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Review

Licorice (*Glycyrrhiza glabra*): Botanical Aspects, Multisectoral Applications, and Valorization of Industrial Waste for the Recovery of Natural Fiber in a Circular Economy Perspective

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Abstract

The Licorice (*Glycyrrhiza glabra*) is a perennial herb traditionally valued for its aromatic and therapeutic properties. In recent years, however, growing attention has shifted toward the technical and environmental potential of the plant's industrial by-products, particularly the fibrous material left after extraction. This review integrates botanical knowledge with engineering and industrial perspectives, highlighting the role of licorice fiber in advancing sustainable innovation. The natural fiber obtained from licorice roots exhibits notable physical and mechanical qualities, including lightness, biodegradability, and compatibility with bio-based polymer matrices. These attributes make it a promising candidate for biocomposites used in green building and other sectors of the circular economy. Developing efficient recovery processes requires collaboration across disciplines, combining expertise in plant science, materials engineering, and industrial technology. The article also examines the economic and regulatory context driving the transition toward more circular and traceable production models. Increasing interest from companies, research institutions, and public bodies in valorizing licorice fiber and its derivatives is opening new market opportunities. Potential applications extend to agroindustry, eco-friendly cosmetics, bioeconomy, and sustainable construction. By linking botanical insights with innovative waste management strategies, licorice emerges as a resource capable of supporting integrated, competitive, and environmentally responsible industrial practices.

Keywords: *Glycyrrhiza glabra*; natural fibers; circular economy; sustainable bioeconomy; green building biocomposites; waste; bioplastics; bioremediation; environmental sustainability; renewable energy

1. Introduction

In recent years, attention to eco-sustainability has gained increasing importance across numerous sectors [1], including construction materials, fashion, the food industry, and technology [2]. The growing awareness of the environmental impact of industrial activities and the scarcity of natural resources has driven the search for more sustainable alternatives, such as the use of natural materials and industrial waste [3]. In particular, the use of natural materials such as wood, bamboo, hemp, licorice, cotton, linen, and other biological resources has become increasingly popular due to their ecological properties [4]. These materials are biodegradable, easily renewable, and require less energy for production compared to traditional materials such as cement or metals. The use of natural

materials not only reduces the ecological footprint, where resources are reused and recycled, but also decreases the amount of waste generated across all sectors. At the same time, the use of industrial waste represents an innovative frontier in the design of new eco-sustainable materials [5]. Materials such as recycled wood, plastics derived from PET bottles, agricultural residues, by-products from cement or steel processing, and biomass ashes have become valuable resources for producing new materials [6]. These wastes, which would otherwise end up in landfills, are transformed into useful components, reducing the need for new raw material extraction and contributing to a more sustainable product life cycle, especially within the framework of the circular economy [7].

The integration of these natural and industrial waste materials into modern applications offers great potential not only to reduce environmental impact but also to foster innovation. In this work, particular attention is given to the possible uses of licorice root waste as a natural material. The challenges linked to this approach, such as finding solutions to ensure durability and functionality, are stimulating the creation of new technologies and production methodologies that could radically transform the industrial landscape to address sustainability challenges, paving the way for more ethical, ecological, and circular production practices [8]. Therefore, it is crucial to gain a deeper understanding of this natural material. Licorice is a plant of ancient origin with a long history of use dating back more than 5,000 years. It was already known in ancient Egypt, where it was used for medicinal purposes, and is mentioned in Greek and Roman medical texts. It is believed that Egyptians also used it for ceremonial and medicinal purposes, including on animals [9]. Archaeological excavations have revealed licorice root remains in the tombs of pharaohs, such as that of Tutankhamun (around 1323 BC) [10]. The Greeks were well aware of the therapeutic properties of licorice, as documented by the physician Dioscorides [11], who included it in *De Materia Medica* as a remedy for respiratory and digestive diseases. The Romans adopted licorice from earlier cultures, using it as a sweetener and for medicinal treatments [12]. In the Middle Ages, licorice became popular in Europe, especially for its therapeutic properties. Records show that in the 1200s medieval monks cultivated it in monastery gardens [13]. During the Renaissance, licorice was also used to treat digestive problems and respiratory illnesses. Physicians of the time, such as Paracelsus, recommended it as a remedy for various disorders. In the Modern era, around the 18th and 19th centuries, licorice began to be commercialized both as medicine and as an ingredient in confectionery, and licorice liqueur became popular in Europe, particularly in Italy, Spain, and the Netherlands.

After centuries of traditional use dating back to the Greco-Roman era, licorice root (*Glycyrrhiza glabra*) continues to represent a botanical resource of great interest, both for its phytotherapeutic properties and for its industrial applications. Today, the scientific and industrial context is re-evaluating its potential in a sustainable perspective, opening innovative investment scenarios. The growing focus on the circular economy has stimulated research into reusing root processing waste, which can be transformed into:

- Natural fiber for composite materials, technical textiles, or biodegradable packaging.
- Residual biomass for biogas or biochar production.
- Substrates for microbial cultures in biotechnology.

These approaches significantly contribute to reducing environmental impact while generating added value from materials once considered mere waste. For effective use of licorice and its derivatives, it is essential to deepen knowledge of its chemical-physical characteristics, particularly regarding the valorization of industrial processing residues. Such understanding enables the identification of sustainable applications, currently under study, and outlines future prospects for the use of these by-products in various sectors. Supporting this analysis, the licorice market outlook [14], shown in the figure below, provides a useful overview of the economic and industrial potential linked to waste valorization and the promotion of more circular production practices.

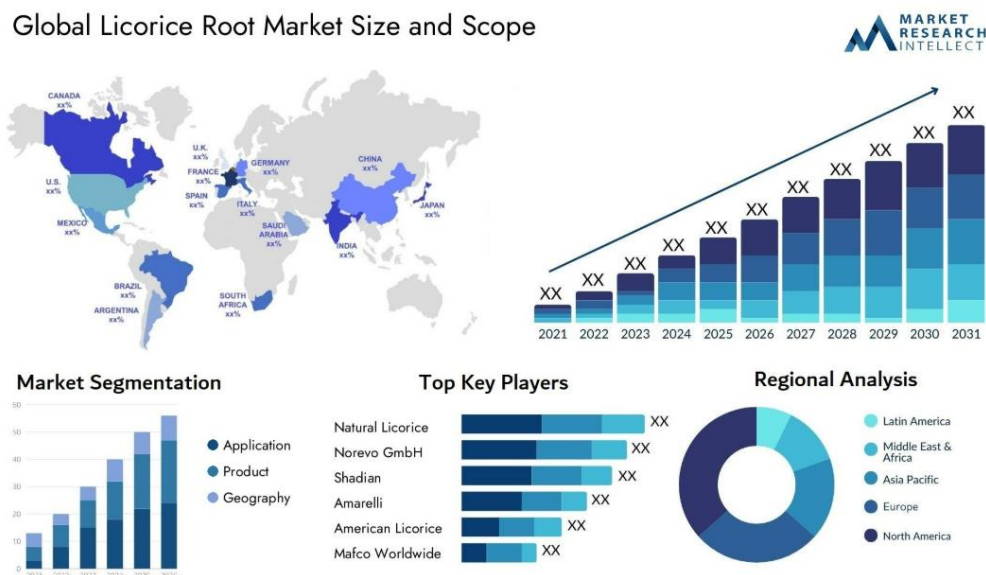


Figure 1. This image provides an overview of the licorice market, covering market dynamics and including a Porter's Five Forces analysis, which explains the five forces: namely, the bargaining power of buyers, the bargaining power of suppliers, the threat of new entrants, the threat of substitutes, and the degree of competition in the global licorice root market. The analysis explores various participants in the market ecosystem, including system integrators, intermediaries, and end users. Furthermore, the report focuses on the detailed competitive landscape of the global licorice root market [14].

