions serves as a rich source for the discovery of bioactive compounds. Continued research into both natural and semi-synthetic coumarins holds great promise for future therapeutic, industrial, and environmental applications[89], as illustrated in **Figure 1**.

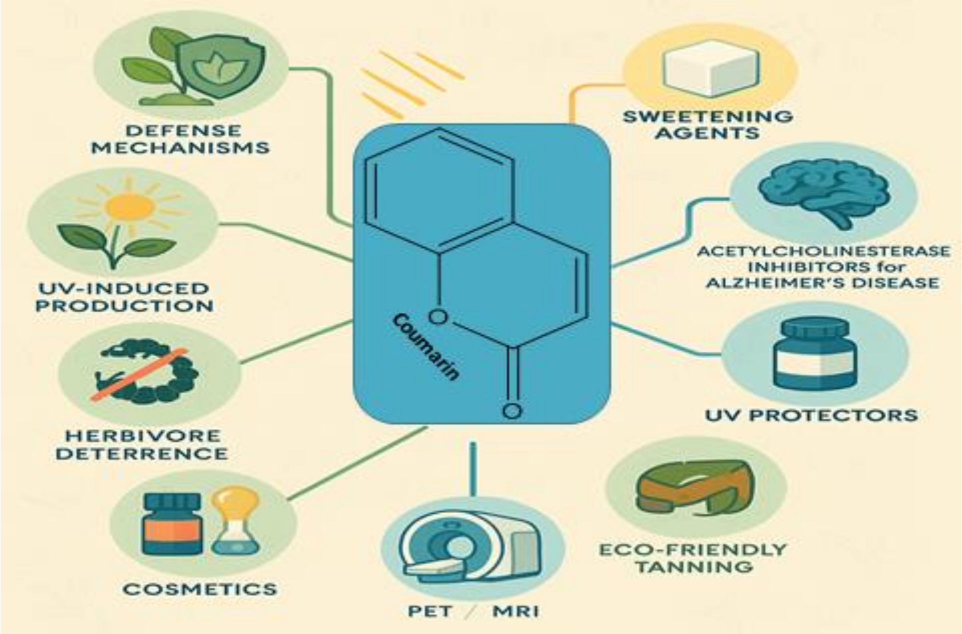

Figure 1. Coumarins: Bridging ecology, industry, and medicine.

7. Environmental impact of coumarins

With growing awareness of environmental pollution and its ecological consequences, researchers have intensified efforts to explore innovative strategies for the biodegradation of wastewater[90]. Increasing reports of ecosystem disruptions, often linked to the uncontrolled release of pollutants into rivers and other water bodies, underscore the urgency of this issue. Numerous synthetic organic compounds have now been identified as environmental contaminants[91]. Many organic substances—both natural and synthetic—such as coumarins, aromatic hydrocarbons, and hydroxycinnamic acids, exhibit resistance to conventional physical treatment techniques used in wastewater management. Nonetheless, a wide range of microorganisms, including bacteria, yeasts, and filamentous fungi, possess the metabolic versatility to degrade these compounds, utilizing them as energy sources or incorporating them into biomass[92–94].

Despite these microbial capabilities, coumarins have not yet been classified as critical environmental pollutants or prioritized for focused ecological studies. Interestingly, certain plant species thriving under specific environmental stressors produce coumarins as part of their adaptive response[95]. These compounds, owing to their distinctive chemical structures and interaction with cellular components, exhibit notable antimicrobial and antibacterial properties[96]. The following two subtitles aim to highlight such unique biological traits and the potential ecological role of coumarins in plant-environment interactions.

7.1. Role in ecosystems

It is reasonable to acknowledge the widespread occurrence of coumarins in nature, particularly considering that their biosynthetic precursor, umbelliferone, is a common phytochemical found in many flowering plants. This suggests a significant biosynthetic potential within the plant kingdom[97]. Several intriguing questions arise in this context. For instance, could the production and subsequent conversion of coumarin into scopolin be an adaptive strategy by some plants to deter seed-eating mammals? Might the toxic properties of coumarins serve a defensive role against herbivores that frequently cause damage to plant tissues?

Although the phytotoxic effects of coumarin derivatives have only recently gained scientific attention, they appear to be highly selective, potent, and reversible. These compounds may exert planticidal effects not directly on plants themselves, but rather through complex biogeochemical interactions at the interface of plant development and environmental factors[98]. Under specific abiotic conditions, the formation of key plant structures involved in the release of coumarins during decomposition may be inhibited or altered, influencing the ecological distribution and impact of these compounds[99].

Our hypothesis concerning the photoactivation of coumarin-mediated biocidal activity suggests a link between plant metabolic pathways and ecological defense strategies. This implies that allelochemicals such as coumarins may be more tightly regulated by environmental cues—such as light exposure—than by random nutrient or stress fluctuations[100]. Moreover, the glycosylated form of coumarin, scopolin, is known to mediate beneficial biochemical effects upon decomposition in the presence of light, indicating that other structurally related, non-genotoxic coumarin derivatives may function in a similar light-dependent, ecologically adaptive manner[101].

7.2. Effects on biodiversity

Coumarins play a nuanced yet significant role in shaping biodiversity across ecosystems, as shown in **Figure 2**. Found in a wide range of plant species, coumarins act as chemical mediators that influence interactions between plants and various organisms, including insects, microbes, and other plants[102]. These compounds can serve as attractants, repellents, or even signaling molecules, depending on the context and concentration. As such, coumarins contribute to ecological balance by affecting species distribution, population dynamics, and the structure of biological communities[103].

