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REVIEW ARTICLES

Use of *Kappaphycus alvarezii* for the production of biotechnological products: A review of patents issued in the last 22 years (2002-2024)

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HIGHLIGHTS

- Analyzed patents from 2003 to 2023 for *Kappaphycus alvarezii* biotechnological applications
- There was a rise in patents in 2022, reflecting increased use of the macroalga
- China and the USA lead with 29 and 15 patents, respectively
- 56% of patents are for the cosmetics industry
- Alga's potential stands out in various industrial applications

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KEYWORDS
Seaweed;
Rhodophyta;
Carrageenan;
Industrial application.

Abstract: *Kappaphycus alvarezii* is cultivated globally and has attracted substantial scientific interest due to its rich chemical composition. Although systematic reviews on this species exist, analyses of patents demonstrating its industrial applicability remain scarce, leaving this field largely underexplored. This study examines patents published between 2002 and 2024 and identifies 93 documents, of which 73 detail applications directly related to product development. A gradual increase in patents has been observed in recent years, with a peak in 2022 (n = 17) followed by declines in 2023 (n = 8) and 2024 (n = 1). China and the United States are the most represented countries, with 30 and 15 patents, respectively. The cosmetics sector dominates (n = 39; 53%), followed by general industry, agriculture, food, and pharmaceuticals. Notable applications include moisturizing and anti-aging formulations (cosmetics), biofertilizers and biostimulants (agriculture), biofilms and bioplastics (general industry), and diverse uses as a functional ingredient. Overall, this review highlights the expanding use of *K. alvarezii* across multiple industrial sectors and underscores its potential as an innovative biological resource due to its chemical complexity. These findings provide a foundation to guide future research and industrial applications involving this macroalga.

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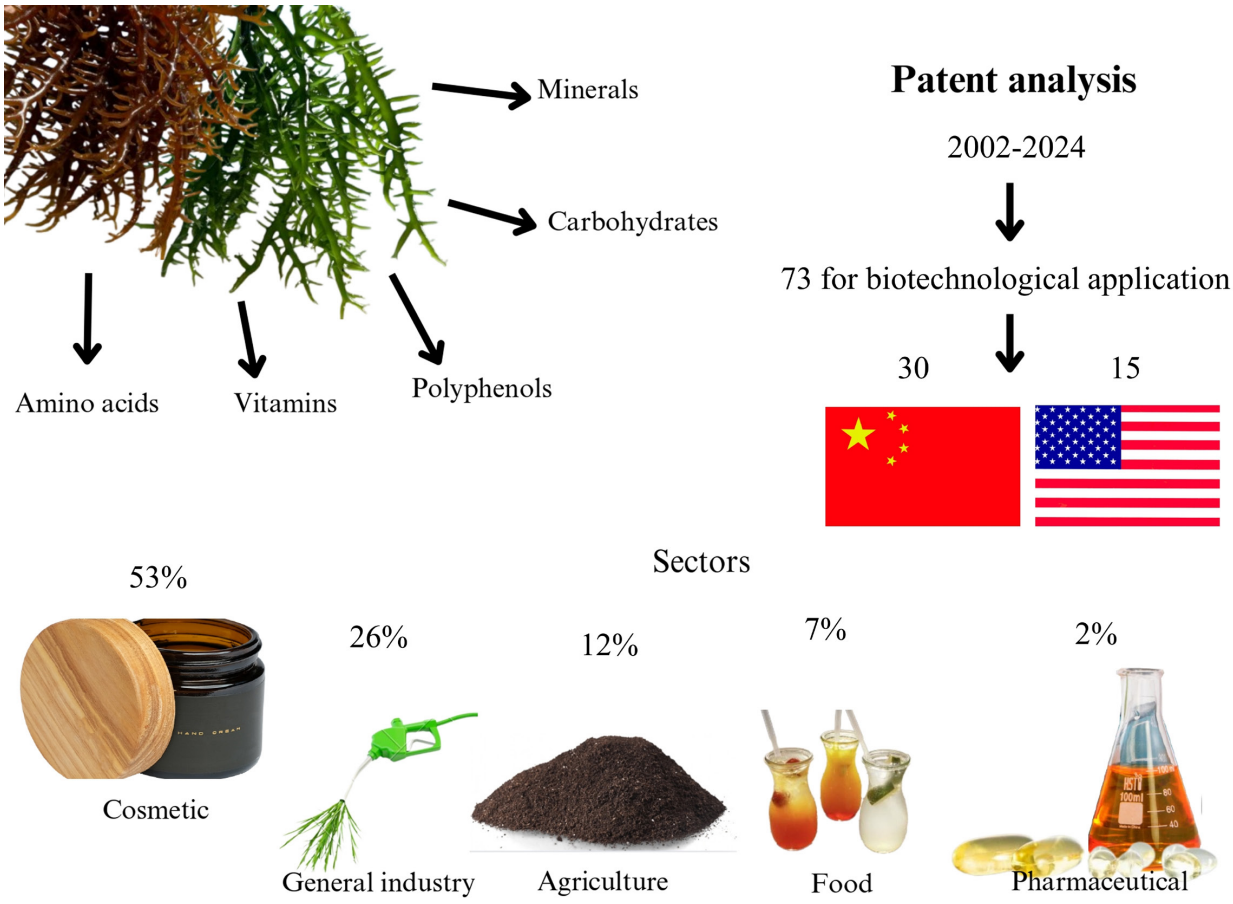
Graphical Abstract



Introduction

Seaweeds have been consumed as food for at least 14,000 years; however, large-scale seaweed cultivation is a relatively recent branch of aquaculture, emerging in the mid-20th century (Ullmann & Grimm, 2021). Algal productivity has increased substantially over the last two decades, with global production rising more than threefold, from 11.8 million tons to 35.8 million tons, between 2000 and 2019 (Food and Agriculture Organization of United Nations, 2021). Additionally, the global algae market is projected to reach US$ 24.9 billion by 2028, with an estimated compound annual growth rate (CAGR) of 7.51% from 2021 to 2028 (Fortune Business Insights, 2021).

Seaweeds are traditionally classified into three groups: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyceae (brown algae). Red algae account for more than 60% of global annual cultivation, and within this group, the red seaweed *Kappaphycus alvarezii* stands out as the fifth most cultivated species worldwide (Rudke et al., 2020). The prominence of *K. alvarezii* is attributed to its diverse chemical profile, which includes polysaccharides, amino acids, minerals, lipids, carotenoids, proteins, steroids, phenolics, flavonoids, saponins, hormones, and quinones. This biochemical richness provides significant potential for high-value applications across the nutraceutical, cosmeceutical, and pharmaceutical sectors. Consequently, it can be used to develop cosmetic products (gels, creams, facial masks), animal feed supplements, human foods (flour substitutes, oxidation-prevention additives), health-related products (antitumor, anti-inflammatory, and antidiabetic formulations), and agricultural biostimulants, as well as materials such as biofilms, biofuels, and nanomaterials (Vaghela et al., 2022; Nunes et al., 2024). Despite its broad applicability and chemical diversity, no comprehensive patent analyses involving *K. alvarezii* have been reported to date. Therefore, this study aimed to examine patent applications filed over the past 22 years (2002–2024) related to the use of *K. alvarezii* in the development of novel biotechnological products across multiple industrial sectors. This work expands upon our previous research; unlike scientific articles, patents provide an industrial perspective on algal applications, highlighting commercial innovation and potential technological advancements.

Material and methods

Study design

A systematic patent review was conducted following PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses – PRISMA Statement Checklist;

Page et al., 2021). Data collection was performed using the Espacenet database (European Patent Office), which provides free access to more than 140 million patent documents from over 90 countries. A supplementary search in the World Intellectual Property Organization (WIPO) database (PATENTSCOPE) retrieved only eight patents, of which three were duplicates, yielding five unique results; due to the limited number of relevant records, this database was not included in the analysis.

In Espacenet, the descriptor "*Kappaphycus alvarezii*" was used as the sole keyword, applied across the entire document (title, abstract, and claims). A publication-year filter was set for patents published between 2002 and 2024, and only English-language documents were included. To maximize data retrieval and avoid overlooking pertinent patents, no filters related to International Patent Classification (IPC) or Cooperative Patent Classification (CPC) groups or subgroups were applied. As a result, all retrieved patents were screened in full.

Quality assessment

Two reviewers (A.N. and G.Z.A.) independently screened all patents to minimize selection bias. Subsequently, all documents were evaluated according to the established inclusion and exclusion criteria. Because no discrepancies arose between reviewers, a third evaluation round was unnecessary. The final mapping was completed on May 15, 2025.

Data extraction

All patents (n = 93) were compiled in a Microsoft Excel® (.xlsx) spreadsheet, including title, application number, applicant, publication year, International Patent Classification (IPC), country, and abstract.

Inclusion/exclusion criteria

Patents describing product development using *K. alvarezii* or its extracted metabolites as a principal ingredient or integral component were included. Patents addressing unrelated approaches were excluded. During the screening of the 93 identified patents, five focused on cultivation techniques or processes for *K. alvarezii*, seven described methodologies without presenting a product or industrial application, and eight were duplicates (Figure 1).

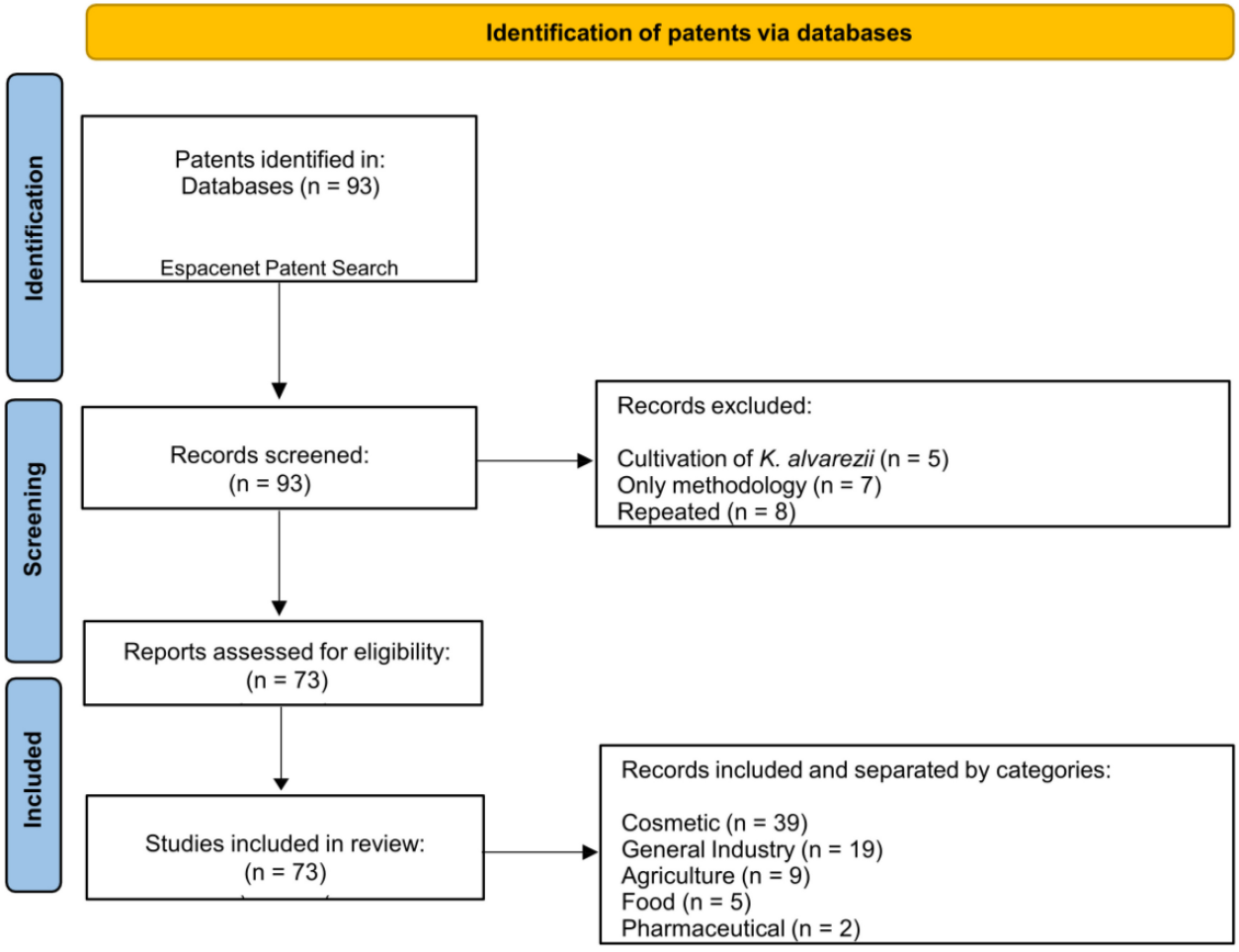


Figure 1. Flowchart based on the PRISMA model for the results of the patent search carried out in the Espacenet database (2002-2024), using the keyword "*Kappaphycus alvarezii*".