In the coming years, *Glycyrrhiza glabra* is expected to become a strategic focus across multiple domains, including:

- agro-industrial start-ups oriented toward the bioeconomy,
- applied research projects in chemical, environmental, and biotechnological fields,
- the cosmetic-pharmaceutical supply chain, increasingly committed to sustainability and traceability.

The integration of primary root utilization with the valorization of industrial by-products highlights licorice as a multifunctional plant, capable of generating profitability, fostering innovation, and advancing sustainable production practices. This study systematically examines these dimensions, addressing both the direct use of the root and the opportunities arising from the recovery and transformation of processing residues. Particular emphasis is placed on the applicative potential of licorice fiber and on future investment scenarios, thereby outlining its role as a strategic resource within the framework of the circular economy and the bioeconomy.

2. The *Glycyrrhiza* Plant: Botanical and Chemical-Physical Characteristics

The licorice plant (*Glycyrrhiza glabra*) is a perennial herb belonging to the Fabaceae family [15]. Global production of licorice root is mainly concentrated in certain regions of the world where climatic conditions are favorable for cultivation. Geographically, this wild plant grows naturally in areas such as North America, Europe, Asia-Pacific, South America, the Middle East, and Africa. Moreover, it is important to consider the relationship between licorice extract producers and the market, which is segmented by form (paste, block, powder, and others), application (food and beverages, cosmetics and personal care, dietary supplements, tobacco products, and other technical-scientific uses). The market was valued at approximately USD 4.7 billion in 2023 and is projected to reach USD 5.4 billion by 2031, with a CAGR of 3.7% from 2024 to 2031. This report includes various segments and an analysis of trends and factors playing a substantial role in the market. The main producing countries worldwide are:

- China: The leading producer of licorice, accounting for about 80% of global production. Chinese licorice is used both for medicinal purposes and confectionery.
- Iran: The second-largest producer, with extensive licorice cultivation across several provinces. Iran exports licorice to many countries.
- Turkey: Also, an important producer and exporter of licorice root.
- Syria and Afghanistan: These countries also contribute significantly to global licorice production.

Licorice extracts, and its main component glycyrrhizin, are widely used in food, tobacco, and both herbal and traditional medicine. Medically, licorice exhibits beneficial properties against ulcers, with anti-inflammatory, antiviral, and hepatoprotective effects [15]. Licorice extract is produced by chopping and extracting the root. The extracted liquid is filtered and then spray-dried to produce a powder, or concentrated to produce a solid block, which generally has a stronger flavor than the powder. According to a study published in 2019 in the International Journal of Plant Production [16], licorice cultivation is mainly concentrated in arid or semi-arid areas where the plant thrives. In China, the cultivated area is estimated at about 50,000 hectares, with production continuing to grow, especially in response to increasing demand in international markets.

The licorice plant, particularly its root, is characterized by a rich chemical composition including glycyrrhizin, flavonoids, saponins, and phenolic acids. These compounds provide the plant with a variety of physical and therapeutic properties, making it useful in numerous sectors such as food, pharmaceuticals, and cosmetics. The botanical characteristics of this plant can be summarized as follows: a) Appearance: The stem is erect, reaching 50–150 cm in height, woody at the base, densely dotted with glands, and covered with white hairs. Leaves are compound, with 11–17 leaflets, and the petiole is densely villous and glandular, yellow-brown in color. Flowers bloom in summer (June to August) and are insect-pollinated [17]. b) Roots: The most important part of the plant is the root, which is woody and contains a high content of glycyrrhizin, a sweet compound with aromatic properties. Roots can extend to great depths, allowing the plant to withstand drought periods. c) Fruits: Indehiscent legumes, oblong or fusiform, measuring (7)10–25 × 7–8 mm, leathery, glabrous or with few bristles, brownish, compressed, containing 2–6 subspherical seeds, 3–3.5 mm in diameter, brown or blackish [18]. d) Habitat: Licorice grows in sandy, well-drained soils and prefers temperate climates. It is frequently cultivated in various parts of the world, especially in the Mediterranean and in some regions of Asia, South America, and North Africa [19].

These characteristics make licorice not only an interesting plant from a botanical perspective but also valuable for its culinary and medicinal applications. It is important to understand its chemical-physical properties, which derive mainly from the chemical composition of the root [20], the part most commonly used in the preparation of extracts and other products. Licorice root contains a variety of bioactive compounds, many of which are responsible for its therapeutic properties. The main chemical substances present in licorice root include:

1. Glycyrrhizin, the principal active compound of licorice, a triterpenoid glycoside. It is responsible for the sweetening properties of licorice (about 50 times sweeter than sugar) and its therapeutic effects, such as anti-inflammatory, antioxidant, and anti-allergic actions [21,22].
2. Flavonoids, which possess anti-inflammatory, antioxidant, and antitumor properties. In addition, acids such as gallic acid and caffeic acid contribute to its antioxidant activity [23,24].
3. Polyphenols, which provide licorice with antioxidant activity and protect cells from oxidative stress [25,26].

Another chemical characteristic is the acidity (pH) of licorice extracts, especially concentrated forms, which can have an acidic pH [27], generally ranging between 4–6 depending on the extraction process. Their chemical reactivity, due to the presence of glycyrrhizin and flavonoids, makes them stable in acidic environments but prone to decomposition under highly alkaline conditions or in the presence of strong oxidants. Glycyrrhizin is also light-sensitive and may degrade upon prolonged exposure to direct sunlight.