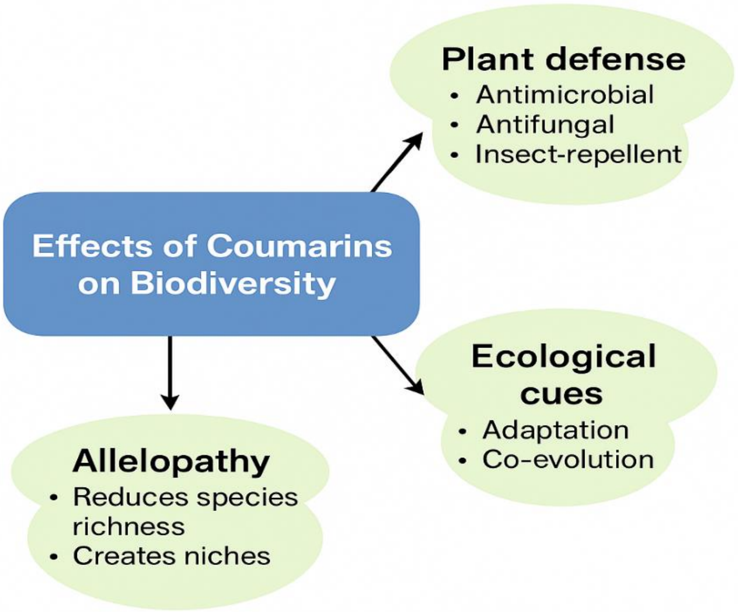

Figure 2. Ecological roles of coumarins and their impact on biodiversity.

One key way coumarins impact biodiversity is through their role in plant defense mechanisms. Their antimicrobial, antifungal, and insect-repellent properties can determine which herbivores or pathogens are able to colonize a plant, thereby shaping the diversity of organisms in a given habitat[104]. For example, certain coumarins selectively inhibit the growth of specific soil microbes, indirectly influencing the composition of root-associated microbiomes. This selectivity can promote symbiotic relationships while deterring harmful invaders, ultimately affecting plant fitness and survival—and by extension, the community of organisms that depend on those plants[105].

Coumarins also influence biodiversity through allelopathy, where they are released into the environment to inhibit the growth of neighboring plant species. This chemical competition can alter plant community composition, sometimes reducing species richness but also creating niches for coumarin-tolerant species to emerge[106]. These shifts can ripple through food webs, impacting pollinators, herbivores, and predators alike. In some cases, such interactions help maintain ecosystem equilibrium, while in others, they may reduce resilience or drive monocultures[107].

Moreover, coumarins may function as subtle ecological cues rather than blunt toxins, allowing organisms to adapt or co-evolve in response to their presence. For instance, some insects and microbes have evolved resistance mechanisms or even dependencies on coumarin-rich environments[108]. These adaptations reflect the dynamic interplay between chemical diversity and biological diversity—where small molecular differences can have large ecological consequences. Thus, coumarins not only mediate immediate biological interactions but also influence long-term evolutionary trajectories[109].

As ecosystems face increasing pressures from climate change and habitat loss, understanding the role of plant-derived compounds like coumarins becomes more crucial. Their ability to shape species interactions, support adaptive responses, and influence community structure suggests that coumarins are more than incidental plant metabolites—they are ecological agents with the potential to modulate biodiversity on multiple levels[110]. Continued research into their ecological functions could offer valuable insights into maintaining ecosystem resilience and guiding sustainable land management practices.

8. Psychological effects of coumarins

In addition to examining the influence of background odors containing coumarins, several studies have directly explored the cognitive (**Table 1**) and behavioral (**Table 2**) effects of specific coumarin compounds in humans. Natural coumarins, among others, have been evaluated using discrimination learning tasks following oral administration. When tested alongside simple odorants, compounds such as coumarin and 3-ethylcoumarin were associated with the highest learning index scores, indicating a noticeable deviation in performance compared to vehicle-treated control groups[111]. Coumarin, in particular, has been found to affect certain cognitive functions. For instance, it has been reported to impair aspects of verbal memory, as evidenced by slower reaction times during cued word recall tasks[112]. Additionally, participants exposed to coumarin via inhalation demonstrated a slight decline in performance during a mathematical speed test, although this effect did not reach statistical significance[113].

Table 1. Cognitive effects of coumarin derivatives in humans.

Coumarin derivative	Cognitive effects	Proposed mechanism(s)	Ref.
Coumarin	Impaired verbal memory, slower reaction times, and minor decline in math task performance	Modulation of GABAergic/cholinergic systems, and	[114]

		influence on cortical excitability as well as memory networks	
3-Ethylcoumarin	Enhanced learning performance in discrimination tasks	Improved sensory-cognitive coupling, and Potential modulation of attention as well as learning-related pathways	[115]
6-Methylcoumarin	Putative stimulant effect	Possible dopaminergic activation, and enhanced central nervous system alertness	[116]
7-Hydroxycoumarin	Potential calming/anxiolytic influence	GABA-A receptor interaction and reduced anxiety-driven cognitive interference	[117]
Umbelliferone (7-Hydroxy-4-methylcoumarin)	Improved stress resilience and mood	Antioxidant action, modulation of neuroinflammation, and indirect effects via mood-cognition link	[118]
Esculetin (6,7-Dihydroxycoumarin)	Suggested memory enhancement and neuroprotection	Antioxidant activity, MAO inhibition, and reduced oxidative stress on hippocampal neurons	[119]
Scopoletin (6-Methoxy-7-hydroxycoumarin)	Reported mood-stabilizing and cognitive-enhancing potential	Modulation of dopamine as well as serotonin levels, MAO inhibition, and anti-inflammatory effects	[120]
Herniarin (7-Methoxycoumarin)	Possible calming or mild sedative effects	GABAergic interaction and potential CNS depressant activity	[121]
Daphnetin (7,8-Dihydroxycoumarin)	Neuroprotective, anti-fatigue, and cognitive-enhancing effects	Inhibition of neuroinflammation as well as oxidative stress and regulation of mitochondrial function	[122]
Aesculetin (6,7-Dihydroxy-4-methylcoumarin)	Potential cognitive protection under oxidative stress conditions	Scavenging of free radicals, neurovascular protection, and anti-inflammatory activity	[123]

Table 2. Behavioral effects of coumarin derivatives in humans.