The remaining patents (n = 73) were categorized by industrial sector. Five distinct application areas were identified and classified quantitatively: cosmetics (n = 39), general industry (n = 19), agriculture (n = 9), food (n = 5), and pharmaceuticals (n = 2). One patent described two applications spanning agriculture and general industry; thus, the final categorization comprised 74 entries.

Results and discussion

Study selection and characteristics

Among the 73 eligible patents, the highest number of publications occurred in 2022 (n = 17), followed by 2021 (n = 9), 2023 (n = 8), and 2019 and 2020 (n = 6 each), representing 63% of all filings during the 20-year period analyzed (Figure 2). Overall, patent applications exhibited a gradual increase until 2022, likely reflecting growing research interest in the industrial potential of *K. alvarezii* and its metabolites (Nunes et al., 2024). Notably, only one application was registered in 2024.

Regarding country of origin, 30 patents were filed in China (41%) and 15 in the United States (20%). Additional filings occurred directly through WIPO (n = 12) and the European Patent Office (n = 4), without attribution to a specific country. Patents were also registered in Australia, Canada, the Czech Republic, Spain, the United Kingdom, Japan, and the Republic of Korea (Figure 3).

China's leading position is consistent with its technological output and expanding innovation landscape. The country has demonstrated rapid growth in patenting activity, with estimates indicating a 30% annual increase in applications between 1999 and 2009, largely stimulated by government patent subsidy programs (Dang & Motohashi, 2015). Within the algae sector, China is the world's largest producer, exerting substantial influence on global import and export markets. Consequently, a considerable proportion of industrial innovations derived from algae originates in China (Kang et al., 2023).

With respect to application sectors, the cosmetics industry represented the predominant category (n = 39), followed by general industry (n = 19), agriculture (n = 9), food (n = 5), and pharmaceuticals (n = 2). One patent addressed two areas (agriculture and general industry), resulting in a total of 74 classified applications (Figure 4).

Cosmetics

The cosmetics sector accounted for the largest number of patents (n = 39). These documents commonly describe formulations incorporating *K. alvarezii* either alone or in combination with other algal species, along with plant extracts and chemical constituents widely used in cosmetic manufacturing (Table 1). The primary applications included moisturizing/hydration (n = 10), anti-aging/anti-wrinkle (n = 7), tightening/firming (n = 5), microbiome balancing and improved makeup durability (n = 4), skin-brightening or clarity enhancement (n = 3), eye-area treatments (n = 3), hygiene (n = 2), reinforcement of the skin barrier (n = 2), prebiotic/probiotic activity (n = 1), hair-related applications (n = 1), and anti-allergy activity (n = 1).

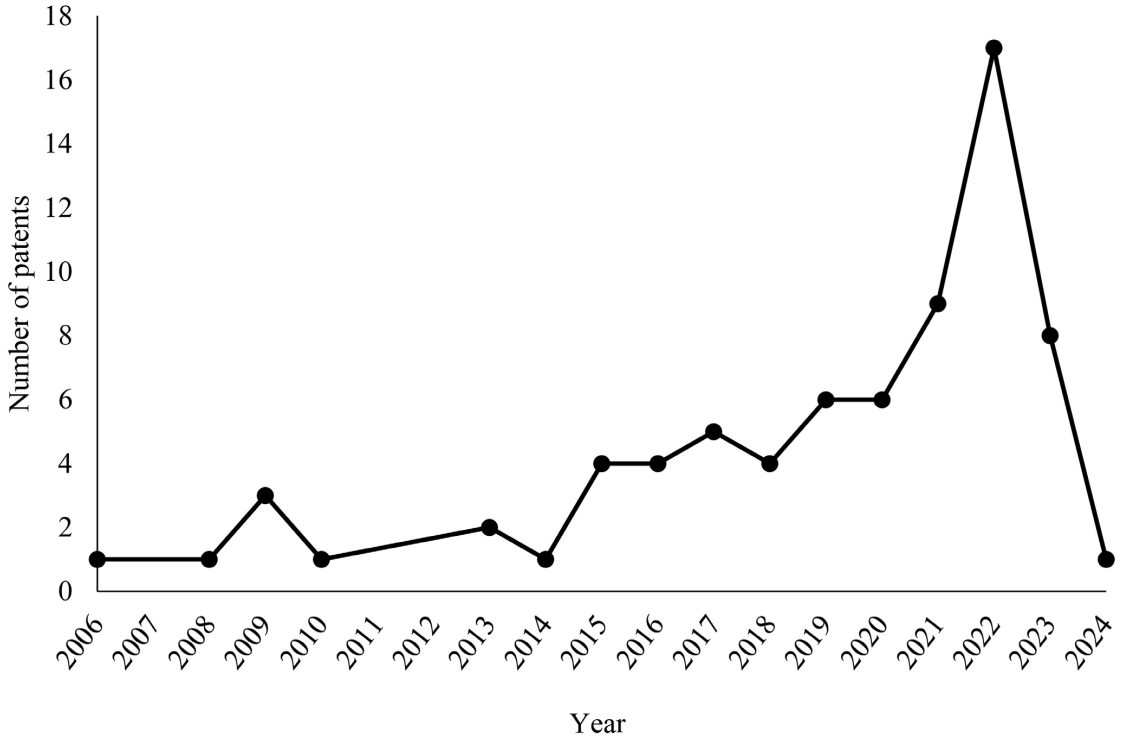


Figure 2. Number of patents published per year between 2002 and 2023 in the Espacenet database using the keyword *"Kappaphycus alvarezii"*.

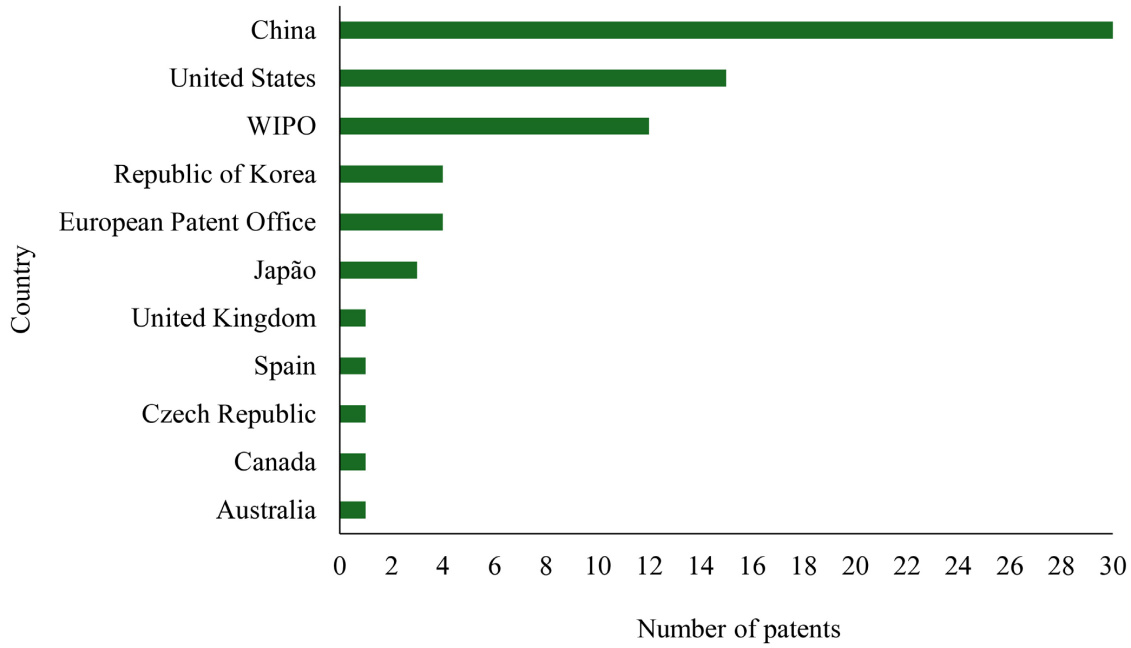


Figure 3. Countries in which patents using *Kappaphycus alvarezii* as raw material were filed between 2002 and 2022.

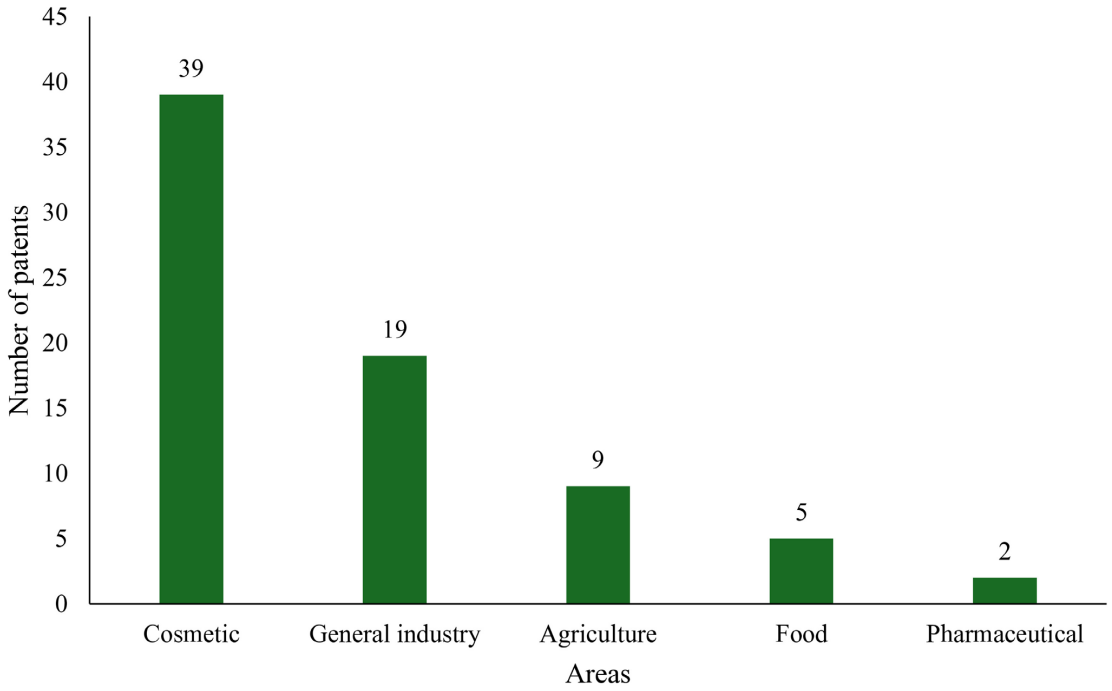


Figure 4. Areas of the industry in which patents using *Kappaphycus alvarezii* patents.

The patent "Water moisturizing cream and preparation method thereof" (Lui & Leng, 2016) described the development of a moisturizing effluent-type cream that produced superior hydration levels in volunteers compared with commercial moisturizers, leaving the skin refreshed without residual oiliness. The patent "Composition containing *Buddleja davidii* extract and application thereof" (Lui & Leng, 2017) introduced a moisturizer that improved skin barrier function and reduced transepidermal water loss in volunteer testing, with higher user acceptance relative to conventional products. In "Face cream composition containing lipid nanoparticles with moisturizing and hydrating effects and preparation method thereof" (Yang et al., 2022), the authors highlighted enhanced hydration of the stratum corneum in clinical evaluations. The formulation employed lipid nanoparticles for transdermal delivery, prolonging the release of functional ingredients and providing greater moisture retention than standard moisturizers.

Table 1. Patents published in the Espacenet database using *Kappaphycus alvarezii* as raw material for product development in the cosmetic sector (2002-2024).

