Agriculture & Food Security

RESEARCH

Open Access

An analysis of the current and potential market opportunities for hempseed and fibre: the case of Scotland?

Wisdom Dogbe[1*], Cesar Revoredo-Giha[2] and Wendy Russell[1]

Abstract

Background The growing demand for eco-friendly food and industrial products have renewed interest in industrial hemp which is a low-cost, biodegradable, sustainable, and multi-purpose plant. Many countries in Europe and Asia have changed their laws to take advantage of the tremendous benefits that industrial hemp present. However, the development of the sector in Scotland is very slow due to stringent laws. The goal of the present study is to present policymakers with economic data on the current and potential market opportunities for industrial hemp, trends in new product development, and the state of the hemp supply chain. This study entails desk-based research primary and secondary data analysis. Primary data were collected from farmers in Aberdeenshire and Scottish borders, and secondary data were collected from the FAOSTATS Office of National Statistics and the Global New Product Database.

Results The results of this study show that the opportunities from hemp seed and fibre are vast: hemp can sequester more carbon dioxide than traditional crops can, improve soil biodiversity, extract toxins from soil through phytoremediation, be used as an eco-friendly insecticide and pesticide, and provide an excellent source of protein, fibre and micronutrient vitamins and minerals, as well as a range of bioactive phytochemicals. The GNPD reveals that over 4000 hemp-based products have been launched worldwide. However, the supply chain for Scottish-grown hemp faces significant bottlenecks. The sector lacks a well-established market route, faces a high licensing costs, lacks hemp seed-pressing centres, etc.

Conclusion This study is relevant because it is the first study to provide a comprehensive analysis of the industrial hemp sector in Scotland. This study makes time-bound recommendations to grow the hemp sector in Scotland, which include regular extension services, easy access to licences for production, the establishment of a hempseed and fibre processing plants, and seed production centre.

Keywords Industrial hemp, Supply chain, Carbon sequestration, GNPD, Scotland

*Correspondence:
Wisdom Dogbe
wisdom.dogbe@abdn.ac.uk
[1] Rowett Institute, University of Aberdeen, Foresterhill, Aberdeen AB25 2ZD, UK
[2] Scotland's Rural College (SRUC), Peter Wilson Building, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK

Introduction

Hemp is one of the world's oldest economic plants. It was developed from wild cannabis plants. Although there is still some uncertainty about the plant's origin, it is believed to have originated in Central Asia more than 3000 years ago [20]. From Central Asia, the plant was transported throughout East Asia, South Asia and Europe.

Industrial hemp (*Cannabis sativa L.*) is different from *sunn hemp, water hemp, hemp sesbania* and *hemp dogbane*, but it is in the same family and species as marijuana. The main difference is based on the concentration of delta-9-tetrahydrocannabinol (Δ^9 THC) in both species. By law, the threshold of Δ^9 THC in industrial hemp is 0.2% on a dry weight basis for the UK [47], whereas in the US, the threshold is pegged at 0.3% Δ^9 THC on a dry weight basis [5].

Before 1000 BC and until the late 1800s, cannabis was used to produce a myriad of necessities, such as cordage, cloth, lighting oil and medicine. Industrial hemp is notable for producing strong and durable natural fibres; it is also used for the manufacturing of fine cloth, rope, twine, canvas and sacking [20].

Hemp was first introduced to the British Isles through European Celts and Picts. Its presence in the UK has been traced back to 343 BC [43]. Hemp was mandated in the British Isles, and as far back as 1175, it was listed as a commodity subject to tithe by the council of Westminster [68]. In the late 1500 s, Thomas Fella suggested sowing hemp for use as fibre and food, as well as for its medicinal properties and oil. This led to the growth of the hemp industry in Britain. To meet the domestic demand for sailclothing and cordage, hemp was imported from Baltic states and Italy, which supplied the finest grades. In 1781, the British government granted a bounty for hemp and flax to encourage farmers to grow it. The production of hemp was encouraged not only in Britain, but also in British colonies. In Britain, Lincolnshire, Norfolk, Suffolk, Dorset and Kent are the main growing counties due to the high demand and profitability of hemp production [43].

In Scotland, hemp cultivation has been documented as far back as the eleventh century [118]. The evidence suggests the cultivation of hemp in Scottish regions such as Dumfriesshire [99] in the eighteenth century, as well as in Lewis [70], Islay [100] and Galloway (Kirk Session Minutes, 1724). According to Whittington and Edwards [118], surrogate evidence such as place names suggests the cultivation of hemp in the following areas in Scotland: “Hemphill (Kilmarnock parish, Ayrshire), Hempland (Torthorwald, Dumfriesshire), Hempriggs (Wick, Caithness) and Hempy Shot (Oldhamstocks, East Lothian). The earliest occurrences traced include Hempbuttis (from 1556 in Auchtermuchty, Fife), Hempriggis (from 1571 in Alves, Morayshire), Hempisfield (from 1642 in Plenderleith, Roxburghshire) and Hempshaugh (from 1663 in Selkirk).”

Industrial hemp was widely used in the UK until the twentieth century, when synthetic fibres, cheap and abundant jute and cotton made hemp uncompetitive (H. M. G. [27]). The decline in the industrial use of hemp was gradually replaced with the misuse of hemp as a psychoactive agent. This resulted in European and North American countries banning the cultivation of cannabis [26]. In 1928, an act was passed that ultimately prohibited hemp cultivation in the UK [67].

Despite the decline in the area allocated to hemp production from 403,000 ha in 1984 to 74,000 ha in 2003, hemp has become attractive for sustainable fibre production [46]. Hemp has the potential to improve soil structure [28] and suppress weed growth and disease resistant [26]. van der Werf [118] concluded that hemp is the ideal crop for sustainable farming systems. Hemp fibre can replace cotton fibre, which relies heavily on irrigation, fertiliser and pesticide use [88]. In addition, the use of hemp fibre as an insulation material is a sustainable alternative for constructing eco-friendly buildings.

Nutritionally, hemp is one of the most useful gluten-free and high-protein crops with little or no impact on the environment [121]. In addition, almost every part of the crop has economic value: fibre, medicine, construction and food. As such, there is a growing demand for products containing industrial hemp ingredients [121], and the launch/relaunch of products containing hemp ingredients has increased exponentially.

The growing demand for sustainable products has renewed interest in hemp as a new low-cost, sustainable, ecological, biodegradable, recyclable, and multi-purpose material [38, 40, 61, 94]. Many countries in Europe and North America have passed legislation allowing commercial cultivation of industrial hemp with low levels of THC [57]. According to [23], more than 30 countries currently grow industrial hemp as an agricultural commodity. The most influential subsectors in the hemp sector are beverage and food, fibre (paper and textiles), and beauty and personal care items. Globally, food is estimated at 4837 billion dollars [35, 36], textiles are valued at 1587 billion dollars [106], and beauty and personal care items are valued at 503 billion dollars [35]. [23] also reported that there are more than 25,000 industrial hemp products in 9 main submarkets, including textiles, agriculture, automotive, food and beverages, paper, furniture, construction, recycling, and personal care. In 2017, hemp-based products contributed over 600 million dollars to the U.S. economy, more than 4 times the value of the soft fruit sector in Scotland.