The physical properties of licorice root and its extracts depend on chemical composition and processing. Some of the main physical properties include:

- a) Color: Dried licorice root is dark brown externally and golden yellow internally. Concentrated licorice extract tends to have a dark hue due to glycyrrhizin and other compounds [28].
- b) Solubility: Glycyrrhizin and other compounds are water-soluble, which is why traditional licorice extraction is performed by infusing or boiling roots in water. Aqueous extracts are viscous and have a syrup-like consistency [29].
- c) Taste: Licorice has a distinctive flavor, sweet and slightly bitter, mainly due to glycyrrhizin, which is about 50 times sweeter than sugar [29].
- d) Density: Dried licorice root has relatively low density and is easily crumbled, facilitating grinding into powder [28].
- e) Thermal behavior: Licorice root has moderate heat resistance, but the extraction of glycyrrhizin and other bioactive compounds can be affected by high temperatures. For this reason, extraction processes are carried out under controlled temperatures to avoid thermal degradation of active principles [30].
- f) Viscosity: Concentrated licorice extracts, particularly those containing glycyrrhizin, may have a viscous consistency, making them suitable for use in candies, syrups, and other confectionery products [31].
- g) Stability: Licorice extracts tend to be stable over time, but their stability can be compromised by factors such as humidity and high temperature. The combined use of ultrasound and cold plasma has significantly improved the yield and concentration of bioactive compounds compared to traditional methods. The study also highlights the effect of temperature and extraction time on the stability of glycyrrhizin [32].

3. Preliminary Stages in the Licorice Supply Chain: Cultivation and Harvesting, Cleaning, and Drying

The licorice plant (*Glycyrrhiza glabra*) undergoes several processes to extract its active compound, glycyrrhizin, and to enable its use in various sectors such as food, pharmaceuticals, cosmetics, and even the biofuel industry [33]. Below is an overview of the main processing stages of licorice (Figure 2):

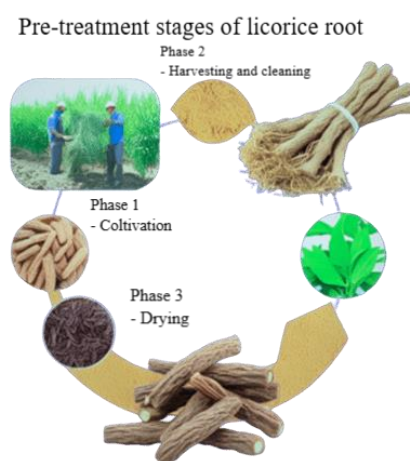


Figure 2. Phase of licorice root processing: from cultivation and harvesting through cleaning, and finally to preparation and drying.

3.1. Stage 1: Cultivation and Harvesting

Cultivation: Licorice grows in sandy, well-drained soils with a temperate climate. Roots can be harvested after about 3–4 years of growth, the time required to achieve a good concentration of glycyrrhizin. Soil selection must be suitable for licorice, which thrives in well-drained, nutrient-rich soils with a neutral pH. A sunny location is essential. Cultivation can be carried out either by seeds or rhizomes. Seeds are sown in spring, while rhizomes can be planted in autumn or spring. Proper care is crucial, as the plant requires regular watering during dry periods. Weed and disease control should preferably use biological methods. The growth cycle of licorice generally takes 3–4 years to develop mature roots ready for harvesting [34]. Harvesting: Roots are extracted from the soil, usually by hand or with specialized machinery to avoid damage. The root is the most utilized part of the plant, as it contains glycyrrhizin, the main compound with therapeutic properties.

3.2. Stage 2: Root Cleaning

Soil Removal: After harvesting, roots are cleaned of soil and impurities. They are sometimes cut into small pieces to facilitate subsequent extraction and processing. Excess soil can be removed manually or with water jets. Washing: Roots are rinsed under running water to eliminate soil residues and impurities. Care must be taken not to damage the roots during this stage [20].

3.3. Stage 3: Root Drying

Cleaned roots are dried to reduce moisture content. Drying can be performed in ovens or natural environments. After washing, roots should be placed on clean clothes or racks in well-ventilated areas. Low-temperature dryers can also be used [35].

Moisture Control: It is essential to ensure that roots are completely dry before storage to prevent mold formation. This process helps preserve the product and makes it easier to handle in subsequent stages [36].

After completing the harvesting, cleaning, and washing operations of *Glycyrrhiza glabra* roots, the plant material is ready to undergo industrial processing. These subsequent stages are essential for the extraction of active compounds and the production of commercial derivatives, as well as for understanding current innovations within the framework of the circular economy.

4. Industrial Processing of Licorice Root

The cleaned and dried root is subjected to controlled thermal treatment, generally through infusion or boiling in water [37], in order to extract bioactive compounds. This process generates two distinct fractions, and to capture the specific features of each product derived from processing, the analysis continues with a separate examination of:

- I. Licorice juice extraction, which allows the desired compounds (such as glycyrrhizin and other flavonoids) to be obtained from the root, producing a juice suitable for various applications in the food, medical, and pharmaceutical sectors, as will be examined in detail in the following sections.
- II. Physical residue (waste), consisting of fibers denatured by the boiling process and non-usable parts. This highlights the need to find solutions for reusing these residues within a circular sustainability framework, which is the focus of this study.

In the following sections, the possible applications of both fractions obtained after the boiling process will be examined in detail.

4.1. Licorice Juice Extract

The extraction of licorice juice [38] from harvested roots is one of the most important processes to maximize juice yield per harvest. Two types of extraction can be employed:

- Water extraction: This is the most common method, where dried or fresh roots are immersed in hot or boiling water for a period of time. Heat facilitates the solubilization of active

compounds, dissolving soluble components such as glycyrrhizin [39]. Hot extraction increases solubility and extraction speed, allowing a more concentrated final product to be obtained in a shorter time compared to other extraction methods.

- Solvent extraction: Ethanol, a polar solvent, can extract a wider range of compounds, including those not water-soluble. Ethanol use enables a more complete extract, containing both water-soluble and less polar compounds [40]. Another approach is the use of water-alcohol mixtures, which optimize extraction by balancing compound solubility. Mixtures can be adjusted depending on the compounds targeted. Water and ethanol are generally considered safe and accessible for use in food and herbal extracts, and are fundamental solvents for extraction processes due to their low cost and safety [41].

The concentrated extract may undergo further processing, namely purification, to remove additional impurities and obtain glycyrrhizin in a purer form. Purification can be achieved through filtration and chromatography techniques [42]:

- a) Simple filtration, used to separate insoluble solids from a solution. For example, after solvent extraction, it can remove solid particles [40].
- b) Vacuum filtration, employed for faster and more efficient separations. A pump creates a vacuum that accelerates liquid passage through the filter [43].
- c) Membrane filtration, which uses porous membranes to separate compounds based on size. It can be useful for concentrating or purifying liquid extracts [44].
- d) Thin Layer Chromatography (TLC), used for monitoring extractions and preliminary compound separation. Licorice residues may include root fragments, powders, resins, or other plant materials not fully extracted during preparation. These physical residues may still contain bioactive compounds such as flavonoids, saponins, alkaloids (e.g., glycyrrhizin), and other phenolic substances, which could be of interest for recovering additional products or for quality evaluation [45].
- e) High-Performance Liquid Chromatography (HPLC), one of the most advanced techniques for compound separation and purification. It uses high pressure to force solvent through a column packed with adsorbent material. It is highly effective for analyzing active components of licorice root [46].
- f) Ion-Exchange Chromatography, used to separate ionic compounds. It can be useful for isolating flavonoids. Beyond chromatography, this study also explores how carbonized licorice residues (char) can be used for adsorption purposes, a theme that may integrate with ion-exchange chromatography applications [47].