Nº	Title and publication number	Action and main compounds	References
1	Combination of carrageenan and C-glycoside and uses thereof CN103906501A	Formulation of a composition containing carrageenan with at least one C-glycoside, which can be used for cosmetic treatment to improve the barrier function or biomechanical properties of the skin. Carrageenan can come from algae *Kappaphycus alvarezii, Eucheuma denticulatum, Eucheuma spinosum, Chondrus crispus, Betaphycus gelatinum, Gigartina skottsbergii, Gigartina canaliculata, Sarcothalia crispata, Mazzaella laminaroides, Hypnea musciformis, Mastocarpus stellatus* and *Iridaea cordata*	Potter et al. (2014)
2	Roe and royal jelly tightening eye care gel and preparation method thereof CN105640854A	Production of an eye care gel using oat seed protein, roe extract, PEG-80 sorbitan monolaurate, hydrolyzed royal jelly protein, *K. alvarezii* extract, *Laminaria ochroleuca* extract, hydrolyzed soy protein, *Ceratonia siliqua* seed, hexapeptide-9, 1,2-pentanediol, hydrolyzed yeast protein, turmeric root extract, glucosyl hesperidin and the like as raw materials	Jia et al. (2016)
3	Water moisturizing cream and preparation method thereof CN105769643A	Water-based moisturizing cream formulation prepared from cyclopentasiloxane, polydimethylsiloxane, cetyl PEG/PPG-10/1 polydimethylsiloxane, cross-linked cyclopentasiloxane/ polydimethylsiloxane polymer, essence, glycerol, butanediol, propylene glycol, panthenol, glycine betaine, sodium chloride, acrylic acid copolymer (ester)/beheneth-25 methacrylate, sodium hydroxide, sodium hyaluronate, daisy flower extract, *K. alvarezii* extract, Chlorella fermented product/white lupine protein, *Glycyrrhiza glabra* root extract, extract of *Bacopa monnieri*, biosaccharide gum, phenoxyethanol/ethylhexylglycerin, and deionized water	Lui & Leng (2016)
4	Composition containing *Buddleja davidii* extract and application thereof CN106491455A	Development of a nourishing and hydrating composition that stably locks the water content in the skin, increasing the cell self-hydration capacity, produced from *Buddleja davidii* extract and algae compound extract (*Undaria pinnatifida, Ascophyllum nodosum, Fucus vesiculosis, Codium tomentosum* and *K. alvarezii*)	Lui & Leng (2017)
5	Collagen skin firming lifting plumping glowing cream CN107233282A	Skin firming, plumping, and plumping collagen cream comprising red ginseng snail secret filter liquor, soluble collagen, hydrolysis collagen, atelocollagen, sodium hyaluronate, *Caesalpinia spinosa* fruit extracts/*K. alvarezii* extracts, nicotinamide, mica, hydrogenated phosphatidylcholine, lysophosphatidylcholine/Sclerotium gum/Xanthan gum/*Aureobasidium pullulans* polysaccharide, *Mentha piperita* extracts, hydroxyethyl acrylate/acryloyl dimethyl sodium taurocholate copolymers	Lui et al. (2017)
6	Composition with anti-aging function and application thereof to cosmetics CN106309236A	Composition with anti-aging function prepared from *K. alvarezii* extract, *Caesalpinia spinosa* fruit extract, hyaluronic acid coated by microcapsules, *X. bracteatum* extract, and water	Pan et al. (2017)
7	Kit and aesthetic system for prevention of skin aging WO2018139835A1	Kit and an aesthetic system for the prevention of skin aging that includes a telomerase activating composition (*Dendropanax morbifera* extract, *K. alvarezii* extract, or a mixture thereof as an active ingredient), a laser that irradiates the skin dermis, a composition for removing topical fat treatment including hyaluronidase and a laser that irradiates the muscle layer of the skin	Son (2018)
8	Cactus-essence-containing skin care product with deep maintenance effect CN107998024A	Product to promote deep and long-lasting hydration produced from Aloe *barbadensis* leaf juice, squalane, *Simmondsia chinensis* seed oil, *Portulaca oleracea*, rose extract, hydrolyzed oat protein, *K. alvarezii* extract, isononyl isononanoate, trehalose, betaine, nicotinamide, sodium hydroxymethyl beta-glucan, hydrolyzed sodium hyaluronate, allantoin and disodium EDTA	Xie (2018)

* The summary was adjusted with the most relevant information about the proposed inventions.

Table 1. Continued...

Nº	Title and publication number	Action and main compounds	References
9	Tensing and/or film-forming cosmetic agent consisting of galactomannans and cross-linked sulphated galactans US2019038543A1	Skin tightening and rejuvenating agent consisting of galactomannans obtained from *Caesalpinia spinosa* and sulfated galactans from carrageenans (from *K. alvarezii*, *K. striatum*, *Eucheuma cottonii*, *Eucheuma spinosum*, *Chondrus crispus*, *Gigartina skottsbergii*, *Sarcothalia crispata*), or from *Fucellaria fastigiata*, from agar (*Gelidium sesquipedale*) or from algae (*Polysiphonia lanosa* or *Codium fragile*)	Paufique (2019a)
10	Cosmetic agent formed by galactomannans obtained from *Caesalpinia spinosa* and cross-linked sulphated galactans obtained from *K. alvarezii* US10987297B2	Cosmetic or dermocosmetic agent to tighten the skin and/or form a film on the skin consisting of galactomannans obtained from *Caesalpinia spinose* and cross-linked sulfated galactans obtained from *K. alvarezii*	Paufique (2019b)
11	Cosmetic compositions for improving wrinkles and skin-lifting and their manufacturing method KR102022368B1	Cosmetic composition to improve skin elasticity and to reduce wrinkles (lifting) comprising biopolymers including extracts of *K. alvarezii*, *Caesalpinia spinosa* fruit, Blacus Lacquer *(Fucus vesiculosus*), *Prunella vulgaris* and *paracres* (*Spilanthes acmella*) and other plants	Han et al. (2019)
12	Bacteriostatic eye care eye patch CN109432234A	Bacteriostatic eye patch for eye care formed of a chitosan fiber layer and an alginate fiber layer. As ingredients it is expected to use: menthae herbal extracts, enzymolysis pearl liquid, nanometric silver colloidal solution, long-core *K. alvarezii* extracts, *Fucus serratus* extracts, saffron rubrans extracts, Sargassum fusiforme extracts, extracts of pomegranate seed, vitamin C, vitamin E, medlar extracts, green tea extracts, lutein, safflower extracts and hydroxyethyl cellulose	Zhang (2019)
13	Massage cream for deeply enabling skin to be compact CN109700731A	Massage cream to allow the skin to become compact in depth containing high fatty acid triglycerides, white mineral oil, avocado oil, phenoxyethanol, collagen hydrolysates, *K. alvarezii* extract, *Polygonati odorati* rhizoma extract, *Radix astragali* extract, of *Radix angelicae*, rhizoma bletillae extract, radix salviae miltiorrhizae, glycerol, sodium hyaluronate, xanthan gum and water	Ji (2019)
14	Eye tightening essence and preparation method thereof CN112022734A	Firming eye essence containing plant extract mix comprising *K. alvarezii* and *Caesalpinia spinosa* fruit and polypeptide blend (palmitoyl tripeptide-1 and palmitoyl tetrapeptide-7)	Cao et al. (2020)
15	Copper glycyl-histidyl-lysine repair essence and preparation method thereof CN111973481A	Skin repair essence composed of 1,3-propylene glycol, butanediol, lactic acid bacteria fermentation lysis blend, oat grain extraction blend, brown algae extraction blend, glycerin, hydrolyzed soy protein blend, a blend of *Syzygium luehmannii* fruit extract, a blend of mulberry root extract, 1,2-hexanediol hyaluronic acid, allantoin, *Centella asiatica* extract, p-hydroxyacetophenone, lotus flower extract, lactic acid, copper glycyl-histidyl-lysine, sunflower seeds, hydrolyzed sclerotium gum, sodium gluconate, *Achillea millefolium* extract blend, *Glycyrrhiza glabra*, acetyl hexapeptide-8, ascorbic acid, *K. alvarezii* extract, reed extract blend, Poria cocos extract blend, pentapeptide- 3 and disodium EDTA	Gong & Du (2020a)
16	Cosmetic composition comprising a *Caesalpinia spinosa* extract, a *K. alvarezii* extract, at least one prebiotic and a probiotic EP3727594A1	Cosmetic agent to maintain the balance of the skin microbiota and to promote and/or to improve the appearance of makeup comprising *Caesalpinia spinosa* extract, *Kappaphycus alvarezii* extract, with at least one pre-biotic and one probiotic	Dumas et al. (2020)
17	Composition for repairing skin barrier and improving sunscreen index, preparation method and application of composition CN111514073A	Composition for repairing the skin barrier and for improving the sun protection index from *K. alvarezii* extract/*Caesalpinia spinosa* fruit extract and a cross-linked polymer of hyaluronic acid or a cross-linked polymer of hyaluronate	Chen et al. (2020)

* The summary was adjusted with the most relevant information about the proposed inventions.

Table 1. Continued...

Nº	Title and publication number	Action and main compounds	References
18	Ceramide activating emulsion and preparation method thereof CN111973501A	Ceramide activating emulsion for skin deep nourishment composed of a mixture of ceramide, extracts of *Phyllacantha fibrosa*, *K. alvarezii*, *Caesalpinia spinosa* fruits, lysates of *Saccharomyces cerevisiae* fermentation product, octyl polymethylsiloxane, acetyl hexapeptide-8, sodium hyaluronate, and *Portulaca oleracea* extraction	Gong & Du (2020b)
19	Eye cream composition with under-eye puffiness removing effect and preparation method thereof CN113786361A	Eye cream with puffiness removal effect composed of *K. alvarezii* extract, tetradecyl aminobutyryl acid valinamide urea trifluoroacetate, dipeptide diaminobutyryl benzyl amide diacetate, and acetyl tetrapeptide-5	Yang et al. (2021)
20	Whitening composition and preparation method thereof CN112716853A	Whitening composition containing *Centellae* herb extract, alpha arbutin, ascorbic acid, nicotinamide, *K. alvarezii* extract, mangosteen extract, tea leaf extract, *Calendula officinalis* extract and *Scutellaria baicalensis* root extract	Yin (2021)
21	Whitening cosmetic containing *Leontopodium alpinum* extract CN112569146A	Whitening cosmetic consisting of squalene, paraffin, olive oil, isopropyl myristate, guar gum, *L. alpinum* extract, mulberry leaf extract, *K. alvarezii* extract and deionized water	Huang (2021)
22	Hair care and hair loss prevention composition and preparation method thereof CN112353713A	Product for hair care and hair loss prevention comprising 4 composition phases. A) water, disodium EDTA, and glycerin; B) glycerol and phenoxyethanol; C) *Undaria pinnatifida* extract, *K. alvarezii* extract, and sea water; D) citric acid and sodium citrate	Wang (2021)
23	3D bionic face-shaping mask CN113749961A	3D bionic facial modeling mask produced in 3 steps with the following components: 1) pure water and p-hydroxyacetophenone; 2) 1,3-propylene glycol, *K. alvarezii* extract and *C. spinosa* fruit extract; 3) malto-oligosaccharide glycoside, hydrogenated starch hydrolysate, algae extract and hexanediol	Wu et al. (2021)
24	Firming essence containing *Kappaphycus alvarezii* extract and preparation method of firming essence CN112472637A	Firming essence to repair skin, supplementing skin moisture and collagen, and increasing elasticity comprising *K. alvarezii* extract, p-hydroxyacetophenone, hexanediol, propylene glycol, glycerol, dipotassium glycyrrhizinate, disodium EDTA, panthenol, trehalose, carbomer, pH regulator, active ingredient firming agent, butanediol and water	Xu et al. (2021)
25	Skin care product with double-cabin structure CN113491653A	Skin care product containing water, glycerin, disodium EDTA sodium acrylate/sodium acryloyl dimethyl taurate copolymer, polysorbate-80, trehalose, isohexadecane, p-hydroxyacetophenone, 1,2-hexanediol, nicotinamide, *Myrtus communis* leaf extract, glycolipid, *Medicago sativa* extract, and *C. spinosa* fruit extract, *K. alvarezii* extract, and acetyl hexapeptide-8	Gao & Shi (2021)
26	Face-brightening and skin-beautifying cream and preparation method thereof CN111281840A	Skin lightening and beautifying cream composed of laurocapram, retinyl propionate, allantoin, potassium 4-methoxysalicylate, tranexamic acid, nicotinamide, glycerin, calcium pantothenate, xanthan, caprylyl glycol, urea, magnesium lactate, ethylhexylglycerin, potassium lactate, serine, alanine, proline, magnesium chloride, sodium citrate, butanediol, hydrolyzed European plum, peony root extract, medlar leaf extract, *Selaginella* extract, arborvitae leaf extract, cyclodextrin, glycolic acid, p-hydroxyacetophenone, papain, semen *Alpiniae katsumadai* extract, and *K. alvarezii* extract	Hong (2022a)
27	Anti-aging composition and anti-aging cosmetic containing same CN114259442A	Anti-aging composition comprising *Cordyceps sinensis* extract, palmitoyl hexapeptide-12, mulberry root extract, beta-alanyl hydroxyprolyl diaminobutyric acid benzylamine, beta-alanyl, *Chrysanthemum indicum* extract, peony root bark extract, ergothioneine, and *K. alvarezii* extract	Su et al. (2022)
28	Peel-off film-forming cosmetic composition US2022054400A1	Film-forming cosmetic composition where the hydrophilic gelling agent can be selected from polysaccharides of natural origin, such as shellac resin, sandarac gum, arabic gum, dammars, elemis, copals, cellulose polymers, extracted from the fruit of *Caesalpinia spinosa* and/or from the alga *K. alvarezii*, and mixtures thereof	Jamin et al. (2022)
29	Face cream composition containing lipid nanoparticles with moisturizing and hydrating effects and preparation method thereof CN113876642A	Facial cream containing lipid nanoparticles with moisturizing effects prepared from sialic acid, *K. alvarezii* extract, and nicotinamide	Yang et al. (2022)

* The summary was adjusted with the most relevant information about the proposed inventions.