Despite the growing market for industrial hemp and its products, commercial production of industrial hemp in Scotland does not exist. Previous studies have studied the cultivation and use of hemp [97, 119], palynological evidence or historical evidence on the cultivation of hemp [34, 43, 95], the re-introduction of industrial hemp, as an arable [120]. However, to the best of our knowledge no study has examined the viability and potential market contribution of industrial hemp in Scotland using both farm survey data and the Global New Products Database (GNPD). Moreover, none of the studies carried out detailed literature review on the economic and environmental benefits of industrial hemp. This is the first study mapping the supply chain profile for both hempseed and fibre in Scotland; analysing the trends in new product development using hemp as an ingredient; and delving deep into the potential market opportunities to support the development of hemp production in Scotland.

This will contribute substantially to the discussion on the need to revamp the industrial hemp subsector in Scotland. First, the study provides detailed comprehensive market analysis highlighting the market potential for industrial hemp in various sectors, including human food, animal feed, composites, furniture, insecticides, pesticides, cosmetology, biofuels, building materials, paper, and textiles. This broad scope highlights the versatility and economic potential of hemp. Second, the study provides a detailed SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) specific to the Scottish hemp sector. This helps to identify the unique challenges and advantages within the local context, offering tailored strategies for growth. Third, the study maps out the supply chain for hempseed and fibre in Scotland, from growers to consumers. This mapping provides a clear understanding of the current infrastructure and identifies gaps and opportunities for improvement. Fourth, the study emphasises the environmental benefits of hemp cultivation, such as carbon sequestration and soil health improvement. This positions hemp as a key player in sustainable agriculture and climate change mitigation. Finally, this is the first report offering strong, time-bound recommendations to advance the Scottish hemp sector, including the relaxation of restrictions on hemp cultivation, development of a strong processing sector, and establishment of a Scottish seed production centre. These recommendations are aimed at fostering a robust and competitive hemp industry in Scotland.

Literature review

This section aims to summarise, collate and synthesise results from existing research on the production and consumption of hemp fibre and seeds worldwide. This desk research[1] gathered online data from published and grey literature as well as government-published data such as FAOSTATS, EUROSTATS and HMRC data. The literature search included studies on the trends, economic value, uses, cost and returns for hempseed and hemp fibre cultivation in the UK and elsewhere. The market potential of industrial hemp in Scotland is a critical consideration in assessing the long-term feasibility of developing the domestic industry. Every part of a hemp plant can be used, with different end-uses making the plant unique [90]. Industrial benefits from hemp can be derived from (1) flowers and leaves; (2) stems or stalks; and (3) seeds.

Human food

Hempseed is beneficial for both animals and humans. Hemp seeds contain approximately 320–380 g/kg of oil [49]. Research has shown that the use of hempseed in food products, beverages, or nutritional supplements is gradually becoming more important, especially in countries such as Canada, the US, France, Germany and the UK [17, 23, 87, 117]. The hemp seed is also a good source of protein. Research shows that 2–3 tablespoons of hemp seeds can supply approximately 11 g of protein [90]. Other studies suggest that hemp seeds contain 20–25% proteins of biological value equivalent to a hen's egg [75], 25–35% lipids, 20–30% carbohydrates and 10–15% insoluble fibres and minerals such as phosphorus, potassium, sodium, magnesium, sulfur, calcium, iron and zinc [17, 25]. They also contain essential amino acids such as methionine, lysine and cysteine [29]. The seed flour is devoid of gluten and does not contain allergens, making it a useful bakery product for people with celiac diseases [59].

The growing interest in the nutritional value of hemp seed can be attributed to increasing the valorisation of agri-food products, the search for new sources of protein and the production of bioproducts, concerns about food allergies, animal welfare issues associated with animal-derived proteins, and a focus on a better environment [87]. For example, studies by Multari et al. [80] and Neacsu et al. [82] showed that hemp is a valuable source of dietary amino acids, beneficially modulating gastrointestinal hormones and promoting satiety in healthy volunteers. In the UK, Good Hemp is the leading producer of hemp-based foods and beverages. Hemp products sold in the UK include hemp oil, hemp milk, and shampoo. According to Crini et al. [23], hemp seed oil is the most expensive product from hemp seeds whilst animal feed made from whole seeds is the least expensive.

Animal feed

In agriculture, hemp crops can be used as: (1) mulch and animal bedding; (2) eco-friendly insecticides/herbicides;

[1] The search focused on articles published in English only. The authors used various combinations of the terms "industrial hemp", "cannabis plant", "market potential", "hempseed", "hemp fibre", "uses of industrial hemp" and "economics of hemp" (and closely related variants of these terms). The searches were not limited to academic journals but also "grey literature" such as government reports, newspaper articles and market research reports. The main search trawl used to solicit literature was Google Scholar, as well as key government reports such as those from Defra.

(3) biofertilisers; and (4) animal feed or bird seeds. For the latter, hemp is a good source of animal feedstuff. The hemp seeds contain approximately 30% protein, 25% starch and 30% oil. The pressed seed produces oil that contains more than 90% polyunsaturated fatty acids [23, 42]. Four main products can be derived from the hemp plant for animal feedstuffs: hemp seed cake/meal, hemp seed oil, hemp seed and the whole plant. Seeds and seed cake can be used as feedstuffs for all types of animal species [13].

Hempseed is also used in aquaculture to feed fish. The aquaculture industry is projected to play a crucial role in the coming decades [14], growing at a rate of 3.9% from 2020 to 2027 [92]. This suggests a potential increase in the demand for aquafeed and hence hempseed.

Composites and furniture

Hemp stalk provides the raw material for both traditional and industrial applications. Hemp can also be used for the production of biocomposites in the automotive industry [23]. Biocomposite materials may consist of natural fibres and a polymer matrix [86]. Hemp scraps have a compact structure with low density and good mechanical strength, making them suitable for use as reinforcing materials in biocomposite materials. Moreover, recent interest in sustainability has led to research into natural fibre-based biocomposite materials, such as those based on bast fibres such as flax, hemp, jute kenaf and ramie [12]. Bast fibres have many advantages over synthetic fibres, such as good mechanical and thermal insulating properties and low energy requirements and costs during production.

Hemp fibre is an excellent substitute for glass fibres in terms of strength and stiffness when used as reinforcement elements in composites. For example, a study by Karus et al. [55] suggested that hemp-based plastic was used by Henry Ford to build car doors and fenders in 1941. This gave the car the ability to withstand ten times the impact of an equivalent metal panel. However, the car did not make it to the market due to prevailing economic limitations. Currently, Germany is the leader in the use of natural fibres in composite materials for automobile applications. The use of natural fibres as automotive composites is estimated to have doubled from 9600 tonnes in 1999 to 19,000 tonnes in 2005; hemp fibres constitute 10% [55]. Hemp can also be processed into different forms for use in automotive interior and exterior applications, e.g., as trunks, head liners, spare wheel covers, parcel trays, car door panels, boot trims, rear shelf and roof liner panels, dashboards, pillar trims, seat shells, underbodies and other applications [22].

Studies on the use of hemp fibres for reinforced thermoplastics have shown that thermoplastics have many advantages over thermoset polymers. For example, a study by Wambua et al. [116] comparing the mechanical properties of natural fibre/PP composites using kenaf, coir, sisal, jute and hemp fibres, all at 40% fibre weight fraction, suggested that the latter had the highest tensile strength of 52 MPa, whereas coir had the lowest tensile strength (10 MPa). Another study by Khoathane et al. [56] investigated the mechanical and thermal properties of hemp fibre-reinforced 1-pentene/PP copolymer composites. The thermal stability of the composites was better than that of the fibres or the matrix as individual entities.