Coumarin derivative	Behavioral effects	Proposed mechanism(s)	Ref.
Coumarin	Altered task performance and reduced motivation or engagement in complex tasks	Sedative-like effects via GABAergic modulation and reduced arousal or attention span	[124]
3-Ethylcoumarin	Increased engagement and response accuracy in learning tasks	Enhanced attentional regulation	[125]
6-Methylcoumarin	Elevated alertness and behavioral activation	Potential CNS stimulation and dopamine-mediated arousal pathways	[116]
7-Hydroxycoumarin	Mild calming or anxiolytic behavioral effects	GABA-A receptor agonism and reduction in stress-related behavioral interference	[117]
Umbelliferone (7-Hydroxy-4-methylcoumarin)	Stress-adaptive behavioral responses and mood elevation	Antioxidant as well as neuroprotective effects and mood-cognition behavioral feedback loop	[126]
Esculetin (6,7-Dihydroxycoumarin)	Improved spatial navigation and exploration in models	Free radical scavenging, preservation of motor coordination, and exploratory behavior	[127]
Scopoletin (6-Methoxy-7-hydroxycoumarin)	Mood elevation, increased sociability, and reduced agitation	Serotonergic and dopaminergic balance, MAO inhibition, and emotional regulation	[128]
Herniarin (7-Methoxycoumarin)	Mild sedative-like behavior and reduced restlessness	CNS depressant properties via GABAergic influence	[129]
Daphnetin (7,8-Dihydroxycoumarin)	Anti-fatigue behavioral patterns and enhanced stamina in physical tasks	Mitochondrial energy regulation and reduction in neuroinflammatory fatigue markers	[130]

Coumarin derivative	Behavioral effects	Proposed mechanism(s)	Ref.
Aesculetin (6,7-Dihydroxy-4-methylcoumarin)	Less behavioral reactivity to stress and improved adaptability	Anti-inflammatory action and stabilization of mood-related neurochemical systems	[131]

Table 2. (*Continued*)

Beyond these findings, other research has shown that human electroencephalographic responses to odors associated with food and beverages—detectable as early as 340 milliseconds after consumption—can be modulated by specific aroma compounds. For example, electroencephalographic activity was diminished in individuals who consumed a beverage containing 8-cineole, suggesting an interaction between olfactory inputs and post-ingestive neural responses[132]. Collectively, these physiological and behavioral studies suggest that exposure to coumarins, whether through ingestion or inhalation, may influence a variety of human cognitive and sensory processes in subtle yet measurable ways[133].

8.1. Impact on mood

A growing body of evidence supports the stress-relieving potential of coumarin-containing compounds[134]. These mood-enhancing properties are thought to be linked, at least in part, to the inhibition of MAO, an enzyme responsible for the breakdown of key neurotransmitters. When MAO activity is reduced, neurotransmitter levels—particularly dopamine and serotonin—increase, which may contribute to improved mood and cognitive function. Notably, the involvement of dopaminergic and serotonergic pathways has been associated with positive affective and neurocognitive outcomes[135]. However, the extent to which these psychological effects depend on dietary intake of coumarins or the efficiency of their absorption remains unclear. While some reports suggest that high dietary levels of certain compounds can modulate the action of MAO inhibitors, this specific interaction with coumarins has not yet been fully explored[136].

Emerging insights suggest that coumarins may exert a more nuanced influence on psychological states than initially assumed—potentially eliciting both calming and stimulating effects. These variations could stem from individual differences in metabolism or interactions among structurally diverse coumarin derivatives. This complexity underscores the importance of avoiding broad generalizations at this stage[137]. Given the potential clinical relevance of coumarin's impact on human behavior, further investigation is warranted. Future research should aim to clarify the behavioral and emotional effects of coumarin exposure, including whether synergistic actions occur among multiple coumarin compounds. Comprehensive studies encompassing *in vitro* models, animal experiments, and human trials are essential to better understand the psychological and neurobiological implications of coumarin intake as part of the broader human-plant relationship.

8.2. Cognitive function

Cognitive decline is a natural part of the aging process, often manifested as mild cognitive impairment or dementia. In recent years, coumarin and its derivatives have drawn significant attention for their potential neuroprotective effects[138]. These compounds have been extensively studied for their cholinesterase inhibitory activity[139], antioxidant capacity[140], anti-aggregation properties[141], and anti-inflammatory effects[142]—all of which are relevant mechanisms in combating neurodegenerative disorders. Among the most promising agents, a carbamate derivative featuring a 7-methoxychromone moiety demonstrated high potency as a selective human acetylcholinesterase (AChE) inhibitor[143]. Notably, the combined administration of donepezil, a standard anti-Alzheimer's drug, with coumarin derivatives has shown synergistic benefits in mitigating cognitive impairments induced by high-fat diets or repeated consumption of oxidized frying oils[144]. Animal studies have also highlighted coumarin’s sweet taste profile alongside its strong antioxidant activity. It has been hypothesized that this dual characteristic might have an ecological function—attracting animals to consume coumarin-rich fruits and disperse their seeds, thereby aiding in the survival of certain plant species[145].