Table 1. Chronological Development of Analytical and Separation Methods Applied to Licorice Juice.

<u>Historical Period</u>	<u>Main Technique</u>	<u>Short Description</u>	<u>Advantages</u>	<u>Limitations</u>
1950 [40]	<i>Simple Filtration</i>	Separation of insoluble solids using filter paper or sieves	Easy, inexpensive	Low selectivity, does not remove fine particles
1960 [43]	<i>Vacuum Filtration</i>	Use of a vacuum pump to accelerate filtration	Faster and more efficient	Still limited in purity
1970 [44]	<i>Membrane Filtration</i>	Porous membranes separate molecules by size (microfiltration, ultrafiltration)	Juice concentration and purification	Higher cost, risk of membrane fouling

1980 [45]	<u>Thin Layer Chromatography (TLC)</u>	Qualitative analysis of compounds (flavonoids, glycyrrhizin)	Quick, inexpensive, useful for screening	Not quantitative, low resolution
1990 [46]	<u>High-Performance Liquid Chromatography (HPLC)</u>	Quantitative analysis and precise separation of active compounds	High sensitivity and accuracy	Requires costly instrumentation
2000 [47]	<u>Ion Exchange Chromatography</u>	Separation of ionic compounds such as glycyrrhizin and salts	High selectivity	Operational complexity
2020 [45–47]	<u>Combined Techniques (HPLC-MS, advanced membranes, preparative chromatography)</u>	Integrated approaches for standardized and pure extracts	Maximum efficiency, industrial standardization	High costs, need for technical expertise

The choice of filtration or chromatography technique depends on the specific objectives of the analysis or purification. It is important to combine different techniques to achieve optimal extraction and purification of the desired compounds from the licorice root extraction and purification process [48].

This purified extract can be applied in several sectors:

- Food industry: It is used as a natural sweetener in candies and other food products thanks to its distinctive flavor and sweetness, which is about 50 times greater than that of regular sugar. It is also often used in dietary supplements for its potential health benefits, including modulation of the immune system. In addition, it is employed in some alcoholic and non-alcoholic beverages to provide a unique flavor, such as in certain beers, liqueurs, and teas [21].
- Herbal medicine and traditional medicine: Licorice is known for its anti-inflammatory, antioxidant, and digestive properties. It is used in infusions and teas to relieve gastrointestinal disorders, coughs, and sore throats. It is also employed in herbal and phytotherapeutic preparations for its anti-inflammatory, expectorant, and digestive effects [49].
- Cosmetic industry: Licorice extract (*Glycyrrhiza glabra*) is widely used in cosmetics for its soothing, anti-inflammatory, and especially skin-lightening properties, due to compounds such as glabridin and liquiritin, which modulate melanin production and reduce skin hyperpigmentation [50].
- Pharmaceutical industry: Licorice extract is an ingredient in certain medicines for the treatment of respiratory and gastrointestinal disorders [49]. Glycyrrhizin, an active compound of licorice, also has antiviral effects. It is important to note that licorice consumption should be moderate, as excessive intake may lead to side effects such as hypertension [51].

Table 2. Chronological Overview of Licorice Juice Uses in Food, Medicine, Cosmetics, and Beyond.

Historical Period	Sector	Main Applications	Notes / Added Value
Ancient Times – Middle Ages 19th–Early 20th Century Mid-20th Century (1950s–1970s)	Herbal medicine e Traditional medicine	Infusions, decoctions for cough, sore throat, digestive disorders	Widely used in Ayurveda, Traditional Chinese Medicine, and Greco-Roman herbalism

	Food industry	Natural sweetener in candies, syrups, teas, and beverages	Glycyrrhizin recognized as ~50x sweeter than sucrose
	Pharmaceutical industry	Syrups for cough, gastroprotective preparations, anti-inflammatory remedies	Standardization of extracts begins
Late 20th Century (1980s–1990s)–2000s	Cosmetic industry	Skin-soothing creams, anti-inflammatory gels, whitening agents for hyperpigmentation	Glabridin and liquiritin studied for skin-lightening
	Nutraceuticals and Functional foods	Dietary supplements, immune-modulating formulations, antioxidant beverages	Growing demand for natural health products
	Broader food and beverage industry	Flavoring in beers, liquors, herbal teas, functional drinks	Expansion into craft beverages and niche markets
2010s–2020s	Integrated applications	Combined use in food, pharma, cosmetics, nutraceuticals, veterinary medicine, and biotechnology	Research on antiviral properties, nanocarriers for cosmetics, and sustainable valorization of by-products
Historical Period Ancient Times – Middle Ages	Sector	Main Applications	Notes / Added Value
	Herbal medicine e Traditional medicine	Infusions, decoctions for cough, sore throat, digestive disorders	Widely used in Ayurveda, Traditional Chinese Medicine, and Greco-Roman herbalism
19th–Early 20th Century Mid-20th Century (1950s–1970s)	Food industry	Natural sweetener in candies, syrups, teas, and beverages	Glycyrrhizin recognized as ~50x sweeter than sucrose
	Pharmaceutical industry	Syrups for cough, gastroprotective preparations, anti-inflammatory remedies	Standardization of extracts begins

Alongside the value of licorice juice, there is an often overlooked but highly significant aspect: the industrial waste derived from root processing. After the extraction of active compounds and concentrated juice, fibrous residues and plant materials remain, which for a long time were considered mere waste. In recent years, however, growing attention to sustainability and the circular economy has led to a re-evaluation of these by-products, which have proven to be rich in residual bioactive compounds (flavonoids, saponins, traces of glycyrrhizin). From this arises the idea of transforming waste into a resource, reducing environmental impact and creating new opportunities for valorization. This study focuses precisely on this aspect: analyzing the possible applications of licorice residues, the techniques of use and processing already available, and future perspectives.