The manufacture of biodegradable and nontoxic plastics based on hemp, referred to as bioplastics, is another important field. From an environmental perspective, Shahzad [96] suggested that hemp fibres can be used to reinforce biodegradable polymers and concluded that natural fibres reinforced with biodegradable polymers result in completely “green” composites. Industrial hemp can be used to reinforce biocomposites to produce green composites, biocomposites, plastic composites, nanomaterials and furniture [39]. A study by Lamberti and Sarkar [63] compared the performance characteristics of 100% woven cotton and 100% woven hemp fabrics for furnishing applications and concluded that hemp is a viable fibre for use in furnishing applications.

Insecticides/pesticides

Hemp has been used as a natural replacement for synthetic pesticides/insecticides because of its high cost and environmental and human damage. For example, Mukhtar et al. [79] assessed the effectiveness of aqueous extracts of industrial hemp and *Zanthoxylum alatum* on the hatching, mortality and infectivity of *Meloidogyne incognita*, which are root-knot nematodes, at different concentrations. They concluded that hemp extract is more effective than *Zanthoxylum alatum* and has high potential for the control of root-knot nematodes, potentially making it the best possible replacement for synthetic nematicides. Benelli et al. [10] also studied the use of essential oil from monoecious hemp cv. Felina 32 against mosquitoes, peach-potato aphids, houseflies and tobacco cutworms. They concluded that monoecious hemp cv. Felina 32 represents a valuable source of green insecticides.

Hemp essential oils have also been tested against a wide range of arthropod pests. For example, Bedini et al. [9] studied the chemical composition of essential oils from industrial hemp, *C. sativa* and hop, and *H. lupulus* and their acute toxicity against the Asian tiger mosquito *Aedes albopictus* (*Skuse*) and the freshwater bladder snail *Physella acuta*. They concluded that hemp essential oil was more effective than hop essential oil was, killing 100% of both invasive mosquitoes and freshwater snails. The rapid development of insecticides resistant to malaria vectors has also necessitated research into the use of essential oils from industrial hemp leaves as alternative insecticides. Abé et al. [1] studied the insecticidal activity of terpenes and aliphatic compounds in industrial hemp leaf essential oil on the malaria vector *Anopheles gambiae s.l.* (Giles). The authors concluded that the compound was effective against *Anopheles gambiae s.l.* (Giles) larvae and adults. These studies confirm the significant market potential of industrial hemp as a good green or natural replacement for synthetic insecticides/pesticides.

Cosmetology

Hemp essential oil is considered a high-value niche product with promising market potential [72, 109]. It can be used for cosmetic products such as essential oils, body oils, body lotions, shampoos, bath gels, soaps, antimicrobes and hand soaps [22]. For example, Bertoli et al. [11] studied the use of ten hemp fibre varieties for the production of essential oils in Italy. The fresh plant inflorescences were hydrodistilled, and the essential oils were characterised via gas chromatography–mass spectrometry (GC–MS). The composition of the aroma emitted spontaneously was also analysed via solid-phase microextraction gas chromatography–mass spectrometry (SPME–GC–MS). The study concluded that hemp fibre inflorescences can be used to produce essential oils as natural flavour and fragrance additives. Ionescu et al. [51] studied the pharmaco-cosmetic potential of four bioactive vegetable oils, including hemp essential oils. The authors concluded that hemp oil presents the greatest advantage for application in the dermato-cosmetic industry because of its optimal omega:omega 3 ratio. In the UK, there are a variety of hemp-based cosmetic products in retail shops, including shampoos and conditioners from well-known brands.

Biofuel

The demand for sustainable energy has led to research into avenues to reduce the global reliance on fossil fuels such as coal, gas and oil-based energy [90]. Both the whole plant and its shives are used for energy [16]. Two main types of biofuels can be derived from the hemp plant [24, 91]: biodiesel made from the oil of the pressed seed and bioethanol and methanol made from the fermented stalk. The forms of biofuel include boiler fuel (solid and pellets), biodiesel (bioethanol and methanol), biogas (methane and biohydrogen) and electricity. Ahmad et al. [3] investigated the use of hemp as a potential source of biodiesel on the basis of detailed physicochemical analysis. The authors concluded that hemp oil biodiesel was clean, environmentally friendly and exhibited fuel properties within the range of the American Standard for Testing Material. Another feasibility study was carried out by Li et al. [64] on converting hemp oil into biodiesel through base-catalysed transesterification. They reported a conversion factor greater than 99.5% and a biodiesel yield of 97%.

Hemp also presents an alternative avenue to produce ethanol. Empirical studies by Sipos et al. [101] have shown that ethanol can be produced from steam pretreatment of dry and ensiled industrial hemp. Kreuger et al. [62] investigated the conversion of industrial hemp to ethanol and methane via stream pretreatment and coproduction and concluded that the coproduction of ethanol and methane from steam pretreated stems resulted in a high yield of transportation fuel.

Industrial hemp presents market opportunities to obtain green and cheaper biofuels, as it does not produce sulphur emissions, either when burned directly or when converted into liquid fuels such as bioethanol. Compared with wheat, corn, sugar beets and sugarcane, industrial hemp also has high biomass and energy yields per hectare.

Building materials

The construction sector contributes significantly to global environmental pollution because of the use of energy and carbon-intensive raw materials. To ensure the construction of sustainable buildings, it is imperative to replace carbon- and energy-intensive resources with new low-environmental-impact alternatives [50]. In building construction, hemp fibres can be used as insulation materials, hemp wool, panels, fibreboard, concrete, cement blocks and mortar. The use of hemp in concrete buildings has the added benefits of carbon sequestration as well as low embodied energy and renewability. Unlike synthetic fibre materials, the use of industrial hemp fibres represents a sustainable solution in building constructions. Hemp fibres can be processed into a variety of more durable commercial products that resemble concrete, wood and thermoplastic [23]. A major advantage of using hemp fibres over synthetic fibres is that they are durable, lightweight, affordable to produce, waterproof, fireproof, self-insulating, resistant to mould, moistureproof, highly breathable and resistant to pests; additionally, they have good heat retention in wintertime and are cool in summer [19, 96]. Arnaud [6] reported that lime and hemp concretes made from the central porous part of hemp stalks or shives have strong thermal and acoustic insulation properties. It can also regulate the humidity inside buildings by absorbing and releasing moisture depending on the air conditions. Pretot et al. [89] performed a life cycle assessment of hemp concrete walls and concluded that compared with traditional construction materials, hemp concrete has a low impact on the environment. Finally, Moujalled et al. [78] performed an experimental and numerical evaluation of the hygrothermal performance of hemp–lime concrete buildings. They concluded that hemp–lime concrete helps maintain a good hygrothermal comfort level in winter and summer, making it an excellent building material. In Scotland, IndiNature, the first natural insulation factory in the UK, uses hemp to produce natural fibre construction insulation for homes.