Several coumarin hybrid molecules are under investigation for their AChE inhibitory properties. Advances in molecular docking have helped rationalize the structure–activity relationships in new series like huprines, guiding the development of more effective inhibitors[146]. Furthermore, structure-based and computational drug design approaches have led to the identification of innovative compounds, such as chirphae prongs and other subunits, that act as competitive inhibitors of both Drosophila and human AChEs[147]. Additionally, N-feruloylamido derivatives of umbelliferone and related polyphenols are being explored for their capacity to modulate neuronal nicotinic acetylcholine receptors highlighting a multifaceted mechanism involving both AChE inhibition and this receptor type modulation in the treatment of cognitive disorders[148].

9. Coumarins and aromatherapy

In aromatherapy, fragrance plays a central and often unique role in shaping therapeutic experiences. Among the most widely recognized and utilized aromatic plants is *Lavandula angustifolia* (lavender), renowned not only for its pleasant floral scent but also for its diverse therapeutic applications[149], as shown in **Figure 3**. Despite its popularity as a fragrance, lavender's medicinal value as a standardized botanical remedy should not be overlooked. Statistically, lavender essential oil is a common ingredient in ambient sprays and wellness products aimed at promoting relaxation and improving sleep quality, largely due to its calming effects on the central nervous system[150]. Beyond its olfactory appeal, lavender offers a broad spectrum of health benefits. Scientific studies have demonstrated its antibacterial properties, its ability to enhance mood, and its potential to modulate immune function. These findings support its integration into complementary health practices that address both physical and emotional well-being[151].

Figure 3. Therapeutic versatility of lavender: From fragrance to healing.

It is also worth noting that the therapeutic value of spa and aromatherapy products extends beyond physical effects. For instance, thymoquinone, a major bioactive compound in *Nigella sativa* (black cumin), has long been recognized for its anxiolytic properties. In combination with lavender, such natural compounds contribute to a more holistic approach to wellness by addressing both mental and physiological health[152]. In perfumery, lavender is prized for its role as a middle note and its capacity to cleanse and balance fragrance compositions. Moreover, clinical studies have indicated that lavender essential oil may help alleviate symptoms of migraine headaches, further underscoring its multifaceted therapeutic potential[153]. While lavender remains a cornerstone of aromatherapeutic and cosmetic formulations, other floral essences such as jasmine (*Jasminum spp.*) are also widely appreciated. Jasmine, known for its rich, sweet aroma, is frequently used in aromatherapy and beauty products, enhancing both sensory appeal and emotional well-being[154].

10. Regulatory aspects of coumarins

Certain coumarin derivatives have demonstrated toxicological concerns, particularly related to hepatotoxicity and phototoxicity. These safety concerns have prompted regulatory authorities around the world to establish guidelines and restrictions to limit human exposure, especially in products intended for prolonged use or direct skin application[155]. In the European Union, coumarins are subject to specific safety evaluations under Cosmetic Regulation No. 1223/2009 [Link]. According to this framework, the presence of coumarins in cosmetic products must be carefully monitored, and their concentration must not exceed established limits. For instance, coumarin is included on the list of substances subject to labeling requirements if present above 0.001% in leave-on products and 0.01% in rinse-off products. These thresholds are based on sensitization potential and are aimed at protecting individuals with fragrance allergies or sensitivities. Furthermore, risk assessments are conducted regularly by the Scientific Committee on Consumer Safety to update safety data and reassess the permitted concentrations [Link].

In addition to the European Union, other regulatory bodies such as the United States Food and Drug Administration (FDA) and Health Canada have also evaluated the safety of coumarins in consumer products[156]. While the FDA prohibits the use of coumarin as a food additive due to its potential hepatotoxic effects observed in animal studies, its presence in cosmetics is not outright banned, provided it meets safety requirements. These differing international regulations underscore the importance of harmonizing toxicological data and developing globally accepted safety standards[157]. Continuing research and monitoring toxicology are essential for improving rules and keeping consumers safe as new information about coumarin risks comes to light.

10.1. Safety assessments

Several pure coumarin compounds have already undergone risk assessment in the United States, forming part of a regulatory framework that may serve as a reference point for guiding future development efforts and minimizing lengthy approval timelines[158]. This approach also emphasizes the importance of ensuring high purity levels in coumarins derived from natural sources, which are often accompanied by other co-occurring constituents. These additional components, although naturally present, may carry unknown toxicological risks and should not be overlooked[159].

In addition, some monitoring studies have reported the presence of coumarins in environmental or occupational settings. However, the concentration detected in these contexts are frequently higher than those encountered through typical dietary intake or environmental exposure, thus limiting their direct relevance to general public health evaluations. Nonetheless, such findings serve as important cautionary signals regarding the potential toxicity of certain coumarin derivatives. These data can be instrumental in identifying specific coumarins that warrant closer scientific scrutiny or regulatory oversight[160].

Particularly concerning are findings of coumarins in indoor dust samples, especially in environments with high contamination levels, such as institutional kitchens or canteens. These settings often also exhibit elevated levels of fluorinated compounds and plasticizers, suggesting a complex mixture of hazardous substances[161]. The co-occurrence of coumarins in such matrices highlights the need for expanded toxicological investigations and could support the prioritization of certain compounds for future research and risk management policies[162].