4.2. Industrial Residue Waste

This residue resulting from the boiling and extraction process may appear as a fibrous, dark compound, consisting of parts of the root itself, such as plant fibers and other insoluble compounds [52]. It is mainly composed of substances not soluble in water, such as fibers, polysaccharides, and other plant compounds that do not dissolve during extraction. Depending on the extraction method and boiling duration, the quantity and composition of the residue may vary. This residue can be discarded or, in some cases, used for other purposes, such as compost or dietary supplements, depending on local, regional, and industrial practices and regulations [53]. Therefore, it is useful to list the various applications currently in use:

- a) Fertilizer-compost: The residue can be used as a soil amendment, helping to improve soil structure and provide nutrients to the surrounding environment, thereby enhancing fertility [54–56].
- b) Biomass for energy: It can serve as a biomass source for renewable energy production through combustion or gasification processes [57–60].
- c) Food industry: The residue can be used as a natural flavoring or coloring agent in certain foods, beverages, and even as an additive in baked goods (pasta, bread, taralli) [61–64].
- d) Shampoo and conditioner: Thanks to its soothing properties, the residue may be employed in hair care products [65–67].
- e) Phytotherapy: Used in herbal preparations, creating a paste or cream to be applied to the body to exploit its therapeutic properties [68,69].
- f) Bio-materials: The lignocellulosic residues of licorice root can be valorized as raw material for biomaterials and bioplastics, due to their cellulose and organic content [70,71].
- g) Bioremediation and water purification: Recent studies confirm the use of licorice residues as adsorbent and bioactive materials for bioremediation and water purification, thanks to the presence of cellulose, lignin, and phenolic compounds [72–74].
- h) Environmental impact and sustainable construction: Licorice root processing residues, rich in cellulose and lignin, can be transformed into bioplastics, compostable materials, and biocomposites for green building. Recent studies, including that of L. Madeo [75], have demonstrated the validity of this approach within the framework of the circular bioeconomy.
- i) Smoke filtration: Standardized extracts of *Glycyrrhiza glabra* root [76,77] (in powder, block, or liquid form) are used in cigarette filters and additives for their flavoring, humectant, and partly antioxidant properties. However, there is no consolidated evidence that the tobacco industry employs industrial licorice residues as toxic attenuators; this remains under study.
- j) Textile industry: Recent studies have analyzed the use of licorice root residues (*Glycyrrhiza glabra*) in textiles [78], both as a source of natural fibers, as an ecological dye [79], and as an antimicrobial agent [80] for eco-sustainable fabrics [81].

These applications highlight the versatility of licorice root and the importance of valorizing its residues. Often, licorice root processing generates waste that is neglected or considered useless; however, the valorization of these materials can have significant economic and environmental impacts [82]. The processing and extraction of licorice involves several stages, from cultivation to

harvesting, through extraction and purification of extracts, up to the production of various types of products.

Table 3. Timeline integrating the years of development for each sector of use of licorice root residues.

Sector of Use	Development Period	Indicative Years	Market Phase	Future Prospects (2025–2035)
Fertilizer / Compost [54–56]	Historical → Current	<2000 – present	Already widespread in organic farming	Certified compost, integration with biochar, green agricultural market
Biomass for energy [57–60]	Initial development → Current	2005 – present	Pilot plants and research	Second-generation bioethanol, advanced gasification New “clean label” products,
Food industry [61–64]	Historical → Current	<1980 – present	Widely used as flavoring	standardized natural additives
Cosmetics [65–67]	Current	2010 – present	Growth in the natural cosmetics market	Eco-friendly product lines for hair and scalp
Phytotherapy (ointments, creams) [68,69]	Historical → Current	<2000 – present	Consolidated use in herbal medicine	Certified dermatological creams, innovative topical products Compostable packaging, green start-ups, sustainable construction
Biomaterials / Bioplastics [70,71]	Initial development → Current	2015 – present	Prototypes and industrial research	Industrial bio-adsorbents for water treatment plants and industries
Bioremediation and water purification [72–74]	Current	2018 – present	Advanced studies and pilot applications	Certified insulating panels, EU incentives, sustainable building market
Sustainable green building [75]	Current (Madeo 2025)	2020 – present	First applications in green construction	Research on alternative natural filters
Smoke filtration (treated residues) [76,77]	Historical → Current	<1970 – present	Use of standardized extracts	Antimicrobial fabrics for sports/medical use, sustainable fashion
Textile industry (fiber, dye, antimicrobial) [78–81]	Current	2020 – present	Research and initial applications	

Ongoing research into new methods of extraction and valorization of residues is leading to increasingly sustainable and innovative developments. Specifically, in the following paragraph, we focus on sharing the scientific progress regarding the various applications of licorice root residues currently under study, as well as their potential future applications.

5. Fiber: Characteristics and Potential Applications

The residual fiber from licorice root, long regarded as a mere industrial by-product, is now emerging as a resource of significant value for the circular bioeconomy (Figure 3).



Figure 3. Licorice root fiber residue, this is the common industrial waste in its raw form without any treatment. The material under examination comes from the company Romano S.r.l., located in Corigliano-Rossano, Cosenza, Italy.

Its lignocellulosic composition, combined with characteristics such as porosity, absorbent capacity, and biodegradability, makes it suitable for multiple production sectors. Although available studies are still limited, research conducted so far has demonstrated that this material can be effectively transformed into innovative and sustainable solutions, reducing environmental impact and replacing fossil-based resources or virgin cellulose. The main identified applications include:

- Green building and construction materials – use of the fiber as reinforcement in insulating panels, lightweight plasters, and eco-compatible composites.
- Eco-friendly paper and cardboard – employment of fibers as an alternative raw material for paper production, reducing dependence on wood-derived cellulose.
- Agriculture and organic substrates – direct or composted use as a soil amendment, improving soil structure, water retention, and resilience under saline conditions.
- Sustainable textiles – valorization of the fiber as a source of natural pigments and as reinforcement in technical fabrics with antimicrobial and fire-resistant properties.
- Biodegradable packaging – integration of the fiber into biopolymers for the production of lightweight, compostable, and environmentally friendly packaging.

In this context, residual licorice fiber emerges as a strategic material, capable of combining technological innovation, sustainability, and waste valorization, opening concrete prospects for the development of more circular and resilient production chains. Its versatile applications, ranging from sustainable construction to biodegradable packaging, highlight its potential as a multifunctional resource across different industrial sectors.

To systematically explore these possibilities, a specific paragraph will be dedicated to each application, analyzing the treatments and characteristics in detail.

5.1. Green Building and Construction Materials

The valorization of residual licorice fiber in the green building sector represents one of the most promising applications within the framework of the circular economy. After appropriate treatments of cleaning, drying, grinding (Figure 4), and mixing with natural binders such as lime, gypsum, or starches, these lignocellulosic residues can be used as reinforcement in decorative wall panels, lightweight plasters, and eco-compatible composite materials.



Figure 4. Industrial waste licorice root, pulverized after the grinding process (a), industrial waste licorice root, broken after the segmentation process (b).

From a technical perspective, licorice fiber is distinguished by its porous structure and lignocellulosic composition, which provide thermal and acoustic insulation properties, while also ensuring lightness and breathability in building materials. These characteristics not only improve building performance in terms of living comfort but also contribute to reducing environmental impact by replacing synthetic materials with a high carbon footprint. Studies have shown that plant fibers derived from licorice residues can be effectively integrated into sustainable building products [75], highlighting improvements in mechanical properties and a reduction in material density. At the same time, research has chemically, thermally, and mechanically characterized licorice root residues, confirming their suitability as a natural filler in polymer composites and construction materials [83]. In this context, licorice fiber is not merely a by-product to be discarded, but a strategic resource capable of contributing to the transition toward more sustainable construction, reducing industrial waste, and promoting the use of renewable materials.