Paper

The pulp and paper industry is a major contributor to environmental pollution because of its high consumption of energy and chemicals. Paper can be produced from the long bast fibres of hemp stems [21]. This makes it an excellent replacement for traditional sources of raw materials for pulp and paper. Industrial hemp is useful for papermaking because of its high yield [74]. Hemp paper also requires fewer chemicals for the treatment of pulp paper [69], and it is useful for producing high-quality paper [7]. Hemp paper is stronger, finer and does not turn yellow when bleached, similar to conventional paper [21]. It can also be used for tea bags and coffee filters [31], wax match paper [32], cigarette papers [53, 122], electrical insulation papers [30], glassine and greaseproof papers, condenser papers [33], technical filters, banknotes, bible paper, and dielectric and medical paper [17]. An empirical study on the use of hemp root bast paper for oil/air filtration for automobile engine oil concluded that hemp papers have better oil/air filtration properties in practical applications than cotton paper does [54].

Textile

Textile production from hemp has been displaced by imports of cotton and synthetics, which are intensive and heavily dependent on inputs of pesticides, fertilisers and water [93]. Hemp bast fibre is a more sustainable replacement for traditional natural and synthetic fibres in the textile industry [4]. Hemp fibre textiles offer excellent protection from ultraviolet rays [58, 123]. Hemp fibres are also useful for textiles because they have good thermal conductivity, which is necessary for heat transfer in summer and heat retention in winter [104]. Hemp fibre textiles have further proven suitable for people prone to allergies and with sensitive skin [60]. Hemp bast fibres are stronger, can hold their shape and stretch less than other natural fibres do [81].

Environmental benefits

Hemp presents a new perspective and opportunities to mitigate climate change. Hemp fibre is considered a crop with low input and low environmental impact [103]. Crops contain approximately 45% of the atmospheric carbon taken up during photosynthesis. The hemp straw produced by 1 ha of land can store approximately 3.06 tonnes of carbon, which limits climate change (van der Werf [113]).

Hemp planted for fibre production requires a high planting density and grows rapidly, allowing it to crowd out weeds, resulting in little to no herbicide usage. However, these potential benefits disappear when hemp is planted for seeds instead of for fibres because of the lower planting density needed. Hemp has been used in soil cleaning through phytoremediation and phytoextraction processes. Hemp grown for fibre can be used as a renewable resource to decontaminate pollutants such as metals; radioactive elements; organics, including pesticides and fertilisers; and oils and solvents from soils [65]. According to Small and Marcus [102], hemp has been used in land reclamation in the oil and gas industry in Alberta. An empirical study by Pejic et al. [85] showed that short hemp fibres are capable of adsorbing metal ions (Pb^{2+}, Cd^{2+} and Zn^{2+}) from single as well as ternary metal ion solutions. Vukcevic et al. [115] studied the use of short hemp fibres, acquired as waste from the textile industry, as biosorbents for the removal of zinc ions from polluted water. They concluded that short hemp fibres are efficient biosorbents for the removal of zinc ions from polluted water. Another study by Bugnet et al. [15] assessed the use of hemp materials (loose fibres and felted fibres) to decontaminate polymetallic aqueous solutions containing aluminium, cobalt, chromium, copper, nickel and zinc. They concluded that both loose and felted fibres have 99% removal efficiency. The study was replicated and confirmed by Loiacono et al. [66].

Hemp fibres also present new opportunities for water and wastewater treatment. For example, Vukčević et al. [114] reported that the carbonisation and activation of waste hemp fibres present an efficient alternative for the removal (adsorption) of pesticides for water purification. Similarly, Zou et al. [124] studied the use of a zeolite–hemp fibre composite for the green removal of aromatic organic pollutants (benzene, toluene and chlorobenzene) from aqueous solutions and concluded that the zeolite–hemp composite exhibited a high degree of removal (above 80%) of these pollutants. This makes the composite an environmentally friendly alternative for water purification.

Industrial hemp has both environmental and biodiversity benefits. Products made from industrial hemp are biodegradable and able to meet the demand for ecologically friendly products [52]. Figure 1 shows the crude mean evaluation of different biodiversity-friendly crops, including hemp for fibre and oil. Tobacco has

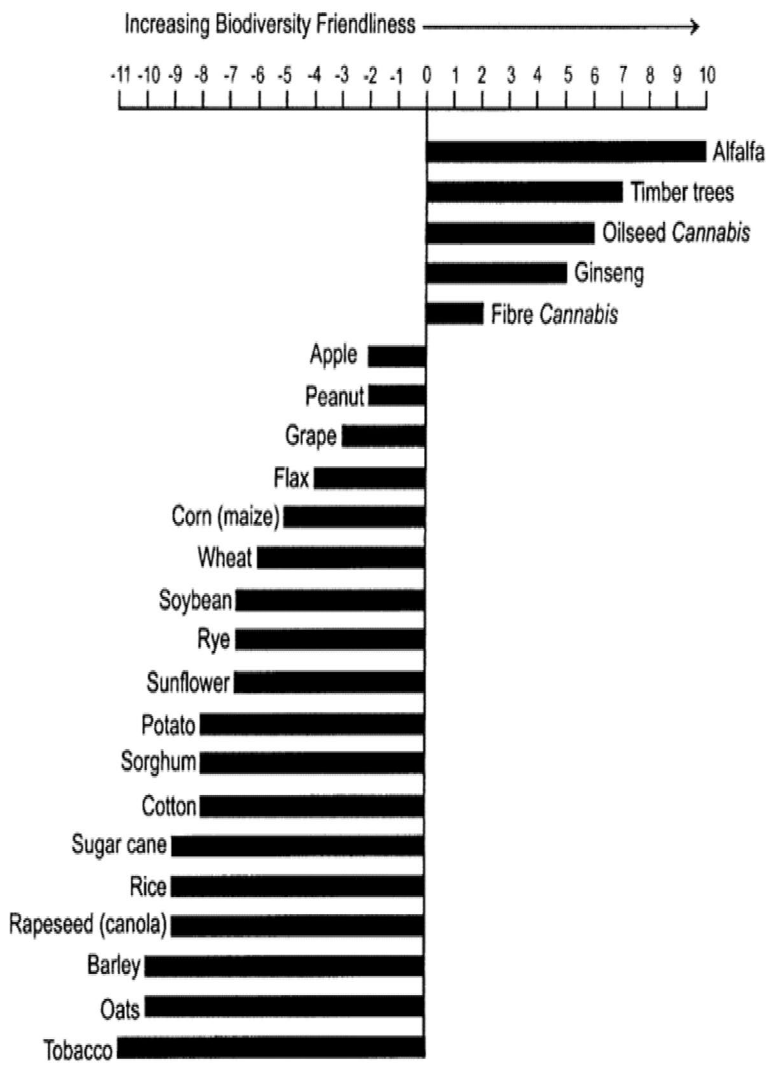

Fig. 1 Crude mean evaluation of the biodiversity friendliness of selected major crops and fibre and oilseed cannabis, based on a scoring system. Source: Montford and Small [77]

the worst score for biodiversity friendliness, whereas alfalfa has the highest biodiversity friendliness. The main annual crops, such as wheat, rapeseed and barley, that are grown in Scotland are found to have negative biodiversity friendliness [77]. Compared with flax, fibre cannabis (hemp fibre and oil) has positive biodiversity friendliness, which has negative biodiversity friendliness. Although both crops have similar uses, hemp could be considered attractive for its biodiversity benefits. It has been suggested [83] that the cultivation of hemp before wheat leaves a clean and loose soil helps maintain soil biodiversity.

Most studies suggest that the main strength of the use of hemp-based materials comes from the production phase because of the "green" origin of these materials, which is associated mainly with carbon sequestration during plantation growth [50].