Table 1. Continued...

Nº	Title and publication number	Action and main compounds	References
30	Moisturizing jade cream CN111150699A	Jade moisturizing cream containing emulsifying agents, emollients, humectants, antioxidants, and skin conditioners, wherein the skin conditioners include one or more of the following components: laurocapram, allantoin, potassium methoxyl salicylate, nicotinamide, [alpha]-arbutin, 3-o acid -ethyl ascorbic acid, honey extracts, propylene glycol, papain, calcium pantothenate, xanthan gum, 1, 2- octanediol, urea, magnesium lactate, ethylhexylglycerin, potassium lactate, serine, alanine, proline, magnesium chloride, magnesium citrate sodium, hydrolyzate of *Prunus domestica*, extracts of *K. alvarezii*, amomi globosi fructus seed extracts, *Paeonia suffruticosa* root extracts, *Folium eriobotryae* extracts, herba Selaginellae extracts, *Cacumen platycladi* extracts, and p-hydroxyacetophenone	Hong (2022b)
31	Oil-control lasting BB cream CN115245478A	Long-lasting oil-control cream comprising an oil absorbent, film-forming agent (*K. alvarezii* extract/*C. spinosa* fruit extract), emulsifying agent, thickening agent, and water	Xie (2022)
32	Makeup fixing spray and preparation method thereof CN115517983A	Makeup fixing spray containing deionized water, a skin conditioner (butylene glycol, allantoin, dipotassium glycyrrhizinate, tetrahydromethyl pyrimidine carboxylic acid, yeast bacteria/zinc ferment, *C. spinosa* fruit extract and *K. alvarezii* extract), a film-forming agent and an atomization improving agent	Wang et al. (2022)
33	Device and method for cleansing the skin and/or keratin fibers WO2022122676A1	Device for packaging and dispensing a composition for cleaning the skin and/or keratin fibers and/or mucous membranes and/or nails, comprising at least one mucopolysaccharide extracted from *Chondrus crispus* or *K. alvarezii*	Pruche & Tournier-Couturier (2022a)
34	Composition for cleansing keratin materials WO2022122674A1	Cosmetic composition for the care, hygiene and/or cleaning of keratinized materials containing carrageenan derived from *Chondrus crispus* or *K. alvarezii*	Pruche and Tournier-Couturier (2022b)
35	Nanofibrous cosmetic membrane containing natural active cosmetic substances CZ36883U1	Resorbable nanofibrous membrane to support skin quality containing hydrophilic aqueous extracts as natural active ingredients derived from various terrestrial and aquatic species, including *K. alvarezii*	Buzgo (2023)
36	Manufacturing method of anti-allergic and anti-red-hip wet tissue for babies CN116509731A	Method for manufacturing anti-allergic and anti-redness wet wipes for babies. The anti-allergic solution contains *K. alvarezii* polysaccharide, algal polysaccharide, glutathione, and sorbitol, providing the wipes with anti-allergic benefits	Chen et al. (2023)
37	Cosmetic composition comprising an extract of *Caesalpinia spinosa*, an extract of *Kappaphycus alvarezii*, and a theobroma cacao l bean hydrolysate US2023210751A1	Cosmetic composition to maintain the balance of the skin microbiota and to promote and/or to improve the durability of makeup consisting of galactomannans obtained by the hydrolysis of native galactomannans of *C. spinosa*, *Cyamopsis tetragonoloba*, *Ceratonia siliqua*, *Cassia angustifolia*, *Cassia fistula*, *Cassia obtusifolia* or *Cassia tora*, *Gleditsia sinensis*, *Gieditsia triacanthos*, *Sophora japonica* and/or *Trigonella foenum-graecum*, preferably *Caesalpinia spinosa* and cross-linked sulfated galactans obtained by hydrolysis of sulfated galactans native to carrageenans (*K. alvarezii*, *Kappaphycus striatum*, *Eucheuma cottonii*, *Eucheuma spinosum*, *Chondrus crispus*, *Gigartina skottsbergii*, *Sacrothalia crsipata*), or *Fucellaria fastigiata*, agar (*Gelidium sesquipedale*) or algae (*Polysiphonia lanosa* or *Codium fragile*), preferably *K. alvarezii*	Dumas et al. (2023)
38	Mask liquid composition with multiple effects as well as preparation method and application thereof CN117860647A	Multi-effect liquid composition for a mask, containing a skin conditioner and an auxiliary matrix. The conditioner includes allantoin, panthenol, a plant extract, and a biological fermentation product. The plant extract features tremella, bergamot, magnolia, white water lily, Crocus sativus, a *Caesalpinia spinosa*/*K. alvarezii* compound, ENNACOMPLEX 262, along with kudzu, *Rhizoma anemarrhenae*, and licorice	Ye et al. (2023)
39	Sensitive skin refreshing and repairing composition as well as preparation method and application thereof CN118948718A	The invention consists of a refreshing and repairing composition for sensitive skin, aimed at clothing and makeup, made from maqui fruit extract, *K. alvarezii* extract, quercetin-3-glucoside, *Kalimeris kwangtungensis* extract, and gellan gum	Zhang et al. (2024)

* The summary was adjusted with the most relevant information about the proposed inventions.

Finally, the invention "Moisturizing jade cream" (Hong, 2022b) reported increased inhibition of L-tyrosinase activity and elevated skin moisture levels in volunteers, without adverse effects on acne. Other selected patents addressing skin hydration did not report clinical trial data. For example, the "Cactus-essence-containing skin care product with deep maintenance effect" (Xie, 2018) described a formulation intended to deeply moisturize the skin, provide long-lasting hydration, reduce dryness and fine lines, and mitigate skin aging, ultimately enhancing skin smoothness. The invention "Copper glycyl-histidyl-lysine repair essence and preparation method thereof" (Gong & Du, 2020a) presented a moisturizer capable of deeply nourishing the skin while imparting a refreshing sensation. The "Skin care product with double-cabin structure" (Gao & Shi, 2021) outlined a product with moisturizing, repairing, and anti-wrinkle functions. The "Nanofibrous cosmetic membrane containing natural active cosmetic substances" (Buzgo, 2023) demonstrated potential moisturizing and anti-wrinkle activity, delayed skin aging, removal of UV-induced damage, enhancement of skin resistance, exfoliating action, and soothing effects on redness.

The patent "Sensitive skin refreshing and repairing composition as well as preparation method and application thereof" (Zhang et al., 2024) focused on a refreshing and repairing cosmetic formulation for sensitive skin comprising maqui berry extract, *K. alvarezii* extract, quercetin-3-glucoside, *Kalimeris kwangtungensis* extract, and gellan gum. According to the inventors, the composition is resistant to UV and blue-light damage and exhibits strong skin barrier-repairing activity. Hydration tests conducted with 25 volunteers indicated effective moisture retention after 10 hours of use. In a repair-performance trial with 30 volunteers with sensitive skin, significant improvements were observed, including the reduction of lactic-acid-induced redness.

The "Mask liquid composition with multiple effects as well as preparation method and application thereof" (Ye et al., 2023) described a multifunctional liquid mask formulation offering hydration, soothing, anti-aging activity, antioxidant effects, and whitening properties while remaining safe, mild, and non-irritating. The composition contains 1–10% of a skin-conditioning component and 90–99% of an auxiliary liquid matrix. The conditioner comprises allantoin, panthenol, a plant extract blend, and a biologically fermented product. The plant extract component includes tremella sporocarp, bergamot leaf, magnolia flower, white lotus flower, *Crocus sativus*, a composite extract of *Caesalpinia spinosa* and *K. alvarezii*, the sensitizer ENNACOMPLEX 262, and composite extracts of kudzu vine root, *Rhizoma anemarrhenae* root, *Sophora* flower buds, and licorice root. A whitening efficacy test involving 110 volunteers confirmed visible whitening after seven days of use. A calming test with 100 volunteers demonstrated strong soothing effects. In a wrinkle-reduction assessment with 100 women, continuous use decreased skin roughness and improved elasticity. Hydration tests with 100 volunteers showed that facial skin moisture remained above 45% six hours after application, indicating long-lasting hydration.

The patent "Anti-aging composition and anti-aging cosmetic containing same" (Su et al., 2022) reported wrinkle reduction in volunteers after seven days of treatment. In "Cosmetic compositions for improving wrinkles and skin-lifting and their manufacturing method" (Han et al., 2019), volunteer testing showed improvements in wrinkles around the eyes, nasolabial folds, glabella, and neck, along with increased hydration and elasticity, stimulation of collagen production, and inhibition of matrix metalloproteinase (MMP). The invention "Roe and royal jelly tightening eye care gel and preparation method thereof" (Jia et al., 2016) described a gel containing fish roe (caviar) and royal jelly with a firming effect around the eye area, with volunteer testing confirming effective tightening.

The patent "Composition with anti-aging function and application thereof to cosmetics" (Pan et al., 2017) demonstrated smoothing effects, wrinkle reduction, and increased skin elasticity in volunteers. The invention "Kit and aesthetic system for prevention of skin aging" (Son, 2018) proposed a telomerase-activating composition (derived from *Dendropanax morbifera* or *K. alvarezii* extract) combined with hyaluronidase and laser irradiation for localized fat removal and skin treatment. Volunteer testing indicated enhanced collagen stability, improved elasticity, reduced wrinkles, improved skin repair, increased hydration, smoother texture, and better pigmentation. The patent "Collagen skin firming lifting plumping glowing cream" (Lui et al., 2017) emphasized the cream's ability to reduce wrinkles, enhance collagen properties, supply nutrients to the skin, alleviate aging, improve elasticity, prevent the formation of fat granules, and maintain overall skin health, although no clinical trial data were provided. The invention "Ceramide activating emulsion and preparation method thereof" (Gong & Du, 2020b) described a rejuvenating milk formulation aimed at restoring moisture, increasing elasticity, reducing roughness, and counteracting sagging, but likewise did not report clinical evaluation.

The patent titled "Cosmetic agent formed by galactomannans obtained from *Caesalpinia spinosa* and cross-linked sulphated galactans obtained from *K. alvarezii*" (Paufique, 2019b) reports a tightening and/or film-forming effect on the skin. The inventors describe a firming agent produced from a combination of a terrestrial plant and a macroalga, which provided toned, firm, and soft skin with well-defined facial contours in volunteers. Conversely, the patent "Tensing and/or film-forming cosmetic agent consisting of galactomannans and cross-linked sulphated galactans" (Paufique, 2019a) proposes a cosmetic agent with a noticeable tensing effect and a "second skin" protective film with lifting properties; however, no volunteer tests were described. The patent "Firming essence containing *K. alvarezii* extract and preparation method of firming essence" (Xu et al., 2021) presents a product capable of rapidly tightening and lifting the superficial skin layer, with dermal penetration enabling tissue repair. Tests conducted on volunteers confirmed a skin-tightening effect. The "3D bionic face-shaping mask" (Wu et al., 2021) highlights the potential of a mask tested in a clinical trial to protect the skin from environmental particulates and deliver anti-wrinkle effects, increased brightness, and reduced pore visibility. The patent "Massage cream for deeply enabling skin to be compact" (Ji, 2019) reports a skin-firming effect, addressing the weak tightening performance of existing skincare products; however, no clinical tests were mentioned.

The patent "Cosmetic composition comprising an extract of *Caesalpinia spinosa*, an extract of *K. alvarezii*, and a *Theobroma cacao* bean hydrolysate" (Dumas et al., 2023) focuses on a product intended to balance the skin microbiota, particularly by enhancing microbial diversity. It aims to strengthen the skin barrier, improve structural integrity and resilience, and mitigate the effects of hypoxic or inflammatory conditions. It also targets the reduction of pore relaxation and the formation of imperfections, including wrinkles and fine lines, while promoting uniform makeup distribution. However, only cell-culture assays were reported, with no clinical testing.