10.2. Legislation overview

A contextual overview of the legal framework is essential to understand the intricate intellectual property rights considerations associated with the innovative technologies. Coumarins—both natural and synthetic—are widely present in various food products, a fact that has been acknowledged by numerous national and international regulatory authorities. Due to their broad occurrence and potential health implications, several countries have enacted stricter regulatory measures for coumarins compared to other volatile substances. These measures often differ significantly across jurisdictions, contributing to a fragmented legal landscape[163]. In response to growing concerns, international food safety initiatives have made strides in harmonizing standards and facilitating the exchange of information regarding qualitative and screening methodologies used for coumarin detection[164]. Regulatory authorities have played a crucial role in these developments by mandating rigorous evaluation of products containing synthetic coumarins, thereby promoting transparency and consumer safety[165].

Current regulations permit the presence of coumarin in various food categories, with a general guideline set at 5 mg/kg for food and beverages. Despite this threshold, enforcement varies, and inconsistencies persist among regulatory bodies of different countries[166]. Furthermore, scientific understanding of coumarin behavior in food matrices remains limited. Key gaps include insufficient data on transfer rates during cooking processes and changes occurring over product shelf life. These uncertainties complicate the accurate estimation of dietary coumarin intake from processed foods[167]. Consequently, there is a pressing need to enhance research efforts focused on the behavior and stability of coumarins in culinary and storage contexts. Strengthening the scientific foundation in this area may not only support more consistent risk assessments but also inform future regulatory adjustments.

11. Future directions in coumarin research

Several studies have indicated a potential link between coumarin exposure and various aspects of human mental and emotional well-being. Emerging evidence also suggests that passive exposure to environmental aromatics may exert subtle yet meaningful effects on psychological health. This investigation considered whether modern indoor lifestyles, which often lack natural scents because many people spend long periods in such environments, might inadvertently impact mental and emotional states[168].

This exploration was grounded in the hypothesis that aromatic compounds could act as compensatory cues, evoking evolutionarily significant environmental signals, or perhaps modulate neural activity, particularly within the hippocampus, through passive olfactory pathways. The broader implications of these findings were considered in the context of humanity's increasingly fragmented relationship with nature[169]. To advance this field, future research should prioritize methodologies that enhance the internal validity of olfactory studies while maintaining ecological relevance. Such efforts could support the development of clinically applicable aromatic interventions aimed at improving psychological well-being[170]. Moreover, replicable studies demonstrating the effects of aromatic exposure on neurological activity, as well as psychological and social functioning, may pave the way for evidence-based guidelines on the therapeutic use of aromatics across diverse clinical settings[171].

11.1. Emerging trends

Coumarins are now gaining recognition as phytostabilizing agents with potential implications for human health and environmental sustainability[172–174]. In an age increasingly focused on ecological responsibility and the minimization of psychological and environmental stressors—often termed "psycho-emissions"—coumarins may serve as key bioactive molecules in aligning health and sustainability goals[175]. Recent studies have revealed their potential in modulating mood and cognitive processes, likely linked to their structural resemblance to serotonin and mild serotonin-like activity. This opens up exciting avenues for plant-derived coumarins in the development of mood-regulating nutraceuticals and dietary interventions aimed at supporting mental wellness[176].

The emerging concept of phytomelatonin—plant-based analogues or precursors of melatonin—adds another layer of interest, suggesting coumarins and related hydroxycinnamic amides may contribute to circadian rhythm regulation and neuroprotection. Although plants do not biosynthesize serotonin in the same pathway as humans, many coumarins serve as potent antioxidants and may function as indirect precursors to phytomelatonin[177]. These properties warrant systematic screening of plant extracts for coumarin content to formulate functional foods. Such efforts may herald a new era of nutrition—one that integrates botanical insights with preventive health strategies and sustainable consumption practices[178].

11.2. Technological innovations

To broaden industrial access to a diverse spectrum of coumarin derivatives, pilot-scale biotransformation experiments employing enzymatic processes have been initiated. These efforts are led by a team with specialized expertise in developing novel catalytic strategies based on whole cell biotransformations, utilizing microbial systems to convert abundant natural substrates into more complex and valuable molecules[179]. The group has made significant progress in engineering enzyme formulations that are currently unavailable for large-scale biotechnological applications. Furthermore, a robust and versatile technology platform has been developed to enable the controlled production of a wide range of fine chemicals. This platform is designed to be both scalable and easily implementable in industrial environments[180]. To support this development, the group employs advanced bioreactor systems, including photobioreactors, which facilitate the translation of laboratory findings into Technology Readiness Levels 5–6 through rigorous design, operation, and performance analysis[181].

One of the principal challenges in large-scale phototrophic microalgal production lies in achieving cost-effective biomass yields while maintaining elevated concentrations of target metabolites. However, such systems can be tailored to generate market-ready, high-value bioproducts, including proteins, omega-3 long-chain polyunsaturated fatty acids, carotenoids, and polyphenolic compounds[182]. Additionally, the microalgae sector is gaining momentum in the production of bioactive compounds with dermal protective effects—such as antioxidant-rich carotenoids—used in nutraceuticals, functional foods, animal feed, and anti-aging cosmetic formulations[183]. Despite the relatively low photocatalytic efficiencies inherent to microalgal systems, their unique adaptive responses and the novel nature of the resulting compounds present promising opportunities[184]. These compounds exhibit potential across multiple technological domains, particularly for applications with pharmacological, cosmetic, or other biofunctional value[185].