Economic outlook

Fortune Business Insights, a global market analyst, projects that the hempseed market is estimated to grow at 11% to approximately 1.6 billion dollars in 2027. In 2019, the market was valued at 0.7 billion, including whole hemp seeds, hemp seed oil, hulled hemp seeds and hemp protein powder [41]. The demand for hemp seed and its products is expected to be fuelled by rising demand for personal hygiene products as well as milk, oil and cheese substitutes and alternative proteins. The relaxation of the restrictions on industrial hemp farming in certain countries, such as Canada and the US, is also likely to drive up the demand for hempseed and its products. Third, the demand for eco-friendly food products and strict climate policies may force producers and consumers to demand more environmentally friendly products.

Data from the U.S. suggest that in 2017 alone, the total retail value of industrial hemp products was 820 million dollars. This figure includes food and body products, clothing, automobile parts, building materials, etc. In 2021, the USDA estimated the total value of industrial hemp to be 824 million dollars, an increase of 4 million compared with the 2017 figure. Approximately 623 million dollars were attributed to floral hemp grown in the open space, 5.99 million dollars were attributed to seed or hempseed grown in the open space, and 41.4 million dollars were attributed to hemp fibre plants grown in the open space. Hemp under protection contributed approximately 112 million dollars. In Europe, France is the largest producer of industrial hemp. Hemp fibre is estimated to generate more than 40 million euros annually in the French economy [83].

Currently, there are no official data on the economic value of hemp and hemp products in Scotland. However, the figures from the U.S. demonstrate the significant economic value of industrial hemp to the national economy.

Hemp legislation in the EU/UK

The United Nations' comprehensive "Single Convention" of 1961 on narcotic drugs includes hemp due to the presence of D9-tetrahydrocannabinol (THC). The term "cannabis" refers to the flowering or fruiting tops of the cannabis plant (excluding the seeds and leaves when not accompanied by the tops), from which the resin has not been extracted; by whatever name they may be designated, "cannabis plant" refers to any plant of the genus cannabis, and "cannabis resin" refers to the separated resin, whether crude or purified, obtained from the cannabis plant [112]. The THC contained in cannabis is also captured within Schedule II of the Convention on Psychotropic Substances of 1971 [111]. This means that any product containing a THC falls within the scope of the convention and hence is illegal for sale on the basis of the General Food Law 2002.

Hemp produced for agricultural purposes versus its medical-grade relative is often defined by low (< 0.2%) levels of the psychoactive compound THC [105]. Hemp low in the THC have been present on the European market since 1994. Its extracts are, however, classified under novel foods, and the sale of its plant or extract (cannabidiol or CBD) is not harmonised under European Union (EU) law. The isolation of CBD was achieved in the early 1940s [2]; however, scientists were only able to determine its full structure in the 1960s [71]. Currently, the EU-authorised hemp varieties (EU Regulation 1307/2013) contain 0.056 (Futura) to 0.27% (Finola) of CBD [84].

In the UK, the Home Office controls the use of illicit drugs and has the authority to implement and enforce narcotic conventions under the Misuse of Drugs Act (MDA) 1971 [108]. The act contains a list of illicit drugs, including cannabinol, cannabinol derivatives, cannabis and cannabis resin (classified as Class B drugs). Misuse of drug regulations (MDRs) (2001) provides requirements for the licensing of production, possession, and supply of illicit substances. These regulations in the UK make it unlawful to possess, import, export, supply and cultivate any plant of the genus cannabis except under a Home Office licence. In summary, all products promoted as food containing THC are considered controlled substances by UK law.

Profitability of hemp seed and hemp fibre production

Hemp is grown on a large scale in some states in the U.S., Canada, China and Europe. The economic viability of hemp cultivation varies annually because of price fluctuations. Table 1 shows data from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), indicating that the production of both hempseed and fibre is more profitable than that of hempseed or hemp fibre only [8]. The situation is similar for hemp production in

Table 1 Profitability of hemp production

	Hemp fibre		Hempseed		Hemp fibre and hempseed	
	Operating expenses ($)	Revenue ($)	Operating expenses ($)	Revenue ($)	Operating expenses ($)	Revenue ($)
	(per acre)	(per acre)	(per acre)	(per acre)	(per acre)	(per acre)
Canada	617	510	424	400	532	580
USA	363.55	680	256.76	476.91	403.49	723
Turkey	1467.25	1155.16	1281.22	1483.52	1802.47	2076.94
France	364.21	876.95				

Source: [8, 18, 44, 110]

Kentucky, US. [110]. In Turkey, the production cost and revenue per acre for hemp fibre, hempseed and hemp fibre and seed farms are greater than those in the US and Canada. The data from France show a relatively high gross margin for hemp fibre cultivation of approximately $512.74/acre [44]. Compared with other crops, hemp has been shown to perform better. For example, Das et al. [24] compared the profitability of industrial hemp when used for seeds and ethanol with that of kenaf, switchgrass and sorghum. Hemp had a profitability of approximately 35–70% greater than that of the other three crops.

Method of analysis

This study performed two main analyses: a descriptive analysis of the Global New Product Database and a SWOT analysis of interviewed data obtained from farmers in Scotland.

Data analysis

Two types of data analysis were carried out: (1) based on the Global New Product Database (GNPD), which contains information about hemp-based products launched by major retail supermarkets and manufacturers between 1997 and 2021. The data are based on products launched in Europe and North America. Each product contains information on the date and country it was first launched, product category, manufacturing company, brand name, positioning claims, prices, package size, brand, product description and storage type, etc. This information was used to assess trends in new product development in the hemp market. (2) Primary data[2] were collected from Scottish farmers in Angus, Aberdeenshire and along the Scottish borders. Currently, there are fewer than 30 hemp growers in Scotland. The questionnaires were sent to approximately 25 farmers in Aberdeenshire and Scottish Borders, seven of whom (28% response rate) fully completed the questionnaire. The data collected information on barriers, opportunities, weaknesses and threats that the Scottish hemp supply chain is exposed to. Data were gathered on the motivations and potential market routes for hemp fibre and hemp seed. These findings allowed us to formulate recommendations that will assist in developing a strong Scottish hemp sector. The analysis is based solely on responses obtained from these farmers. Although small in number, these responses allowed us to outline the existing supply chain as well as the strengths, weaknesses, opportunities and threats (SWOT) that these farmers foresee in the sector.

Teoli et al. [107] define SWOT analysis as a strategic tool used by an organisation to assess its performance against its competitors. In supply chain analysis, Görener et al. [45] define the concept as a systematic approach and support system for studying both internal and external factors of the supply chain. These internal and external factors are divided into four parts: strengths, weaknesses, opportunities, and threats (SWOT). SWOT has been used extensively in the literature. For example, Shinde et al. [98] used this method to review new perspectives and recent developments in the supercapacitor industry. Similarly, Farrokhnia et al., [37] used the method to determine the implications of the ChatGPT for educational practice and research. The procedure used to carry out the SWOT analysis for the Scottish hemp sector is described in Fig. 2 below. The interview questions answered by the farmers were structured to illicit the SWOT of the hemp sector.