The "Makeup fixing spray and preparation method thereof" (Wang et al., 2022) demonstrated, through clinical trials, the effectiveness of a spray for fixing makeup and forming a quick-drying film. The patent "Oil-control lasting BB cream" (Xie, 2022) reports volunteer testing of a cream designed to maintain makeup quality while providing oil control. The "Peel-off film-forming cosmetic composition" (Jamin et al., 2022) presents a peelable, film-forming composition for long-lasting makeup maintenance. Volunteer tests indicated that the product dried quickly and produced a uniform, flexible, and durable film.

The invention "Face-brightening and skin-beautifying cream and preparation method thereof" (Hong, 2022a) describes a cream developed to achieve whitening and enhance skin appearance. Tests conducted on the human face indicated increased skin vitality and improved hydration relative to controls. Two additional patents, "Whitening composition and preparation method thereof" (Yin, 2021) and "Whitening cosmetic containing *Leontopodium alpinum* extract" (Huang, 2021), propose formulations intended to reduce melanin content; however, only the former was tested on volunteers.

The patent "Eye cream composition with under-eye puffiness removing effect and preparation method thereof" (Yang et al., 2021) describes a multi-component cream for reducing under-eye puffiness, validated through volunteer testing. The patent "Eye tightening essence and preparation method thereof" (Cao et al., 2020) refers to a firming essence for the eye area, also validated on volunteers. In contrast, the patent "Bacteriostatic eye care eye patch" (Zhang, 2019) details a double-layer product (a base layer and a functional layer), but reports no human testing.

In the hygiene sector, the patent "Device and method for cleansing the skin and/or keratin fibers" (Pruche & Tournier-Couturier, 2022a) describes a packaging and dispensing device for a composition intended to cleanse the skin, keratin fibers, mucous membranes, and nails. Human testing confirmed its cleansing efficacy. A second patent, "Composition for cleansing keratin materials" (Pruche & Tournier-Couturier, 2022b), presents a formulation for the care, hygiene, and cleansing of facial and body skin and keratin fibers (hair and beard). Volunteer testing demonstrated effective cleaning performance and favorable sensory characteristics.

The patent "Combination of carrageenan and C-glycoside and uses thereof" (Potter et al., 2014) outlines cosmetic compositions developed to support high-quality skin barrier function and optimal biomechanical properties; however, no human testing was reported. Finally, the patent "Composition for repairing skin barrier and improving sunscreen index, preparation method and application of composition" (Chen et al., 2020) describes a formulation intended to repair the skin barrier and enhance the sunscreen index, with testing performed solely on a 3D human skin tissue model. Other patents targeted prebiotic/probiotic applications and hair-related effects. The granted patent titled "Cosmetic composition comprising a *Caesalpinia spinosa* extract, a *K. alvarezii* extract, at least one prebiotic and a probiotic" (Dumas et al., 2020) demonstrated improvements in skin barrier formation, maintenance of structural integrity, activation of the skin's resistance under hypoxic conditions, preservation of energetic homeostasis, enhanced resilience to stress, and protection against toxins. Tests were conducted on cells only. The findings indicated support for skin system maintenance and/or microbiota balance. The invention "Hair care and hair loss prevention composition and preparation method thereof" (Wang, 2021), validated through volunteer testing, describes a product with anti-hair-loss activity, improved wet and dry sensory perception, and increased hair strength.

A patent providing anti-allergic and anti-redness effects (Chen et al., 2023) concerns the manufacture of wet wipes specifically designed for infants' buttocks. Titled "Manufacturing method of anti-allergic and anti-red-hip wet tissue for babies," it describes a process in which a fabric is immersed in an anti-allergic solution. The fabric is produced by carboxylating viscose, reacting it with modified polyhydroxyl castor oil, and applying a spunlace process. The anti-allergic solution, containing *K. alvarezii* polysaccharide, glutathione, and sorbitol, imparts anti-allergic properties to the wipes. No clinical testing information was provided.

The cosmetics sector was the most prominent area, comprising 39 patents, consistent with the global trend toward eco-friendly product acceptance (Ali et al., 2022). In this highly competitive market, rapid changes necessitate constant updates to product portfolios to incorporate natural, safe, and effective ingredients. This trend similarly applies to cosmeceutical and nutricosmetic products, relatively recent market segments experiencing increasing demand. These products incorporate active ingredients capable of improving skin appearance and contributing to the prevention and treatment of dermatological conditions (López-Hortas et al., 2021). Within this sector, the development of anti-aging products was notable. Generally, these formulations involved combinations of seaweeds and were proposed in the form of masks (Thu et al., 2018) or creams (Janarthanan & Senthil Kumar, 2019). Additionally, the literature highlights the development of gels and hydrogels that leverage the gelling properties of carrageenan. The incorporation of active ingredients into these systems has demonstrated the potential to enhance skin exfoliation and reduce transepidermal water loss, providing immediate benefits (Melo & Campos, 2019). Such improvements were achieved by optimizing product stability, viscosity, dispersion, pH control, and reducing syneresis (Fransiska et al., 2021).

The review by Shafie et al. (2022) emphasizes that, in the cosmetics sector, the use of *K. alvarezii* is intrinsically linked to the properties of carrageenan. As a sustainable raw material for green cosmetic formulations, carrageenan can replace chemical ingredients commonly used in commercial products. This substitution is supported by its biological

activities, including antioxidant, anti-melanogenic, and anti-photoaging effects. Consequently, *K. alvarezii* represents not only a low-cost alternative to synthetic compounds but also a contributor to environmentally sustainable innovations.

General Industry

In the general industry sector, 19 patents were identified, one of which also appears under agriculture (US2013005009A1 – Table 2). Seven patents pertained to the fuel and energy sector, five to biofilms/bioplastics, four to general formulations, two to nanomaterials/polymers, and one to building materials (Table 2). Among the fuel/energy-related patents, the invention titled "Dye-sensitized solar cell containing photoautotroph producing dye" (Dasol, 2016) describes a method for fabricating a solar cell sensitized by a dye produced by a photoautotrophic organism (including *K. alvarezii*). This semiconductor device converts light directly into electrical energy via the photovoltaic effect. In this system, the solar cell incorporates a microorganism capable of producing the dye used for sensitization, enabling self-production. This innovation addresses limitations in electrical conversion efficiency, ensuring both improved efficiency and operational stability.

Table 2. Patents published in the Espacenet database using *Kappaphycus alvarezii* as raw material for product development in general industry (2002–2024).

Sector	Nº	Title and publication number	Aim of the invention	Year of publication
Fuel/Energy	1	Designer organisms for photosynthetic production of ethanol from carbon dioxide and water WO2008039450A2	Photosynthetic ethanol production based on engineered plants, algae, or transgenic plant cells. In this scenario, the endogenous mechanism that regulates photosynthesis was domesticated. Consequently, the reducing power (NADPH) and energy (ATP) obtained from the photosynthetic splitting of water and the electron transport process, coupled with the proton gradient, are utilized for the immediate synthesis of ethanol directly from carbon dioxide and water	Lee (2008)
	2	Designer organisms for photobiological butanol production from carbon dioxide and water CA2716364A1	A photobiological butanol production technology relying on engineered transgenic plants, algae, blue-green algae (cyanobacteria and oxychlorobacteria), or plant cells is proposed. Engineered photosynthetic organisms are created with a domesticated endogenous photobiological regulatory mechanism, and the reducing power (NADPH) and energy (ATP) acquired from the photosynthetic process are used for the synthesis of butanol directly from carbon dioxide and water	Lee (2009)
	3	Process for integrated production of ethanol and seaweed sap from *Kappaphycus alvarezii* US2013005009A1	A process for the integrated production of biofertilizer and ethanol from *K. alvarezii* was invented. Sap released was used to obtain a biofertilizer and the residual biomass, rich in carrageenan, was used to obtain ethanol	Mody et al. (2013)
	4	Designer photoautotrophic and hydrogenotrophic production of alcohols and biodiesel US2015353961A1	The invention discloses hydrogenotrophic biofuel production pathways directed by the Calvin cycle in engineered autotrophic organisms, such as oxyphotobacteria and transgenic algae. It outlines the associated designer genes and transgenic organisms designed for the autotrophic production of alcohols and biodiesel from carbon dioxide, hydrogen, and/or water. The alcohols encompass methanol, ethanol, propanol, 1-butanol, 2-methyl-1-butanol, isobutanol, 3-methyl-1-butanol, 1-hexanol, 1-octanol, 1-pentanol, 1-heptanol, 3-methyl-1-pentanol, 4-methyl-1-hexanol, 5-methyl-1-heptanol, 4-methyl-1-pentanol, 5-methyl-1-hexanol, and 6-methyl-1-heptanol	Lee (2015)
	5	Process for improved seaweed biomass conversion for fuel intermediates, agricultural nutrients and fresh water US9452993B2	An integrated process for the production of 5-hydroxymethylfurfural (HMF), potassium sulfate, levulinic acid, and formic acid from κ-carrageenan extracted from *K. alvarezii* is proposed. This process specifically addresses enhanced conversion of *K. alvarezii* granules obtained after the extraction of fresh seaweed sap into fuel intermediates, agricultural nutrients (fertilizers), and freshwater	Ghosh et al. (2015)

* The summary was adjusted with the most relevant information about the proposed inventions.

Table 2. Continued...

Sector	Nº	Title and publication number	Aim of the invention	Year of publication
Fuel/Energy	6	Dye-sensitized solar cell containing photoautotroph producing dye KR102255296B1	A method for manufacturing a dye-sensitized solar cell is proposed. The dye is derived from photoautotrophic organisms, enabling the stable and efficient generation of electricity. This is achieved through the self-production of dyes, sensitized by the solar cell itself	Dasol (2016)
	7	Autotrophic production of alcohols and biodiesel using self-flocculation EP3133163A1	The invention discloses hydrogenotrophic biofuel production pathways directed by the Calvin cycle in engineered autotrophic organisms, such as oxyphotobacteria and transgenic algae. It outlines the associated designer genes and transgenic organisms designed for the autotrophic production of alcohols and biodiesel from carbon dioxide, hydrogen, and/or water. The alcohols encompass methanol, ethanol, propanol, 1-butanol, 2-methyl-1-butanol, isobutanol, 3-methyl-1-butanol, 1-hexanol, 1-octanol, 1-pentanol, 1-heptanol, 3-methyl-1-pentanol, 4-methyl-1-hexanol, 5-methyl-1-heptanol, 4-methyl-1-pentanol, 5-methyl-1-hexanol, and 6-methyl-1-heptanol	Lee (2017)
Biofilm/ bioplastic	1	Process of preparation of biodegradable films from semi refined kappa carrageenan AU2004325362A1	Semi-refined kappa carrageenan extracted from *K. alvarezii*, known for its cost-effectiveness, is employed for the preparation of durable and biodegradable films. Notably, the material offers the advantage of being recyclable	Bhattacharya et al. (2006)
	2	Bioplastic composition, bioplastic product including the same and relative production process WO2022167933A1	The proposed process involves the production of a bioplastic material with low environmental impact and eco-sustainability. The bioplastic is developed directly from biological materials or microorganisms, or through classical chemical synthesis using renewable monomers	Fedeli (2022)
	3	Composite, process for preparing the composite, and implementation thereof US2022204730A1	The process involves the creation of a composite material, including at least one type of algae or algal extract, at least one ammonium salt, and at least one component chosen from an oleophilic component or an amphiphilic component. This biodegradable composite is versatile and can be shaped into various forms, with a particular emphasis on film and bioplastic production	Ayyakkalai et al. (2022)
	4	New single-use packaging US2025033851A1	The development of plastic packaging involves encapsulating liquids within a membrane that includes an extract derived from marine algae or a cellulose polymer. This innovative approach aims to enhance the functionality and sustainability of packaging materials	Paslier & Gonzalez (2022)
	5	Algal composite WO2024124291A1	The invention relates to a bioplastic composition that includes biomass from algae or algae-derived materials, specifically *K. alvarezii* and *Eucheuma denticulatum*	Krishnan et al. (2023)

* The summary was adjusted with the most relevant information about the proposed inventions.

Table 2. Continued...