12. Case studies on coumarin application

Coumarins have been extensively studied for their diverse range of applications, spanning from therapeutic and cosmetic uses to roles in agriculture and advanced material sciences, including photonics and electronics[186]. This head and its associated two subheads provide an updated overview of recent advancements in coumarin-related research, with particular emphasis on their utility in cosmetics, nanoparticles as well as thin film development, and rational drug design[187]. Where applicable, links between synthetic approaches, molecular structures, and corresponding biological or material performance are discussed. Key coumarin derivatives, such as umbelliferone and scopoletin, are briefly introduced, highlighting their structural features and roles in applied studies[188]. Examples include their analysis in cosmetic formulations, where they function as preservatives, and in environmental applications, such as markers in soil bioremediation. The incoming subtitles also explore fundamental investigations into layered nanostructures incorporating heterojunctions, as well as the influence of silver ions and uncapped silver nanoparticles on the bioactivity of coumarin compounds[189].

Recent synthetic advancements in the field of heterocyclic chemistry have led to the development of novel coumarin and 7-aminocoumarin derivatives. These compounds have demonstrated promising antifungal and anticancer activities[190]. The background and relevance of these findings are further supported by discussions on cutaneous melanin interactions and the incorporation of coumarins into branched polyurea or polyester-based materials[191]. Additionally, the incoming subtitles present data from biological and physicochemical assays involving coumarin derivatives modified with piperazine or piperidine moieties, underlining their potential in both biomedical and material science applications[192].

12.1. Pharmaceutical developments

The therapeutic potential of naturally inspired coumarins extends far beyond their traditional roles as agents of aroma or flavor enhancement. These compounds may play a significant role in the prevention and treatment of various diseases[193]. In addition to modern pharmaceutical advancements, evidence from coumarin-containing medicinal plants supports the notion that optimal health outcomes may arise not solely from isolated laboratory-based compounds, but from the synergistic interactions among multiple bioactive constituents found in natural health products—such as functional foods, herbal tonics, aromatic oils, and nutraceutical formulations[194].

Historically, plants rich in coumarins have been widely employed for their diverse pharmacological properties. These include analgesic, anti-inflammatory, antitumor, antioxidant, antiviral, antifungal, antibacterial, anticoagulant, hepatoprotective, antiarrhythmic, antihyperglycemic, antihypertensive, anticonvulsant, and antidepressant activities[195–197]. Additionally, coumarin-based remedies have been used as cardiotonics, neurotonics, spasmolytics, neuroprotectants, vasodilators, estrogenic agents, and for managing conditions such as cachexia, nausea, osteoporosis, gastric ulcers, and parasitic infections[198–200]. Traditional knowledge, particularly from Amerindian ethnomedicine, also highlights the use of coumarin-containing plants in the management and prevention of neurodegenerative disorders[201]. This wide therapeutic spectrum positions coumarins as valuable candidates for further investigation, offering promising secondary leads for the development of novel therapeutic agents.

12.2. Cosmetic industry

Coumarins of plant origin are gaining considerable attention in the cosmetic industry due to their multifunctional bioactivities, including antioxidant, anti-inflammatory, and antimicrobial propertie[202–204], as graphically illustrated in **Figure 4**. Their beneficial effects on acne-prone skin and potential influence on hormonal balance further support their use in formulating safe and natural cosmetic products[205]. Numerous plant families—such as Ranunculaceae, Asteraceae, and Apiaceae—serve as rich sources of coumarins with documented wound-healing, anti-aging, and skin-regenerating effects. These natural compounds contribute to environmentally sustainable cosmetic formulations by acting as free radical scavengers, which enhance both the efficacy and safety of skincare products[206].

The integration of herbal extracts into cosmetic preparations allows for the development of balanced and mild formulations that provide maximal therapeutic benefit while minimizing adverse effects[207]. Plants with well-established antioxidant and antimicrobial potential are also being investigated as sources for plant-derived sunscreens, offering safer alternatives with reduced environmental impact[208]. Importantly, cosmetics developed from botanical sources not only offer targeted efficacy but also demonstrate antimicrobial action against common contaminants in cosmetic formulations, including yeast species associated with skin conditions[209]. The growing interest in herbal-based ingredients underscores their emerging prominence as key components in next-generation cosmetic products.

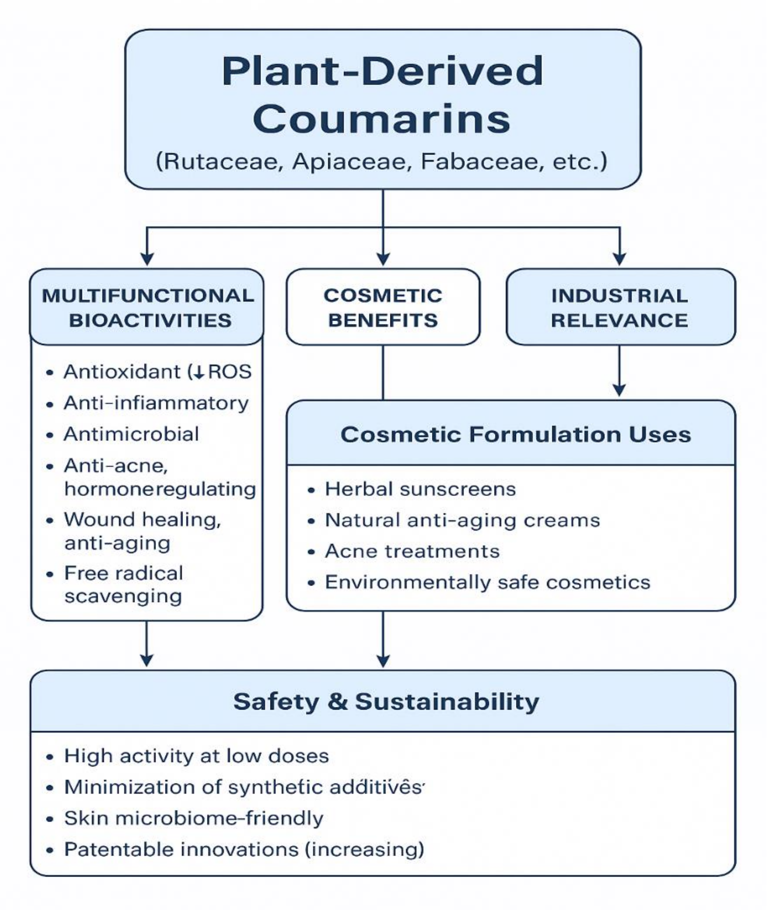

Figure 4. Coumarins in cosmetics: Biological activities, formulation uses, and sustainable innovation.