Results and discussion

Trends and developments in the hemp processing sector

Figure 3 shows the trend in the number of hemp-based products launched worldwide from 1997 to 2021. The growth in the number of products launched was slow from 1997 to 2012, possibly due to strong restrictions on the farming of industrial hemp across the world. The number of hemp-based products launched began to experience exponential growth from the start of 2013. This could be due to the relaxation of restrictions on the farming of industrial hemp, increasing demand for sustainable products, and the growing number of health- and nutrition-driven consumers. In 2021, the total number of hemp-based products launched was 713 products compared with eight products in 1997, approximately 88 times greater.

Figure 4 shows the countries and the number of hemp-based products launched from 1997 to 2021. These countries launched more than 99% of the total hemp-based products launched worldwide, whereas the others[3] launched less than 1%. The top five countries in descending order are the US, Germany, Canada, the UK and France. The US is the largest manufacturer of products with hemp ingredients, whereas Singapore is the least. The two North American countries, Canada and the US, produced approximately 29% of the total number of products. As shown in Table 1, industrial hemp is very profitable in North America, and it is driven by the relaxation of regulation. The UK launched 10%, and the remaining 61% was distributed among the remaining

[2] The study received ethical approval from the Rowett Institute Ethics Approval Committee of University of Aberdeen.

[3] Belarus, Chile, Colombia, Indonesia, Israel, Philippines, Tanzania, Argentina, Cameroon, Egypt, Ghana, Guatemala, Kuwait, Pakistan, Peru, UAE.

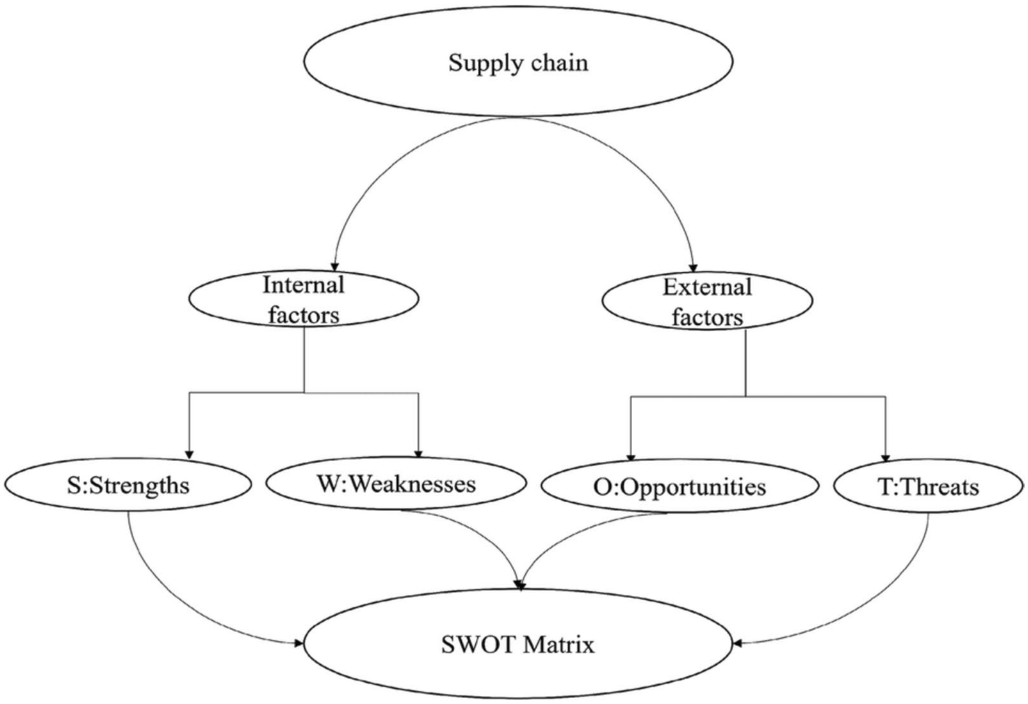

Fig. 2 The procedure used in the SWOT analysis. Source: Meena et al. [73]

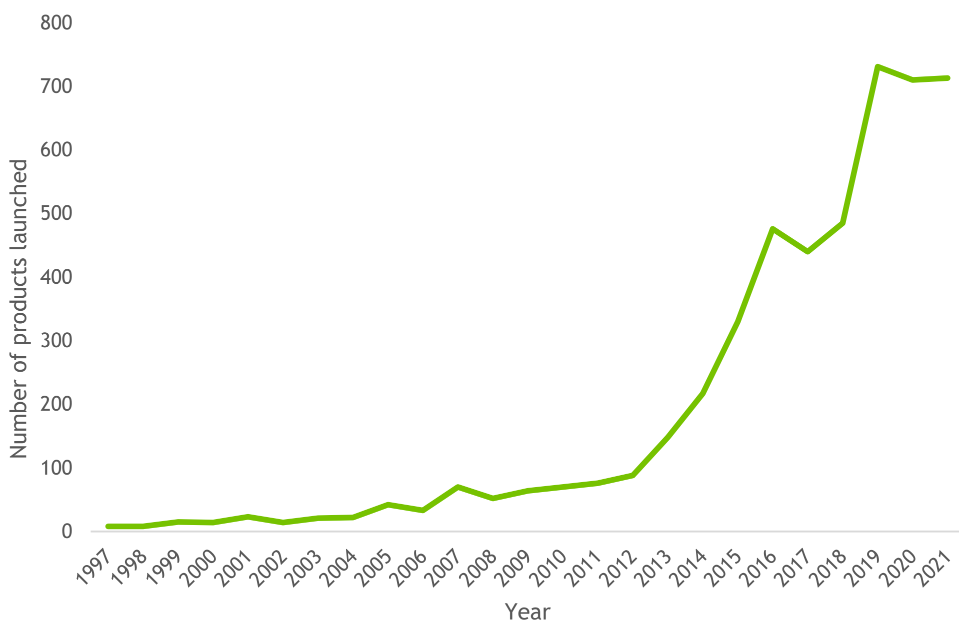

Fig. 3 The number of hemp-based products launched worldwide from 1997–2021. Source: Authors' own computation on the basis of the Global New Product Database (2022)

countries. Although the UK is not among the top growers of industrial hemp in the world, it is among the top five manufacturers/companies launching hemp-based products. This suggests that the hemp ingredients used in the UK are sourced externally. From Fig. 13 it is evident that farmers are not able to grow the crop on a large scale due to stringent regulation of the crop in the UK.