Sector	Nº	Title and publication number	Aim of the invention	Year of publication
General formulations	1	Use of natural antioxidants during enzymatic hydrolysis of aquatic protein to obtain high quality aquatic protein hydrolysates US2015274791A1	Addresses the utilization of natural antioxidants extracted from seaweed to inhibit oxidations in enzymatic hydrolysis process of aquatic proteins derived from fish, aquatic mammals, crustaceans, and/or mollusks. The objective is to obtain high-quality aquatic protein hydrolysates with desirable biological activity. These hydrolysates find application in the development of various products, including food products, food supplements, pet food, animal feed, fish feed, fertilizers, pharmaceutical preparations, medicines and/or cosmetics	Halldorsdottir et al. (2015)
	2	Incorporation of water-soluble component(s) into anhydrous formulations WO2015164657A1	A method for incorporating a water-soluble component into a relatively hydrophobic and/or anhydrous formulation was developed. This involves a formulation of an emulsifying agent designed to encapsulate a hydrophilic compound, forming reverse micelles for the inclusion of hydrophilic compound or compounds in the hydrophobic and/or anhydrous formulation. This approach can be applied for the formulation of pharmaceutical or cosmetic productse	Burnison & Stahl (2015)
	3	Formulations of hydrophilic compounds EP3265177A1	A formulation comprising a continuous hydrophobic phase, a hydrophilic phase, at least one hydrophilic compound substantially dissolved in the hydrophilic phase and a stabilizing component was developed. This formulation finds application in pharmaceutical and cosmetic areas, among others, owing to the stability of incorporated biologically active compounds.	Burnison et al. (2018)
	4	Seaweed-based powder CN111818811A	The invention involves the preparation of a seaweed-based powder with improved functionality and exhibiting excellent rheology. The formulation finds various industrial applications, including foods, beverages, nutraceutical products, dietary supplements, feed, personal care, pharmaceuticals, and industrial uses	Agoda-Tandjaw et al. (2020)
Nanomaterials/ polymers	1	Process for the production of graphene sheets with tunable functionalities from seaweed promoted by deep eutectic solvents US10549997B2	The invention refers to a process for the scalable production of graphene nanosheets doped with Fe_3O_4/Fe, Sn, and Zn from naturally abundant seaweed resources, such as *Sargassum tenerrimum*, *S. wighti*, *Ulva faciata*, *U. lactuca*, and *K. alvarezii*	Prasad et al. (2018)
	2	Super absorbent polymer fiber yarn comprising kappa carrageenan and producing method thereof KR102259576B1	The invention describes a method for producing a superabsorbent polymer fiber yarn made from natural substances, which is environmentally friendly and harmless to the human body, and can be widely applied to sanitary products, medicine, and agriculture. The method involves a spinning solution made with a raw material containing a kappa-carrageenan component (extracted from *K. alvarezii*) in a cross-linking solution	Shim et al. (2019)
Building Material	1	Use of carrageenan as a viscosity-modifying admixture in a flowable cementitious suspensions WO2022104469A1	The invention proposes the use of carrageenan as a viscosity-modifying mixture in a fluid cementitious suspension, which can be used as mortar and/or mortar for a self-leveling floor, crack injection or anchor seal, or a self-consolidating fluid cementitious suspension, such as fluid concrete	Yahia et al. (2022)

* The summary was adjusted with the most relevant information about the proposed inventions.

The patent "Autotrophic production of alcohols and biodiesel using self-flocculation" (Lee, 2017) emphasizes the potential of engineered transgenic plants, including transgenic algae, cyanobacteria, oxychlorobacteria, plant cells, or bacterial cells, to produce biofuels. These organisms use reducing power (NADPH), hydrogen (H_2), and energy (ATP) derived from photosynthetic and/or hydrogenotrophic processes for the autotrophic synthesis of alcohols and biodiesel from carbon dioxide and water. The same inventor is credited with several related patents, including "Designer photoautotrophic and hydrogenotrophic production of alcohols and biodiesel" (Lee, 2015), describing an invention from 2011 and another from 2017. Additionally, two other patents by this inventor focus on ethanol and carbon dioxide production ("Designer organisms for photosynthetic production of ethanol from carbon dioxide and water" - Lee, 2008) and butanol and carbon dioxide production ("Designer organisms for photobiological butanol production from carbon dioxide and water" - Lee, 2009). In all cases, the underlying principle is consistent: engineered transgenic plants (e.g., algae) or plant cells are modified to produce biomolecules by exploiting photosynthesis-regulation transgenes encoding enzymes that convert an intermediate of the Calvin cycle into ethanol, butanol, and carbon dioxide, without forming glucose, starch, or other complex materials.

The patent "Process for improved seaweed biomass conversion for fuel intermediates, agricultural nutrients, and fresh water" (Ghosh et al., 2015) described an enhanced process using *K. alvarezii* granules – obtained after extracting fresh seaweed sap – to improve the production of fuel intermediates, agricultural nutrients (fertilizers), and freshwater. This process enabled the sustainable and integrated production of hydroxymethylfurfural, potassium sulfate, and a combined levulinic acid/formic acid fraction. Additionally, the patent "Process for integrated production of ethanol and seaweed sap from *K. alvarezii*," previously discussed in the agricultural sector, introduced an integrated approach for producing ethanol and sap for agricultural use. For ethanol production, after carrageenan extraction from the macroalgae, the residual granules served as a carbohydrate-rich sugar source (Mody et al., 2013).

Regarding patents related to the development of biofilms/bioplastics, the invention "Process of preparation of biodegradable films from semi-refined kappa carrageenan" (Bhattacharya et al., 2006) reported a biodegradable film produced from semi-refined κ-carrageenan extracted from *K. alvarezii*, described as environmentally friendly. The patent titled "Bioplastic composition, bioplastic product including the same, and relative production process" (Fedeli, 2022) also describes a low-impact, eco-sustainable process for producing bioplastic materials from seaweed extracts, such as *Rhodophyta gracilaria*, *R. gelidiaceae*, *K. alvarezii*, *Mastocarpus stellatus*, and *Chondrus crispus*. These algae are rich in gelling substances, including agar and carrageenan, enabling bioplastic production.

In "Composite, process for preparing the composite and implementation thereof" (Ayyakkalai et al., 2022), a biodegradable composite was developed comprising at least one seaweed, an ammonium salt, an oleophilic component, and an amphiphilic component. This composite can be molded into various formats, including films, thermoformed inserts, laminates, banners, packaging materials, trash bags, and shopping bags. In "New single-use packaging" (Paslier & Gonzalez, 2022), membranes composed of seaweed extracts or cellulose polymers were developed to encapsulate liquids, providing an economically and environmentally sustainable alternative for the food and cosmetics industries. The patent "Algal composite" (Krishnan et al., 2023) further describes plastic compositions incorporating algal biomass or algae-derived materials. The selected species – *K. alvarezii* and *Eucheuma denticulatum* – are notable for their sulfated polysaccharides, carrageenan and ulvan, respectively.

Regarding patents in the "general formulations" category, the invention "Formulations of hydrophilic compounds" (Burnison et al., 2018) described a topical formulation containing at least one hydrophilic compound within a continuous hydrophobic phase or phases and a hydrophilic phase. The formulation has applications in the cosmetic and pharmaceutical sectors due to the abundance of biologically active compounds in algal matrices. The same inventors developed "Incorporation of water-soluble component(s) into anhydrous formulations" (Burnison & Stahl, 2015), which applies the same principle to create topical compositions (e.g., pharmaceutical or cosmetic) by incorporating water-soluble components into relatively hydrophobic and/or anhydrous formulations. Both patents cite the possibility of using *K. alvarezii* extract and galactans as hydrophilic components.

The patent "Use of natural antioxidants during enzymatic hydrolysis of aquatic protein to obtain high-quality aquatic protein hydrolysates" (Halldorsdottir et al., 2015) proposed a solution to oxidation during the hydrolysis of aquatic proteins. Natural antioxidants from marine algae extracts can inhibit oxidation processes during hydrolysis, increasing the bioactivity of the final products and reducing bitterness. Among the antioxidants mentioned is seaweed extract from *K. alvarezii*.

The patent "Seaweed-based powder" (Agoda-Tandjaw et al., 2020) described a seaweed-derived powder suitable for use in foods, beverages, nutritional products, dietary supplements, feed, personal care products, pharmaceutical formulations, and industrial applications. The powder facilitates the preparation of gels with excellent rheological and textural properties, expands product development possibilities, and enhances health-related characteristics. The powder is also claimed to improve gel formation with minimal effects on other product attributes and is suggested to contribute to the management of conditions such as obesity, dyslipidemia, hypertension, and diabetes. Its dispersion in personal care formulations improves the appearance of products and promotes optimal distribution of active substances to hair and skin.

Concerning patents focused on nanomaterials/polymers, "Process for the production of graphene sheets with tunable functionalities from seaweed promoted by deep eutectic solvents" (Prasad et al., 2018) describes an improved process for producing functionalized graphene nanosheets from fresh seaweeds. The granular biomass of algae, such as *K. alvarezii*, is used to generate graphene via pyrolysis in the presence of eutectic solvents under an inert atmosphere, following the extraction of liquid fertilizer for agricultural use. The patent "Super absorbent polymer fiber yarn comprising kappa carrageenan and producing method thereof" (Shim et al., 2019) highlights the development of a superabsorbent polymer fiber yarn produced from κ-carrageenan extracted from *K. alvarezii*.

This polymer can absorb moisture hundreds of times its weight and is intended mainly for hygiene products such as baby diapers, feminine hygiene items, and adult diapers. Additional applications include cold-storage and heat-retention packaging, moisture retention agents, soil modifiers, and food packaging materials.

In the field of building materials, the ungranted patent "Use of carrageenan as a viscosity-modifying admixture in flowable cementitious suspensions" (Yahia et al., 2022) proposed the use of carrageenan as a viscosity-modifying additive in fluid cementitious systems, including self-compacting concrete. Because seaweed possesses substantial quantities of cell-wall polysaccharides, these biomolecules can be exploited as biopolymers. *K. alvarezii* may contain more than 50% κ-carrageenan by weight; accordingly, its incorporation into cementitious formulations enhanced both plastic viscosity and yield stress in cement pastes, producing values twice as high as those of the reference mixture.

In the general industrial sector, our review on the application of *K. alvarezii* in product development (Nunes et al., 2024), based on literature published between 2017 and 2023, identified several patent-active areas. A total of 14 publications were associated with the biofilms/bioplastics/biopolymers sector, 13 with fuel/energy, 7 with nanomaterials, 3 with civil/forestry engineering, 3 with biorefinery, 2 with environmental applications, and 2 with renewable materials and biosolvents. Among these, the development of biofilms/bioplastics/biopolymers and fuel/energy was particularly prominent. Masarin et al. (2016) demonstrated the feasibility of glucose production from carrageenan residues, indicating that a *K. alvarezii* biorefinery could be fully exploited to simultaneously generate bioplastics and biofuels. In addition to being recognized as the primary industrial source of carrageenan, *K. alvarezii* has also been reported to exhibit high carbohydrate content. Hessami et al. (2018), evaluating twenty-nine tropical algal species collected in Malaysia, found that *K. alvarezii* yielded the highest levels of total carbohydrates (71.22%) and total reducing sugars (34.12%). Fermentation of these sugars by *Saccharomyces cerevisiae* produced 20.90 $g \cdot L^{-1}$ of bioethanol.

Agriculture

In the agricultural sector, nine patents were published between 2002 and 2024: four addressing applications as biofertilizers/fertilizers, four describing biostimulants/stimulants, and one focusing on a gel-based product (Table 3).

Regarding patents describing biofertilizers/fertilizers, the invention "Process for integrated production of ethanol and seaweed sap from *K. alvarezii*" (Mody et al., 2013) claimed an integrated system for producing ethanol and sap from harvested fresh seaweed. The inventors described the use of electrodialysis to process wastes containing potassium sulfate and sodium sulfate, in combination with calcium sulfate generated during neutralization, as well as residual materials obtained after ethanol distillation, to formulate a fertilizer. However, no greenhouse or field trials were reported to validate the agricultural efficacy of the product, as the patent primarily focused on ethanol-production steps, aligned with the general industry.

In the biofertilizer category, the patent "Seaweed extract-coated fertilizer for better crops and soil health" (Hegde et al., 2021) described a fertilizer coated with extracts from *K. alvarezii*, *Ascophyllum nodosum*, *Ecklonia maxima*, *Durvillea potatorum*, *Macrocystis pyrifera*, *Sargassum* spp., and/or *Laminaria digitata*. Agronomic tests conducted on cucumber crops compared treatments using urea coated with seaweed and/or seaweed extracts to an uncoated urea control. In general, seaweed-coated urea resulted in higher cucumber yields.

The patent "Method for the manufacture of a solid, particulate fertilizer composition comprising an additive" (van Belzen & Colpaert, 2022) described the production of a solid, particulate fertilizer formulated with a primary nutrient, an additive, and/or a micronutrient. The additive consisted of a seaweed extract selected from *K. alvarezii*, *A. nodosum*, *E. maxima*, *D. potatorum*, *M. pyrifera*, *Laminaria digitata*, *Sargassum* spp., or their mixtures. No field evaluations were reported.