13. Public perception of coumarins

Public interest in natural compounds such as coumarins has been steadily growing in recent years. Gaining insights into societal perceptions of these substances is critical for policymakers and stakeholders aiming to balance technological innovation with consumer acceptance[210]. From a regulatory standpoint, the wide-ranging applications of natural coumarins—particularly in pharmaceutical and cosmetic formulations—underscore their potential value[211]. Moreover, emerging prospects such as transgenic applications of coumarins bring forth novel legal and ethical considerations that merit early analysis[212]. To investigate the factors shaping public attitudes toward synthetic and natural coumarins, especially in the context of food packaging, a face-to-face questionnaire was administered to a sample population in Central Italy. The findings suggest that public perception is largely influenced by three key factors: the intended use of the compound (e.g., providing antimicrobial protection or being a natural component of fruit cell walls), the expected benefits, and the nature of the compound, specifically whether it is perceived as "natural" or potentially unsafe[213].

The incoming subtitles provide valuable insights into how biotechnological applications of coumarins are received by the public and identifies persuasive narratives that could enhance informed decision-making and risk communication. It emphasizes that early-stage innovation strategies should integrate public perception to foster responsible development and deployment. Tailoring communication strategies to specific population segments, especially when introducing novel technologies, can significantly enhance acceptance[214]. In the case of natural products, emphasizing their origin and perceived safety proves particularly effective. These findings can aid regulatory bodies in facilitating the acceptance and approval of new natural compounds that, despite scientific validation, may still face skepticism from the public[215].

13.1. Cultural attitudes

The interrelationship between the environment, society, and culture is deeply intertwined. Since ancient times, humans have been fascinated by the ecological behaviors, survival strategies, and therapeutic properties of both insects and plants. In response to environmental degradation and increasing urbanization, natural elements such as green spaces, parks, and home gardens have gained symbolic and practical importance. These spaces not only offer a refuge from pollution but are also recognized for their positive effects on both physical and mental health[216]. As such, they play a foundational role in shaping cultural identities and are visibly integrated into architectural expressions—especially in heritage routes and earthquake-prone regions where traditional building typologies reflect ecological responsiveness[217]. Beyond physical design, these green environments are essential in fostering a psychological and ecological connection between humans and nature. This interaction forms the core of environmental or ecological psychology, which emphasizes how lived and designed spaces influence emotional well-being, a sense of belonging, and holistic health[218].

Amid this growing understanding of nature's psychological value, there is renewed interest in naturally derived therapeutic agents[219]. Plant-derived compounds with psychoactive or mood-enhancing properties, long used in traditional healing systems, are increasingly recognized within formal pharmacological frameworks—particularly when produced via standardized synthetic routes under rigorous quality control[220]. Within this context, coumarin—a naturally occurring compound found in various plant species known for their ecological and psychological interactions—has emerged as a molecule of interest. The present study advocates for the synthesis and further exploration of coumarin as a plant-based therapeutic agent, grounded in an interdisciplinary framework that merges natural product chemistry with ecological-human psychological insights.

13.2. Awareness and education

Prioritizing the development of a well-educated and environmentally conscious population is essential, especially as traditional agricultural knowledge and practices alone may no longer suffice in addressing modern environmental and sustainability challenges[221]. A promising strategy involves fostering a wisdom-based economy, one that integrates formal education with experiential learning drawn from experts and local practitioners. Expanding agricultural literacy empowers individuals to respond more proactively to ecological concerns and to contribute meaningfully to sustainable development[222]. To achieve this vision, educational policies must go beyond conventional frameworks. Agricultural and environmental education should be made accessible not only to students—our future stewards of the land—but also to unemployed individuals, seasonal farm workers, and older adults seeking to reconnect with nature and expand their knowledge of sustainable practices[223].

Financial incentives and institutional support for those advancing knowledge in farming and environmental stewardship can further enhance participation. Such support would encourage deeper engagement in both intellectual and manual endeavors that align with sustainability values and promote resilient communities[224]. Notably, the emergence of grassroots initiatives like the Landcare movement exemplifies a transformative shift in the way agricultural communities interact with the environment. These efforts reflect a growing commitment to ecological responsibility that transcends symbolic desires for cleaner air[225]. Instead, they embody a practical, value-driven reconnection with the land. Ultimately, traits such as self-motivation, openness to learning, perseverance, and an entrepreneurial mindset are vital for driving progress. These personal attributes have the potential to overcome the inertia of bureaucratic systems and foster a more dynamic, community-driven bioeconomy—even in the absence of immediate financial rewards[226].

14. Interdisciplinary approaches to coumarin studies

Numerous studies included highlight the diverse disciplinary perspectives through which coumarins have been explored—ranging from biology, chemistry, and ecology to ethnobotany, mycology, pharmacognosy, pharmacology, and phytochemistry[227]. This diversity reflects either an interdisciplinary methodology or the convergence of independent investigations from distinct academic domains. The varied themes presented here reveal that each discipline employs its own conceptual framework and technical vocabulary to study coumarins[228]. Nonetheless, despite this disciplinary diversity, there remains a notable consistency in how coumarins are visualized and described across both ecological systems and culturally constructed worldviews[229].