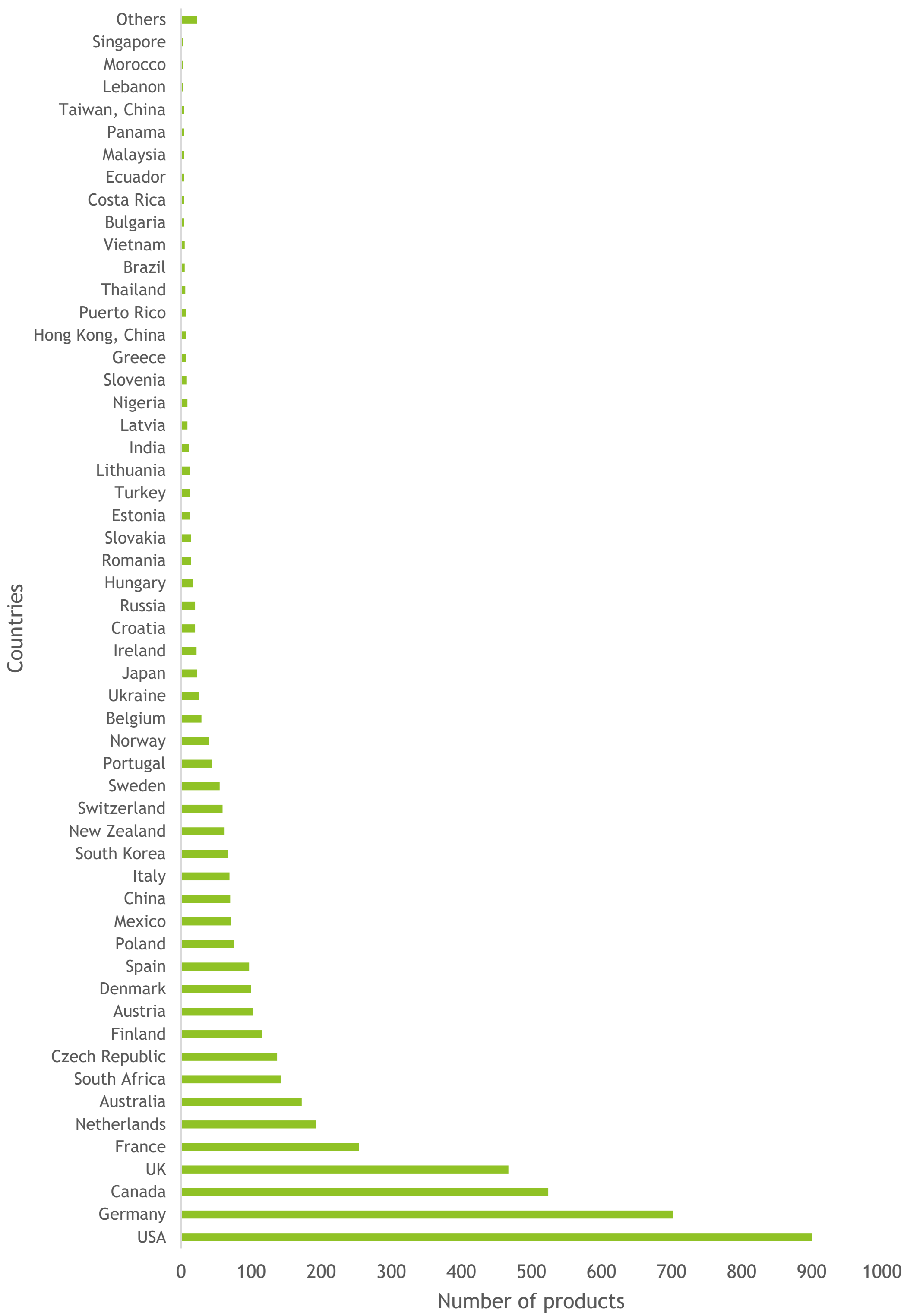

Fig. 4 Number of hemp-based products launched by countries from 1997–2021. Source: Authors' own computation on the basis of the Global New Product Database (2022)

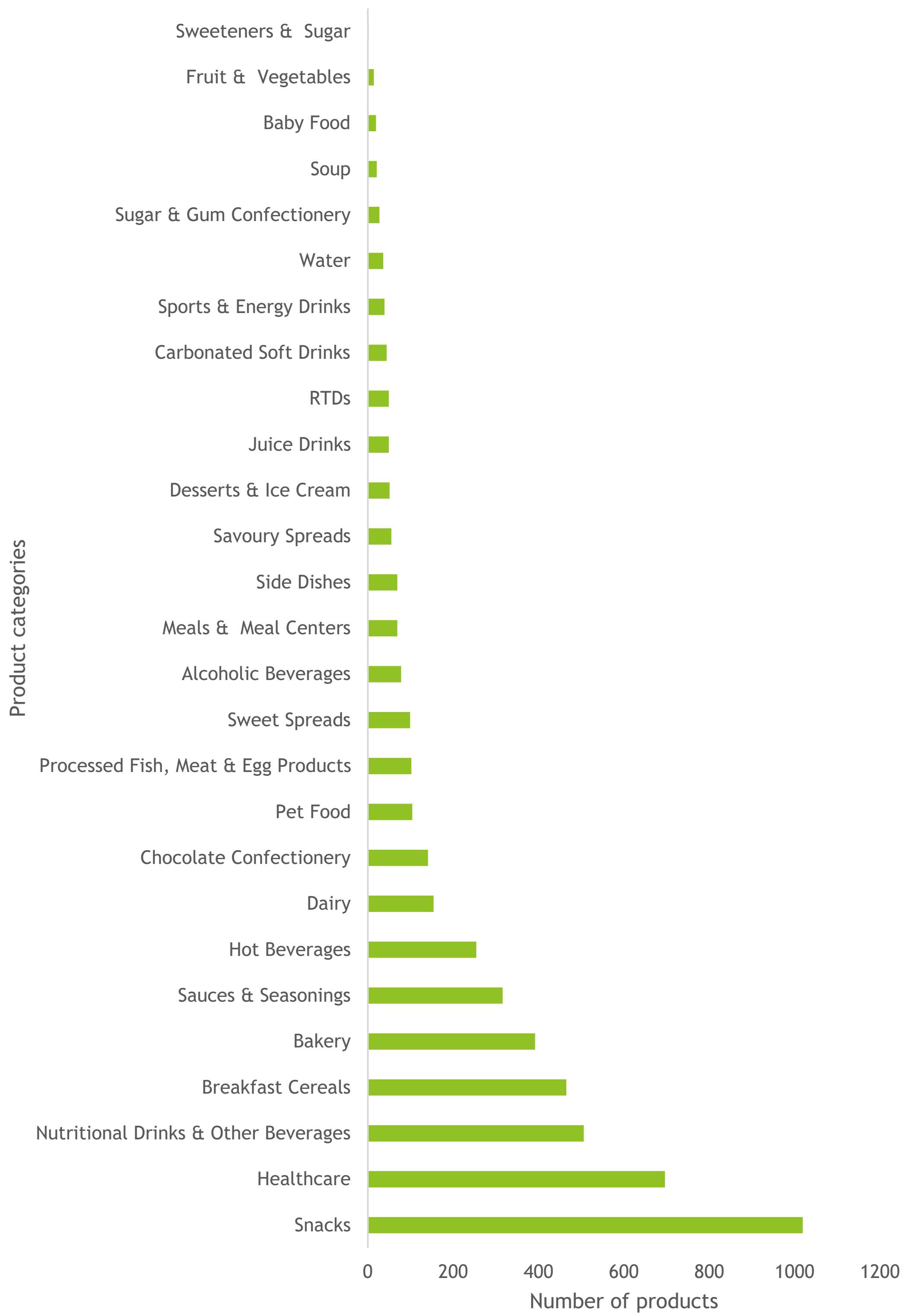

Fig. 5 Categories of hemp-based products launched worldwide from 1997–2021. Source: Authors' own computation on the basis of the Global New Product Database (2022)

Figure 5 presents the categories of products launched worldwide from 1997 to 2021. A total of 4870 unique products were launched. The category with the largest number of products launched is snack-based food products (1019), whereas sweeteners and sugar have the least number of products (2). Healthcare products constitute the second-largest category with hemp-based ingredients. A total of 696 healthcare products containing hemp ingredients were launched between 1997 and 2021, followed by nutritional drinks and other beverages, breakfast cereals and bakery products. On the basis of these numbers, it can be deduced that the demand for hemp-based products is driven by nutritional and health concerns. Comparing Fig. 5 and Fig. 13, it is evident that farmers and consumers have different motivations for using the crop. Whilst nutritional and health concerns are paramount to consumers, farmers are motivated by the environmental and the economic benefits of the hemp crop.