The invention "Aqueous composition comprising seaweed" (Ward et al., 2023) described a formulation containing phosphorus, boron, and seaweed extracts (from *K. alvarezii*, *A. nodosum*, *E. maxima*, *D. potatorum*, *M. pyrifera*, *L. digitata*, *Sargassum* spp., or their mixtures). In tests on strawberry plants, application of 2 $L \cdot ha^{-1}$ of the solution containing 50 $g \cdot L^{-1}$ of seaweed extract resulted in significant increases in flower number after 30 days, fruit number after 60 days, and boron content in both fruits and sprouts. The active US patent "A biostimulant formulation for improving plant growth and uses thereof" (Nori et al., 2017) addressed a biostimulant composed of a juice (extract) or hydrolysate obtained from the pulp of one or more seaweed species. The formulation included *Kappaphycus striatus*, *K. alvarezii* (*Eucheuma cottonii*), *Eucheuma denticulatum*, *Halymenia durvillaea*, *Chondrus crispus*, *Halymenia durvillei*, *Porphyra purpurea*, *Euchuema isifonne*, *Hypnea musciformis*, *Solieria filiformis*, *Mastocarpus stellatus*, *Porphyra capensis*, *Gracillaria* sp., or combinations thereof. Validation tests demonstrated increased root length in maize seedlings treated with seaweed juice (SWJ) or seaweed pulp hydrolysate (SWO), particularly when both were applied in combination. Positive effects were also observed on horse gram sprout length, cotyledon expansion in cucumber, and rice grain yield.

The patent "Gibberellic acid (GA_3)-free *K. alvarezii* sap and its application thereof" (Ghosh et al., 2016) describes a GA_3-free sap extracted from *K. alvarezii* that functions as a biostimulant in mung bean seeds. Following treatment, the inventors reported increased α-amylase activity during germination. Additionally, positive regulation of disease-responsive genes (PR-3 and PR-5) was observed in tomato plants. Spraying trials conducted on maize plants resulted in yield improvements of 25.8% (first dry season), 35.3% (post-rainy season), and 35.2% (second dry season).

The patent "Bio-stimulant formulation from *K. alvarezii* and *Caulerpa* sp." (Ghosh et al., 2023) describes a biostimulant composed of *K. alvarezii* and *Caulerpa* sp., containing nitrogen, phosphorus, potassium, sodium, sulfur, aluminum, copper, iron, manganese, zinc, calcium, magnesium, total phenolics, total proteins, and total lipids. According to the inventors, this formulation provides a balanced nutrient profile capable of enhancing plant growth, increasing stress tolerance, and improving overall crop health.

Table 3. Patents published in the Espacenet database using *Kappaphycus alvarezii* as raw material for product development in the agricultural sector (2002-2024).

Nº	Title and publication number	Action and main compounds	References
1	Process for integrated production of ethanol and seaweed sap from *Kappaphycus alvarezii* US2013005009A1	A process for the integrated production of biofertilizer and ethanol from *K. alvarezii* was invented. Sap released was used to obtain a biofertilizer and the residual biomass, rich in carrageenan, was used to obtain ethanol	Mody et al. (2013)
2	Gel medium for cultivating plant and method of cultivating plant JP2013111024A	The production of a gel medium containing iota-type carrageenan for plant cultivation, including seed sowing, was proposed	Terada & Aihara (2013)
3	Gibberellic acid (GA3) free *K. alvarezii* Sap and its application thereof US2016060183A1	A product formulated from *K. alvarezii* sap, free of gibberellic acid (GA3), was proposed as a plant stimulant and for increasing the yield and quality of various crops	Ghosh et al. (2016)
4	A biostimulant formulation for improving plant growth and uses thereof US10358391B2	A biostimulant formulation obtained from the juice or hydrolyzate of the pulp of different algae (*K. striatus, Eucheuma cottonii, Eucheuma denticulatum, Halymenia durvillaea, K. alvarezii, Chondrus crispus, Halymenia durvillei, Porphyra purpurea, Eucheuma denticulatum, Euchuema isiforme, Hypnea musciformis, Solieria fihiformis, Mastocarpus stellatus, Porphyra capensis, Gracillaria* sp.), used separately and in combinations, was proposed	Nori et al. (2017)
5	Seaweed extracts coated fertilizer for better crops and soil health US2021323885A1	A urea-based fertilizer, or an inorganic fertilizer containing one or more nitrogen, phosphorus or potassium, coated with seaweed and/or seaweed extract (*K. alvarezii, Ascophyllum nodosum, Ecklonia maxima, Durvillea potatorum, Macrocystis pyrifera, Sargassum* spp., and/or *Laminaria digitate*) was proposed	Hegde et al. (2021)
6	Method for the manufacture of a solid, particulate fertilizer composition comprising an additive EP4293000A1	The fabrication of a solid, granular fertilizer composition is described, comprising a primary nutrient and an additive (*K. alvarezii*, *Ascophyllum nodosum*, *Ecklonia maxima*, *Durvillea potatorum*, *Macrocystis pyrifera*, *Sargassum*, *Laminaria digitata*, and mixtures thereof), a biostimulant and/or a micronutrient to enhance plant growth	van Belzen & Colpaert (2022)
7	Method for producing plant biostimulant from marine plants US2024298650A1	The production of a plant biostimulant is described, derived from seaweed (*Agardhiella tenera*, *K. alvarezii*, *Eucheuma spinosum*, *Chondrus crispus*, and *Gracilaria* sp.). This biostimulant is organic and non-toxic, promoting growth and revitalizing plants	Abdul-Akbar (2023)
8	Bio-stimulant formulation from *Kappaphycus alvarezii* and *Caulerpa* sp. WO2024194894A1	The biostimulant was formulated using *K. alvarezii* and *Caulerpa* sp. When applied as a foliar spray, it can enhance the productivity of various crops	Ghosh et al. (2023)
9	Aqueous composition comprising seaweed GB2608994A	An aqueous composition comprising phosphorus, boron, and seaweed separately or in the mixture (*K. alvarezii, Ascophyllum nodosum, Ecklonia maxima, Durvillea potatorum, Macrocystis pyrifera, sargassum, Laminaria digitata*) was proposed as fertilizer	Ward et al. (2023)

* The summary was adjusted with the most relevant information about the proposed inventions.

The patent *"Method for producing plant biostimulant from marine plants"* (Abdul-Akbar, 2023) proposes the use of *Agardhiella tenera*, *K. alvarezii*, *Eucheuma spinosum*, *Chondrus crispus*, and *Gracilaria* sp. to produce a biostimulant intended to improve crop productivity, fruit production, flower initiation, and plant biomass.

The Japanese patent "Gel medium for cultivating plant and method of cultivating plant" (Terada & Aihara, 2013), which remains active, describes the use of a gel culture medium for agricultural production. The gel is based on iota-carrageenan from *Eucheuma denticulatum* or kappa-carrageenan from *K. alvarezii* and exhibits antibacterial properties. However, the gel alone did not yield satisfactory results for plant growth (cilantro, clover, red shiso, bok choy, komatsuna, and leek), requiring supplementation with minerals such as iron.

Studies evaluating commercial products corroborate several claims reported in patents involving *K. alvarezii* or its derivatives. These products are often blended with other algae and with micro- and macronutrients to enhance plant growth and improve agronomic performance. Karthikeyan & Shanmugam (2014) demonstrated the effectiveness of a *K. alvarezii*-based foliar product in increasing fruit weight and nutritional content in four banana cultivars. Similarly, Kumar et al. (2020) and Shukla et al. (2023) reported that commercial *K. alvarezii* biostimulants promoted cotyledon expansion in cucumber, affected amylase activity, and modulated the expression of genes associated with auxin and cytokinin metabolism, thereby influencing cell division and expansion. Biostimulants have also improved general plant physiological responses. In the study by Kumar et al. (2020), transcriptomic analyses of maize roots revealed differential expression of genes related to nitrogen metabolism, root development, seed formation, grain yield, and drought tolerance following treatment.

Food

Five patents were identified in the food sector, two published in 2009 and three in 2022 (Table 4).

Table 4. Patents published in the Espacenet database that use *Kappaphycus alvarezii* as raw material for developing products in the food sector (2002-2024).

Nº	Title and publication number	Action and main compounds	Year of publication
1	A method for the preparation of refreshing drink and use thereof KR101396812B1	The production of a nutritional, tasty, and affordable drink made from *K. alvarezii* sap was proposed. The process includes the refining of the sap and the preparation of a palatable drink, in addition to providing an adequate shelf life	Ghosh et al. (2009)
2	Processed food having tropical *Kappaphycus alvarezii* as raw material, and method for producing the same JP2009089671A	A Method for the preparation of processed food products obtained from fresh, frozen, or dried *K. alvarezii* biomass mixed with vinegar, sake lees, or bran pickle was proposed	Ono et al. (2009)
3	A stabilizer composition comprising microcrystalline cellulose WO2022159807A1	A stabilizing composition comprising colloidal microcrystalline cellulose co-processed with unrefined and unmodified red algae flour (*K., Eucheurna, Gigartma, Chondrus, Iriadae, Mazzaella, Mastocarpus, Sarcothalia.e Hipnéia, Ftircellaria, Gracilaria, Gelidium, Gelidiella. Pterocladia, Haiymenia e Chondracan*), that can be used as a stabilizer for edible products, was proposed	Anankanbil et al. (2022)
4	Food ingredient WO2022079114A1	A food ingredient (called flour) obtained from seaweed of the class Rhodophyta (*Euchema striatum, Kappaphycus striatus, Euchema alvarezii,* and *K. alvarezii*), separately or in combination, which can be used in different mixtures, was proposed	van der Zaal et al. (2022)
5	Plant based gelling fibre, method and application thereof US2022007701A1	The method for the production of an antioxidant-rich gelling fiber from red seaweed (*Kappaphycus striatus, Eucheuma cottonii, Eucheuma denticulatum, Halymenia durvillaea, K. alvarezii, Chondrus crispus, Solieria chordalis, Porphyra purpurea, Euchuema isiforme, Hypnea musciformis, Solieria filiformis, Mastocarpus stellatus, Mastocarpus papillatus, Porphyra capensis, Gelidium amansii, Furcerllaria* spp., *Gigartina* spp, *Gracillaria* spp., *Iridea* spp., *Anatheca* spp., *Meristotheca* spp., *Ahnfeltia* spp. *Gynmogongrus* spp. *Phyllophora* spp., and combinations) with gelling and/or thickening properties, which can be used in food industry, was proposed	Giri et al. (2022)

* The summary was adjusted with the most relevant information about the proposed inventions.

The patent *"A method for the preparation of refreshing drink and use thereof"* (Ghosh et al., 2009) describes the use of sap extracted from *K. alvarezii* to produce a refreshing, palatable, and nutritious beverage containing proteins, carbohydrates, fibers, iodine, and metals such as iron, manganese, and zinc. Although the method includes the use of activated charcoal or carbon filtration to remove fishy odor and the addition of flavors (e.g., lime, herbs, spices, carbon dioxide) to improve taste, no sensory evaluation was reported.

The patent "Processed food having tropical *K. alvarezii* as raw material, and method for producing the same" (Ono et al., 2009) addresses the development of a processed food product incorporating *K. alvarezii*, which contains a high dietary fiber content. The seaweed may be cut and consumed directly or after further processing. The method includes the preparation of fresh, frozen, or dried raw materials and the incorporation of additional seaweeds or vegetables to adjust flavor and color. Techniques for room-temperature preservation, such as vinegar marination, were also described. The text emphasized the novelty of the seaweed as a food ingredient in Japan and suggested potential for establishing a new food industry, although no sensory analyses were included.

The patent "A stabilizer composition comprising microcrystalline cellulose" (Anankanbil et al., 2022) describes a stabilizer consisting of colloidal microcrystalline cellulose co-processed with flour from unrefined and unmodified red algae containing high kappa- and low iota-carrageenan (25–70% and 10% dry weight, respectively). The flour may be derived from species of *Kappaphycus*, *Eucheuma*, *Gigartina*, *Chondrus*, *Iriadae*, *Mazzaella*, *Mastocarpus*, *Sarcothalia*, *Hypnea*, *Ftircellaria*, *Gracilaria*, *Gelidium*, *Gelidiella*, *Pterocladia*, *Halymenia*, and *Chondracanthus*. Applications tested included use as a stabilizer in pasteurized flavored chocolate milk and vanilla-flavored coffee cream.