5.2. Eco-Friendly Paper and Cardboard

The use of residual licorice fiber in the production of eco-friendly paper and cardboard represents a concrete opportunity to reduce dependence on virgin cellulose and to valorize an agro-industrial by-product otherwise destined for disposal. Licorice fiber, being rich in cellulose, hemicellulose, and lignin, can be treated with mechanical pulping or mild chemical processes to separate the fibrous components and make them suitable for papermaking. The fibrous residue of licorice root, rich in cellulose, hemicellulose, and lignin, can be transformed into pulp through targeted pre-treatment that enhances its structural properties.

In the first phase, the fiber is dried and ground to reduce residual moisture, decrease particle size, and increase specific surface area, thereby facilitating subsequent disintegration. At this point, two complementary approaches can be applied: mechanical pulping, which exploits the physical fragmentation of fibers to obtain pulp with high cellulose yield, preserving much of the lignin and thus imparting robustness and natural tones to the product, albeit with higher energy consumption; or mild chemical pulping, based on low-concentration alkaline solutions or enzymatic treatments, which selectively remove part of the lignin and foreign substances without compromising cellulose integrity, unlike the aggressive processes typical of conventional papermaking.

The fibrous pulp thus obtained is finally pressed and dried to form sheets of paper or cardboard characterized by good mechanical strength, biodegradability, and environmental sustainability, with the added advantage of maintaining natural brown-yellowish tones that reduce the need for chemical bleaching. Scientific investigations conducted by Huang and colleagues [63] confirmed the effectiveness of these treatments: FTIR analyses highlighted partial lignin removal, while SEM observations showed cleaner and more compact fibrous surfaces, suitable for forming stronger inter-fiber bonds. These results demonstrate that properly treated licorice fiber can serve as a valid

alternative to traditional cellulose sources, contributing to the development of a more sustainable papermaking chain in line with the principles of the circular bioeconomy.

After treatment, paper and cardboard obtained from residual licorice fiber exhibit a set of properties confirming their validity as sustainable alternatives to traditional raw materials. The presence of relatively long fibers and a residual lignin fraction gives the material robustness and flexibility, qualities confirmed by mechanical tests such as tensile strength and burst index, which showed values comparable to those of papers produced from other non-wood fibers [78].

From an environmental perspective, these products are fully biodegradable, as demonstrated by degradation tests under controlled composting conditions, and they help reduce pressure on wood-derived cellulose, positively contributing to deforestation mitigation. An additional advantage lies in their intrinsic aesthetic value: residual lignin imparts natural brown-yellowish tones, allowing bleaching processes to be limited or eliminated, thereby reducing the overall environmental impact of the production chain. Scientific investigations have further confirmed the quality of the material through various analytical techniques. Thermogravimetric analysis (TGA) revealed good thermal stability of the treated fiber, while X-ray diffraction (XRD) confirmed an adequate degree of cellulose crystallinity, a parameter closely linked to mechanical strength. Finally, scanning electron microscopy (SEM) observations showed the formation of a compact and well-interconnected fibrous network, responsible for the final mechanical performance and structural cohesion of the material.

In summary, paper and cardboard derived from licorice fiber combine technical performance, biodegradability, and environmental sustainability, standing as a concrete example of applying the principles of the circular bioeconomy.

5.3. Agriculture and Organic Substrates

The fibrous residue of licorice root, thanks to its lignocellulosic composition and residual bioactive compounds, represents a resource of great interest for sustainable agriculture. Its use as a soil amendment or component of organic substrates improves the physical, chemical, and biological properties of soil while reducing agro-industrial waste production. The treatment required is relatively simple and low-impact: the fiber can be shredded to reduce particle size and increase surface area, promoting microbial decomposition; it can be composted, mixed with other organic residues such as manure or plant waste, initiating aerobic processes that stabilize organic matter and reduce phytotoxicity; or it can be used directly, exploiting its ability to retain water and improve soil porosity. Recent studies have also shown that solid-state fermentation applied to licorice residues not only improves stability but also enables recovery of flavonoids and bioactive compounds, with positive effects on soil microflora and the agronomic value of compost [84].

Functionally, applying residual licorice fiber to soil provides several benefits. Its porous structure ensures high water retention capacity, particularly useful in arid environments, while the organic matter input enriches soil carbon content and stimulates microbial activity. The fiber also contributes to improving soil physical structure, increasing porosity and aggregate stability, and reducing compaction phenomena. A particularly relevant aspect concerns salinity reduction: research has shown that adding sweet licorice root improves the physico-chemical properties of saline soils, reducing soluble salt concentrations and promoting crop growth [85]. In parallel, integrating licorice extracts with melatonin has demonstrated biostimulant effects, improving growth and productivity of fava beans in cadmium-contaminated and highly saline soils, confirming the synergistic role of fiber and its residual metabolites as agents mitigating abiotic stress [86].

Overall, scientific evidence converges in demonstrating that residual licorice fiber is not a mere by-product, but a multifunctional amendment capable of improving soil quality, increasing crop resilience, and reducing the environmental impact of agricultural systems, fully consistent with the principles of the circular bioeconomy.

5.4. Sustainable Textiles

The fibrous residue of licorice root represents an interesting resource for the sustainable textile sector, both as a source of natural pigments and as fibrous reinforcement in composite materials for technical fabrics.

From a treatment perspective, pigments can be extracted through aqueous processes or eco-compatible solvents, obtaining natural dyes in yellow-brown tones. These pigments, as demonstrated [79], can be successfully applied to bio-mordanted cotton fabrics, ensuring good color yield and stability, while reducing environmental impact compared to synthetic dyes.

In parallel, raw licorice fiber can be used as natural reinforcement in technical fabrics and composite materials. Its lignocellulosic structure provides additional mechanical properties and, above all, introduces functional characteristics of interest. In particular, natural dyes derived from licorice have shown antimicrobial activity, as evidenced by the systematic review [80], which highlighted the potential of plant pigments in limiting microbial proliferation on fabrics. Furthermore, experimental studies have highlighted the flame-retardant potential of the fiber and its extracts: research reported in the *Journal of Textile Research* demonstrated that incorporating licorice root into fabrics can reduce flame propagation [87], opening prospects for applications in technical clothing and protective equipment.

Overall, the use of residual licorice fiber in sustainable textiles combines aesthetic and functional performance: on one hand, it provides natural and biodegradable colorations; on the other, it introduces antimicrobial and flame-retardant properties that enhance durability and safety of materials. These characteristics, together with reduced environmental impact compared to conventional processes, make licorice a promising candidate for the development of innovative and circular textiles.