This title and its associated two subtitles now turn to integrative studies that aim to synthesize these perspectives or highlight underlying debates and epistemic tensions[230]. Firstly, the ecological significance of coumarins is addressed through multiple lenses—including botany, analytical chemistry, and ethnoecology. Integrating scientific and traditional ecological knowledge in such contexts raises methodological, epistemological, and terminological challenges, particularly when aiming for inclusive, participatory research frameworks[231–233]. Secondly, coumarins serve as a point of connection between plants and humans and are examined within the fields of ethnobiology, ethnomedicine, and ethnopharmacology. Each of these disciplines brings distinct historical traditions and conceptual foundations that must be acknowledged to foster genuine interdisciplinary dialogue, rather than subsuming differing viewpoints under a single, homogenizing narrative[234–236].

Thirdly, the psychological and sensory dimensions of coumarins are studied through diverse avenues such as flavor science, olfaction, mind-altering plant compounds, and human–plant interactions[237]. These perspectives are rooted in different scientific and experiential understandings of cognitive and affective responses. The multifaceted nature of coumarins, therefore, presents both an opportunity and a challenge for interdisciplinary engagement[238]. By critically examining areas of convergence and divergence, future research can promote more inclusive and dialogic collaborations. Importantly, avoiding reductionist interpretations or exclusionary frameworks allows for a deeper recognition of the complex roles that coumarins—and the organisms producing them—play in natural and cultural systems[239]. Embracing this complexity enriches our understanding and avoids assigning overly simplistic or objectified ontologies to nature’s constituents.

14.1. Collaboration between fields

The natural environment holds significant potential to address several pressing public health challenges and to support more sustainable healthcare approaches. Despite this, urban settings predominantly situate contemporary healthcare systems, which often rely on pharmaceutical solutions developed within this context[240]. In contrast, there is growing recognition of the beneficial role that nature can play in promoting human health and well-being, leading to increased interest in nature-based therapies[241]. This subtitle focuses on the promising role of plant-derived bioactive compounds—particularly coumarins—in contributing to physical and mental health. As a representative class of phytochemicals, coumarins exemplify how naturally occurring compounds can both enhance individual well-being and help re-establish meaningful connections between local ecosystems and healthcare practices[242].

Mounting evidence supports the notion that even brief interactions with natural environments can yield considerable health benefits. Studies consistently report that exposure to green spaces improves subjective well-being, enhances vitality, and supports cognitive recovery from stress and mental fatigue. These effects are especially relevant given that many lifestyle-related diseases—such as cardiovascular conditions, metabolic disorders, and immune dysfunctions—are influenced by disruptions in the body's core regulatory systems[243].

As interest in nature-based healing grows, interdisciplinary research involving psychology, environmental science, and biology has begun to explore these effects more deeply[244]. However, while many studies on biophilia have looked at how green spaces affect our minds, there are fewer that have carefully investigated the biological reasons for these benefits, especially the role of phytochemicals, which humans might naturally respond to positively[245]. This highlights an urgent need for collaboration between phytochemists, neuroscientists, and health psychologists. By learning more about how coumarins impact mood, immune system, and heart health, researchers can create the scientific support needed to include nutraceuticals in preventive healthcare plans and lessen the dependence on traditional medications[246].

14.2. Integrating knowledge

An essential initial step toward fostering a more holistic understanding of coumarins involves bridging environmental insights with human-related perspectives. This integration requires synthesizing existing knowledge from both domains in a cohesive manner. At its core, this is a mimetic process—when researchers express admiration for the multifaceted roles of coumarins in nature, that appreciation has the potential to influence broader discourse[247]. Therefore, scientific literature on coumarins should evolve beyond a purely chemical focus. It should encompass aspects such as pharmacological activity, traditional and modern human applications, sensory characteristics, routes of exposure, ecological interactions, and patterns of species distribution. Such an inclusive approach would enrich our comprehension of coumarins and their significance in both natural ecosystems and human health[248].

15. Conclusion

Coumarins represent a class of biologically privileged compounds, valued for their diverse physicochemical and pharmacological properties. Their broad spectrum of biological activities enables them to target a wide array of diseases, while also offering numerous applications of economic, nutritional, psychological, and cultural significance. Naturally occurring coumarins are widespread across various environmental matrices and are particularly abundant in edible and medicinal plants, many of which serve as primary sources for dietary supplements. These plants have been integral to traditional medicine systems for centuries, contributing to the management of various health conditions. Characterizing the coumarin content of these plants is essential not only for advancing therapeutic development but also for promoting environmental sustainability and public health. Natural coumarins serve as valuable scaffolds for the synthesis of bioactive agents, preservatives, molecular carriers, and as templates in the rational design of novel drug candidates via bioisosteric modification.

In this study, we highlight the extensive chemical diversity that emerges from simple coumarin cores, as derived from natural biodiversity. These foundational molecules are central to the carbon-based architecture of life and represent a promising starting point for sustainable molecular innovation. Importantly, our approach emphasizes not only the biomedical and societal value of coumarins but also the ethical imperative to harness these resources responsibly. To ensure long-term access to these bioactive compounds, conservation of wild native plant species is critical. Many of the molecules we value today originate from such biodiversity hotspots, and their continued availability depends on ecological preservation. The future role of natural products—including their use as pharmaceuticals, flavoring agents, preservatives, and drug carriers—is intrinsically tied to the protection of ecosystems that sustain them.

Conflict of interest

The authors declare no conflict of interest.

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