The patent "Food ingredient" (Zaal et al., 2022) describes an ingredient containing carrageenan extracted from seaweeds of the class *Rhodophyta* (genera *Kappaphycus*, *Eucheuma*, *Gigartina*, *Chondrus*, *Iriadae*, *Mazzaella*, *Mastocarpus*, *Sarcothalia*, *Hypnea*, *Furcellaria*, *Gracilaria*, *Gelidium*, *Gelidiella*, *Pterocladia*, *Halymenia*, and *Chondracanthus*). The product is intended to enhance the stability of foods by replacing other additives. It is also proposed as a texturizing agent for products such as soy beverages, plant-based desserts, gelatin-free mousse, and meat-alternative protein systems, including plant-based sausages.

The patent "Plant based gelling fiber, method and application thereof" (Giri et al., 2022) concerns the extraction, processing, and preservation of an antioxidant-rich gelling fiber (polysaccharide) derived from red seaweeds (*K. striatus*, *K. alvarezii*, *E. denticulatum*, *H. durvillaea*, *C. crispus*, *S. chordalis*, *P. purpurea*, *E. isiforme*, *H. musciformis*, *S. filiformis*, *M. stellatus*, *M. papillatus*, *P. capensis*, *G. amansii*, *Furcerllaria* spp., *Gigartina* spp., *Gracillaria* spp., *Iridea* spp., *Anatheca* spp., *Meristotheca* spp., *Ahnfeltia* spp., *Gynmogongrus* spp., *Phyllophora* spp., and combinations thereof). The resulting fiber exhibited superior gelling and/or thickening properties relative to fibers obtained from fresh, unprocessed seaweed, while retaining the natural antioxidant characteristics of the fresh biomass. Functionality was validated in cocoa suspension for chocolate-milk applications.

The use of *K. alvarezii* is predominantly linked to the gelling and thickening properties of carrageenan's. Its incorporation into food products dates back to the 1970s and has been widely exploited for textural modification in dairy products, jellies, and processed meats. In dairy systems, one of its principal applications is the prevention of phase separation; a 2% carrageenan concentration can yield yogurt with no visible syneresis for extended periods. In jellies, studies have shown that 1.5% (w/v) carrageenan enhances hardness, chewiness, and cohesiveness, while reducing syneresis compared with gelatin-based formulations. In meat products, *K. alvarezii* is used for gel formation and moisture retention, which is particularly important in low-fat formulations. This application reduces hardness and increases juiciness, significantly affecting sensory attributes. Additionally, several products have undergone evaluation following the incorporation of *K. alvarezii*, including bread (Munandar et al., 2019), pasta (Hasanah et al., 2021), and muffins (Mamat et al., 2018), where seaweed flour was used to enhance nutritional value. The seaweed has also been incorporated into sausages (Pindi et al., 2017) and sardines (Chaula et al., 2019) to reduce water loss and mitigate lipid oxidation.

Pharmaceutical

In the pharmaceutical sector, only two patents were identified, one published in 2010 and the other in 2021 (Table 5). The patent "A composition for wound healing" (Suhaila et al., 2010) presents a formulation that improves wound healing, tissue repair, and cardiovascular protection. It is specifically aimed at accelerating healing in individuals with impaired recovery processes, such as diabetic patients. The invention proposes the use of plants from the genus *Ipomoea* or the family *Arecaceae*, or optionally seaweeds, individually or in combination. The algal species considered include *E. cottonii*, *K. alvarezii*, *C. lentillifera*, and *S. polycystum*. Efficacy tests were conducted on diabetic male Sprague–Dawley rats. The patent "Sugar chain-binding polypeptide, a polynucleotide encoding the same and pharmaceutical composition containing the same" (Hori et al., 2021) describes a pharmaceutical composition for the treatment or diagnosis of viral diseases. The active component is a sugar chain-binding polypeptide engineered to exhibit higher binding affinity than natural lectins. The improved sugar-binding properties derive from the KAA1 lectin of *K. alvarezii*, consisting of four repeats of a 67-amino-acid domain. One experiment demonstrated SARS-CoV-2 inactivation following treatment with KAA1, as the lectin binds to the sugar moieties present on the viral surface. There is a clear disparity between the number of scientific publications and the number of deposited patents concerning *K. alvarezii* applications. In our review (Nunes et al., 2024), we identified 26 publications in the pharmaceutical field between 2017 and 2023. These included six studies on cancer prevention and treatment using *K. alvarezii* extracts, five on antidiabetic potential, three on effects on the nervous system, three on antioxidant and anti-inflammatory activity, two on cyclooxygenase inhibition, two on antiviral properties, two on cell adhesion and tissue development, one on antifungal activity, one on oral-health promotion, and at least one on metabolic-syndrome prevention. This broad academic exploration contrasts with the limited number of patents.

Table 5. Patents published in the Espacenet database that use *Kappaphycus alvarezii* as raw material for product development in the pharmaceutical sector (2002-2024).

Nº	Title and publication number	Action and main compounds	Year of publication
1	A composition for wound healing WO2010039024A1	A composition that can be orally administered and/or topically applied to improve wound healing, tissue repair, and protection of cardiovascular health, comprising an extract of vegetative parts of *Ipomoea*, *Arecaceae* plant family, and/or seaweed (*Eucheuma cottonii, K. alvarezii, Caulerpa lentillifera, Sargassum polycystum*, and combinations) was proposed.	Suhaila et al. (2010)
2	Sugar chain-binding polypeptide, polynucleotide encoding the same and pharmaceutical composition containing the same JP2021013375A	The invention dealt with a sugar chain-binding polypeptide (modified lectin) from the alga *K. alvarezii*, which can be used as an agent for the treatment and diagnosis of various viral diseases	Hori et al. (2021)

* The summary was adjusted with the most relevant information about the proposed inventions.

Even considering a 20-year span, patents represent only 8% of the number of scientific papers in the pharmaceutical domain, underscoring the need for greater translation of academic research into patentable innovations – potentially constrained by the lengthy development timelines required for new therapeutics.

Gaps and perspectives

The analysis of patents involving the red seaweed *K. alvarezii* revealed several gaps and promising directions for future research and innovation. A predominant trend in scientific publications is the use of *K. alvarezii* in combination with other seaweeds – particularly red algae – for novel industrial applications. Many research groups have explored algal biochemical diversity and shown increasing interest in combining different species to enhance product performance. Such approaches generate promising solutions for multiple industrial sectors. Blended seaweed formulations can yield products with improved sensory attributes, enhanced nutritional profiles, and specific functional properties relevant to the food and cosmetics industries (Del Mondo et al., 2021; López-Hortas et al., 2021). These combinations may also offer more robust and adaptable solutions compared with single-species products. Despite these advantages, there remains a limited number of patents focused exclusively on *K. alvarezii*, indicating an untapped opportunity for targeted research on the unique characteristics and applications of this species.

Another noteworthy gap concerns the lack of robust clinical trials within cosmetic-related patents. Despite the substantial number of patents in the cosmetics sector, the absence of comprehensive clinical studies represents a critical limitation. Rigorous clinical assessments are essential to substantiate claims of efficacy and safety (Antignac et al., 2011). The lack of clinical validation for seaweed-based cosmetic formulations limits product credibility and market acceptance, highlighting the urgent need for investments in clinical research to establish a scientific foundation for the safety and efficacy of *K. alvarezii*-derived cosmetic products. Addressing this gap requires comprehensive and interdisciplinary research efforts, not only to support the development of new formulations but also to verify their performance through clinical testing.

Moreover, given the wide range of benefits attributed to seaweed-based products, it is essential to address potential adverse effects associated with their use. A major concern in food, cosmetic, and agricultural applications involves chemical contamination of raw materials, as seaweeds can bioaccumulate heavy metals and pesticides in polluted coastal environments, and they are frequently used for bioremediation of marine pollution (Agarwal et al., 2022; Sundhar et al., 2023). *K. alvarezii* also exhibits strong bioaccumulation capacity, although this is not permanent; adequate washing can render it safe for consumption (Tresnati et al., 2021). Sundhar et al. (2023) similarly demonstrated that thermal processing can significantly reduce pesticide concentrations, ensuring product safety when consumption remains within regulatory limits. Additionally, *K. alvarezii* contributes to carbon capture, aligning with the principles of the "blue economy." Carbon-emitting industries could potentially use *K. alvarezii* cultivation to generate carbon credits, contributing to climate-change mitigation (Bhushan et al., 2023; Firman et al., 2023). The biomass can also be fully utilized, including in agriculture, while residual fractions can serve as substrates in various biotechnological processes. This complete-use approach aligns with circular bioeconomy principles (Sudhakar et al., 2024; Trivedi et al., 2023; Nunes et al., 2024).

A key factor supporting the development of *K. alvarezii*-based products is its broad availability. Large-scale cultivation already occurs in Malaysia, Fiji, Vietnam, Tanzania, South Africa, and China, supported by the species' adaptability to diverse climatic conditions (Liu et al., 2019). Small-scale cultivation systems are also viable for maintaining stable prices for shellfish farmers and industry stakeholders. In India, for example, *in situ* cultivation and internal purchasing systems have reduced market fluctuations. Controlled cultivation monitoring is also feasible, particularly with regard to temperature regulation and disease control (Zuniga-Jara & Marin-Riffo, 2016). Therefore, expanding *K. alvarezii* cultivation to ensure a steady supply of raw material appears feasible. Nonetheless, despite the identification of more than 70 patents, it remains evident that the translation of scientific research into commercial products lags considerably behind academic output.

An analysis of biotechnological developments based on *K. alvarezii*, considering scientific publications from 2017–2023, identified 152 studies across various sectors: cosmetics (n = 5), animal nutrition (n = 12), human food (n = 20), health/medicine (n = 33), agriculture (n = 34), and general industry (n = 48) (Nunes et al., 2024). These findings demonstrate substantial research activity and highlight the species' versatility. However, this large body of academic work has not resulted in a proportional number of patent filings, revealing a significant gap between research output and commercialization. While academia has developed numerous potential applications, this innovation is not adequately reflected in the patent landscape. Strengthening collaboration between academia and industry could help bridge this gap by facilitating the transfer of research into market-ready technologies and products (Awasthy et al., 2020).

It should be noted that one of the limitations that may have contributed to the lower number of patents compared to scientific publications is the exclusive focus on patents available in English. This approach may exclude relevant innovations documented in other languages. However, English was chosen because it is the primary interface language of the Espacenet platform. Moreover, each country maintains a national patent system, and these platforms are not always interconnected with international databases such as Espacenet, which was used in this study. Therefore, while this limitation reflects global patenting trends, it may not fully capture the breadth of innovation occurring worldwide.

Another factor influencing the slow progression of patented innovations into the consumer market is the need for more efficient regulatory structures. For instance, in Brazil, no patent applications for *K. alvarezii* have been recorded, likely linked to current restrictions on algal cultivation and commercialization (Brasil, 2020). Additionally, Brazil's patent approval process is considerably lengthy, taking up to 10.8 years, compared to 2.4 years in the United States, 3.0 years in Europe, and 1.95 years in Japan (Garcez Júnior & Moreira, 2017). Streamlining patent evaluation processes is essential to facilitate a more rapid transition from innovation to market deployment. Regulatory frameworks could also be strengthened through market incentives such as eco-certifications and green chemistry programs, which encourage the development of sustainable technologies. These incentives not only enhance consumer confidence but also align with global trends favoring environmentally responsible solutions, potentially fostering an increase in patent filings.

Globally, there is an urgent need for increased investment and incentive structures to support research and development in *K. alvarezii* and other sustainable bioresources. Coordinated actions are essential to overcome existing challenges and promote seamless integration of *K. alvarezii* derivatives into commercial markets. Advancing interdisciplinary strategies that combine biotechnology, business development, and regulatory expertise will be key to addressing commercialization barriers. As the biotechnological landscape evolves, adopting an integrated approach may significantly enhance the technological and economic potential of *K. alvarezii*, contributing to sustainability and growth across multiple industrial sectors.

Conclusion

This study demonstrates a growing number of patent applications over the past five years related to the use of *K. alvarezii* as a raw material for biotechnological products. The cosmetics sector is particularly prominent, accounting for 53% of all applications, with a significant proportion originating from China. The general industry sector – comprising fuel and energy technologies, biofilms/bioplastics, general formulations, nanomaterials/polymers, and building materials – also shows substantial activity, representing 26% of patent filings. By contrast, agriculture, food, and pharmaceuticals require further advances, especially when compared with academic publications that highlight the abundance of bioactive compounds and physicochemical properties of industrial relevance. Finally, the broad adaptability of *K. alvarezii* to diverse environmental conditions facilitates its cultivation in multiple countries, strengthening its value as a versatile raw material. The utilization of *K. alvarezii* emerges as a sustainable and ecologically viable alternative for biotechnological innovation across a wide range of industrial sectors.

Conflict of interests

The authors declare no conflicts of interest.

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