5.5. Biodegradable Packaging

The fibrous residue of licorice root, when properly treated, serves as a natural filler for the production of biodegradable packaging materials, representing a valid alternative to fossil-based plastics. Pre-treatment of the fiber is a crucial phase: it is first dried to reduce residual moisture and stabilize its properties, then ground to obtain a fine and homogeneous particle size, capable of improving dispersion within the polymer matrix. Subsequently, the fiber can be pressed or directly mixed with biopolymers such as PLA (polylactic acid) or modified starches, thereby increasing the mechanical strength and dimensional stability of the final material.

From a performance perspective, the resulting composites exhibit lightness, biodegradability, and a significant reduction in the use of fossil plastics, with a lower environmental impact compared to conventional materials. Moreover, the presence of lignocellulosic fiber contributes to improving certain functional properties, such as stiffness and fracture resistance, while maintaining a good degree of flexibility.

Scientific investigations have provided solid evidence supporting these applications. Studies have characterized licorice root residues as potential fillers in composite materials, highlighting that their integration reduces material density and enhances overall sustainability [78]. Other studies have further examined the chemical, thermal, and mechanical characterization of the fiber, revealing its composition rich in cellulose, hemicellulose, and lignin—elements that confer robustness and versatility [75,83]. Significant thermal stability and good resistance to degradation have emerged, qualities fundamental for use in industrial processes such as extrusion and molding. The fiber has shown thermal transitions compatible with bio-based polymer matrices and a surface morphology capable of promoting effective adhesion within composites. Structural property tests confirmed a significant improvement compared to pure biopolymers, making licorice fiber a highly valuable functional reinforcement.

These results demonstrate how an agro-industrial by-product can be transformed into a high value-added resource, contributing to waste reduction and the development of innovative materials perfectly aligned with the principles of the circular bioeconomy.

5.6. Comparison among the Main Application Sectors of Licorice Fiber

The comparative analysis of the different sectors of use highlights how, through simple and low environmental impact treatments, residual licorice fiber acquires physico-mechanical and functional properties of great interest, establishing itself as a versatile resource for the development of sustainable materials (Table 4).

Table 4. Main applications of residual licorice fiber, with indication of treatment, characteristics, and strategic importance.

Application sector	Fiber treatment	Obtained characteristics	Importance
Bio-construction and building materials [75,83]	Drying, grinding, mixing with binders (lime, gypsum, starches)	Thermal and acoustic insulation, breathability, good mechanical strength	Reduces the use of synthetic materials with high carbon footprint; contributes to sustainable construction and housing comfort
Eco-friendly paper and cardboard [63,78]	Mild mechanical or chemical pulping separate cellulose; pressing and drying	Good mechanical strength, natural cellulose; coloration intensive bleaching	Alternative to virgin cellulose; reduces deforestation and valorizes agro-industrial residues
Agriculture and organic substrates [84–86]	Crushing, composting, direct use as soil amendment	High water retention capacity, supply of organic matter, improvement of soil structure, reduction of salinity	Improves soil fertility and resilience; supports crops under water or saline stress conditions
Sustainable textiles [79–87]	Extraction of natural pigments (water or eco-compatible solvents); use of raw fiber as reinforcement	Natural yellow-brown dyes, antimicrobial properties, potential flame retardancy	Provides ecological alternatives to synthetic dyes; enhances safety and durability of fabrics
Biodegradable packaging [75,78,83]	Drying, grinding, pressing; combination with biopolymers (PLA, starches)	Lightness, biodegradability, good mechanical strength, reduction of fossil-based plastics	Promotes the development of compostable and circular packaging; reduces the environmental impact of traditional plastics

Thanks to its chemical-physical versatility, licorice fiber adapts to different production contexts, generating environmental benefits (waste and CO₂ reduction), economic benefits (new production chains), and social benefits (local employment and sustainable innovation). In summary, it embodies the concept of active circular material, capable of transforming an agro-industrial residue into a strategic lever for sustainable multi-sector innovation.

6. Market Outlook and Future Investments

The valorization of licorice root residues is positioned at the center of the transition toward production models based on the circular bioeconomy, combining waste reduction, resource

efficiency, and value creation across multiple supply chains. Lignocellulosic residues can be transformed into secondary raw materials for high-demand market sectors (bioplastics, green building, water purification, natural cosmetics, sustainable textiles), generating economic, industrial, and environmental benefits.

European policies reinforce this trajectory: the Green Deal [88] aims for climate neutrality by 2050, the Circular Economy Action Plan (2020) promotes bio-based materials and extended producer responsibility, while the European Bioeconomy Strategy [89] valorizes biomass and agro-industrial residues as feedstock for innovative materials.

In this context, licorice residues become a strategic asset for decarbonization and product innovation, thanks to their versatility (natural additives, bio-adsorbents, fillers for biocomposites, dyes, and antimicrobial finishes). To maximize impact, investment strategies should focus on three main directions:

- i. Industrial scalability, with pilot plants and modular lines for biomaterials and green building.
- ii. Supply chain integration, through supply agreements, traceability, and quality standards.
- iii. Green finance, leveraging European programs (Horizon Europe, LIFE, Innovation Fund) and ESG instruments to reduce CAPEX and OPEX.

To clarify the framework of opportunities, Table 5 summarizes the main utilization sectors of licorice root residues, indicating for each the estimated market value, expected growth rate (CAGR), required investment level (CAPEX), technological maturity (TRL), and scientific interest.

Table 5. Utilization sectors of licorice root residues: estimated market value, CAGR (2025– 2030), required CAPEX, technological maturity (TRL), and scientific interest.

Utilization sector	Estimated market value	CAGR (2025– 2030)	Required CAPEX	Technological maturity (TRL)	Scientific interest
Fertilizer / Compost	~€2 billion	4–5%	Low (composting plants already widespread)	TRL 8–9 (consolidated technology)	Moderate: studies on organic amendments and biochar
Biomass for energy	~€10 billion	6–7%	Medium-high (gasification/digestion plants)	TRL 6–7 (pilot/industrial)	High: research on bioethanol and bioenergy from lignocellulosic residues
Food industry (flavorings, additives)	~€12 billion	3–4%	Low (extraction and standardization)	TRL 9 (consolidated use)	High: numerous studies on

Utilization sector	Estimated market value	CAGR (2025 – 2030)	Required CAPEX	Technological maturity (TRL)	Scientific interest
Natural cosmetics (shampoo, conditioner)	~€50 billion	5–6%	Medium (extraction and formulation lines)	TRL 7–8 (pre-commercial/industrial)	natural extracts and clean label products High: growing research on licorice bioactives (antioxidants, soothing agents)
Phytotherapy (ointments, creams)	~€8 billion	3–4%	Low	TRL 9 (consolidated use)	Moderate: clinical and pharmacognostic studies Very high: strong academic interest in lignin and cellulose from residues
Biomaterials / Bioplastics	~€15 billion	10–12%	High (biopolymer and compounding plants)	TRL 5–6 (advanced research, prototypes)	Very high: recent studies on natural adsorbents and licorice-derived biochar
Bioremediation / Water purification	~€200 billion	7–8%	Medium (water treatment plants)	TRL 5–6 (pilot)	

Utilization sector	Estimated market value	CAGR (2025 – 2030)	Required CAPEX	Technological maturity (TRL)	Scientific interest
Eco-sustainable construction (Bio-construction)	~€600 billion	8–9%	High (production lines for panels and composites)	TRL 6–7 (pilot/industrial)	Very high: works by Madeo et al. (2025) and others on biocomposites
Smoke filtration (extracts, not residues)	~€5 billion	Stable (0–1%)	Low	TRL 9 (consolidated use)	Low: few studies, more related to additives than residues
Textile industry (fiber, dye, antimicrobial)	~€40 billion	Medium (natural spinning and dyeing plants)	TRL 5–6 (research and prototypes)	High: recent studies on natural dyes and plant fibers	

From the analysis, two macro-categories emerge:

1. Mature sectors (food, phytotherapy, fertilizers), characterized by consolidated technologies, reduced CAPEX, and moderate growth.
2. Emerging high-potential sectors (bioplastics, green building, bioremediation, sustainable textiles), with high CAGR, strong scientific interest, and medium-to-high investment requirements, but with significant return prospects.

To visualize the dynamics of investments and technological maturity, (Figure 5) presents a functional scheme and a timeline highlighting the relationships between the intrinsic characteristics of licorice fiber (lignocellulosic composition, natural pigments, adsorptive capacity) and the specific needs of different sectors (thermal insulation for green building, natural dyes for textiles, bio-adsorbents for water purification, bioactives for cosmetics).

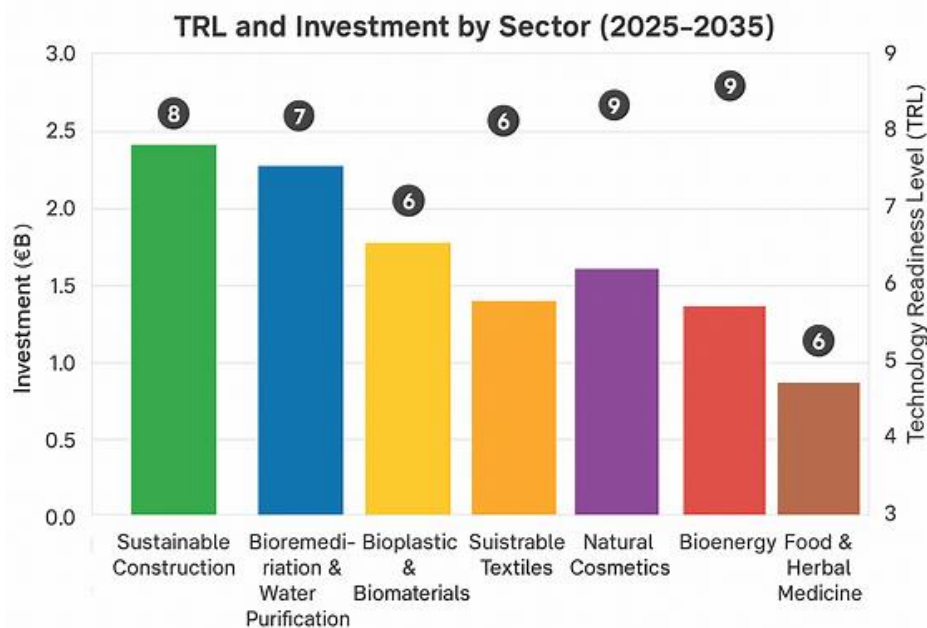


Figure 5. Timeline of projected investments (2025–2035) in key sectors using licorice root residues, with indication of technological maturity (TRL).

The timeline shows the distribution of projected capital between 2025 and 2035 across the main strategic sectors of the bioeconomy, linking economic scale and TRL: from already consolidated sectors (natural cosmetics, green building) to those still in development (bioplastics, textiles).

Between 2025 and 2035, licorice root residues will become a strategic resource for several industrial sectors, with a total investment volume estimated at over €8.5 billion. The priority sectors will be Green Building (€2.5 billion), Bioremediation and Water Purification (€2.0 billion), and Bioplastics and Biomaterials (€1.2 billion), which together will absorb more than 65% of the projected capital. In these areas, a four-phase trajectory is expected: launch of pilot projects between 2025 and 2027, large-scale expansion in the period 2027–2030, market consolidation between 2030 and 2032, and finally diversification and internationalization by 2035.

Alongside these leading sectors, emerging fields such as Sustainable Textiles (€1.0 billion) and Natural Cosmetics (€0.8 billion) show strong potential, supported by growing demand for eco-friendly and clean-label products. More mature sectors, such as Food and Phytotherapy (€0.4 billion), will continue to ensure stability and continuity, while Bioenergy (€0.6 billion) will remain marginal but may grow as a complement to the energy transition.

Overall, the investment trajectory highlights a clear shift toward high value-added applications with strong environmental impact, confirming licorice residues as a key raw material for the circular bioeconomy of the coming decade.

5. Conclusions

In this review, an overall overview has been provided on the characteristics and applications of licorice, with particular attention to processing residues and, above all, to the recovery of the lignocellulosic fiber obtained from them.

The analysis highlights how licorice root, already widely used in the food, pharmaceutical, and cosmetic sectors for its functional properties, generates a significant amount of lignocellulosic residues during industrial processes. From these residues, a valuable plant fiber can be obtained, characterized by chemical-physical properties that make it suitable to replace fossil or synthetic resources. It is therefore not merely a by-product, but a circular raw material capable of being transformed into innovative solutions for high-potential sectors: bioplastics and biomaterials, green

building, natural cosmetics, bioremediation and water purification, sustainable textiles, and bioenergy.

Scientific research has demonstrated that this fiber possesses versatility and multifunctionality, being able to act as structural reinforcement, natural pigment, bio-adsorbent, or bioactive component. In this way, it contributes not only to reducing pollution and the use of virgin resources, but also to promoting a greener and more resilient economy. At the same time, the licorice market is continuously expanding, with growing demand in the food and pharmaceutical sectors: a context that encourages companies to invest in research and development, as shown by recent collaborations between industrial enterprises and venture capital funds, aimed at integrating scientific innovation and economic sustainability. The fiber derived from licorice residues emerges as a strategic, high value-added resource, capable of simultaneously meeting industrial, economic, and environmental needs. The future challenge will be to develop innovative methodologies and advanced technologies to optimize its use, maximizing benefits for both industry and society. In this perspective, licorice becomes an emblematic example of how scientific research, industrial investments, and sustainability policies can converge to build a more circular, competitive, and environmentally respectful future.

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