Figure 6 shows the trends in the number of products launched under different claim categories from 1997 to 2021. The number of products launched experienced an increasing trend across all claims categories. The dominant claims category across all years is health and nutrition, suggesting that demand for hemp-based products is driven by consumers who are healthy and nutrition conscious. Products with demographic claims are the second most important. These are products targeted at specific demographic groups in the population, i.e. vegans, elderly individuals, children, etc. Products with sustainable claims are the third most important in the hemp products market. Although globally sustainability is third for consumers, Fig. 13 shows that sustainability (environmental benefit) is the priority of farmers. These products are driven by consumers who are environmentally focused. Convenience and safety claims are the least important in the hemp market, as shown by the figure. This suggests that manufacturers do not believe that consumers are interested in hemp-based products with such claims.

Figure 7 shows trends in the number of products launched under different claims categories in the UK from 1997 to 2021. The number of products launched under the different categories follows a similar pattern to those launched worldwide. Products with demographic, health and nutritional claims constitute the majority across all years. The number of products launched under these two claims, including sustainability, increased exponentially after 2014. Products under safety and convenience claims were low across all years until 2016. In 2021, 47, 57, 54, 15 and 10 products were launched under sustainable, health and nutrition, demographic, safety, and convenience claims, respectively. Comparing the UK to global trends confirms that, for consumers,

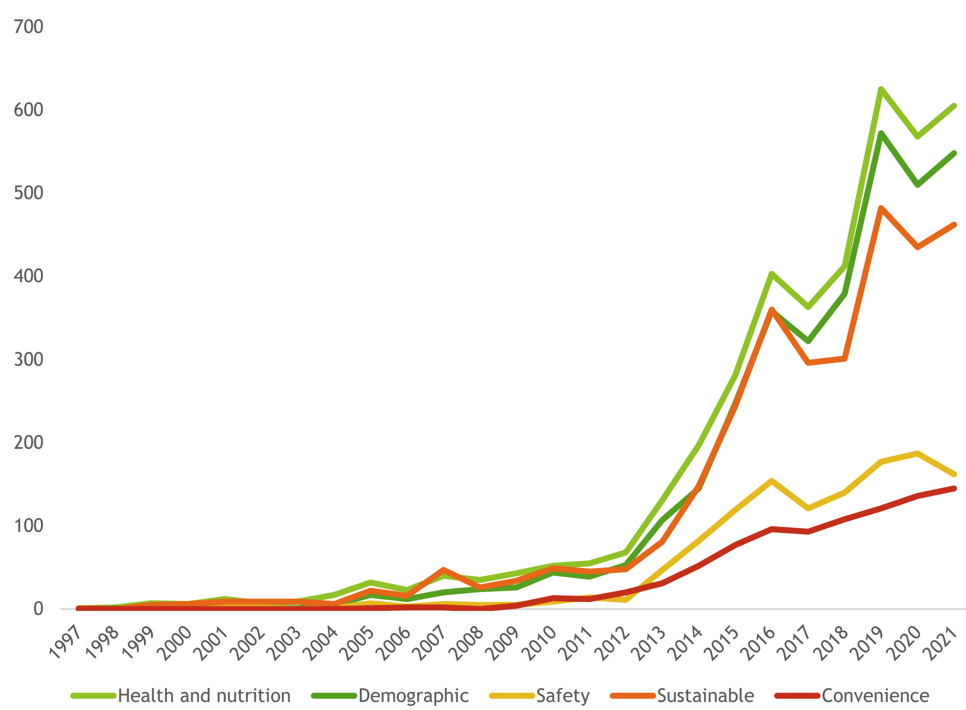

Fig. 6 Trends in the number of products launched by claim category from 1977–2021. Source: Authors' own computation on the basis of the Global New Product Database (2022)

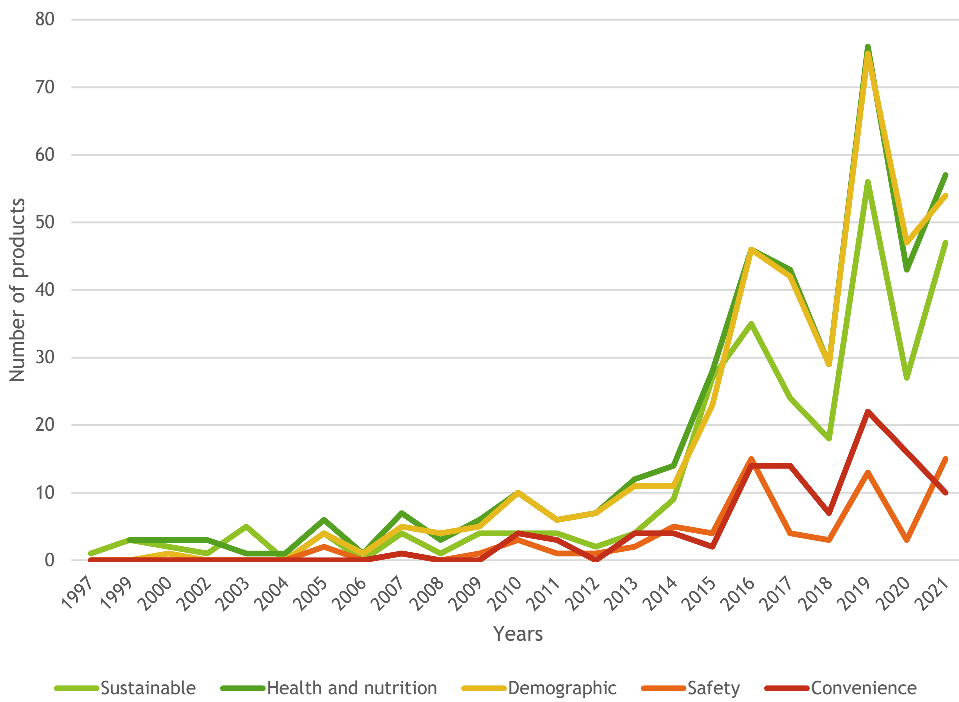

Fig. 7 Trends in the number of products launched under different claims categories in the UK. Source: Authors' own computation on the basis of the Global New Product Database (2022)

sustainability is the third most important driver of buying hemp-based products.

Figure 8 presents the top 20 claims associated with hemp-based products launched in the UK from 1997 to 2020. The claims positioned with more than a 5% share are all ethical: environmentally friendly packaging, gluten-free, high/added fibre, GMO-free, no additives/preservatives, vegan or no animal products, vegetarian and organic. Organic hemp-based products are the most popular, while the least common among the top 20 are low/no/reduced calorie products.

Figure 9 shows the number of products launched by claims category by the top five companies in the UK. Products with health and nutrition claims are the products launched the most by all five companies. The companies with the largest number of products in ascending order are 9Brand Foods, The Food Doctor, Braham and Murray, Naturya and Wholebake. Products with demographic claims are the second most common products launched by the five companies. The largest number of products under this claim was launched by Wholebake, whereas the lowest number was launched by Food Doctor. Products with sustainability claims are the third largest, whereas safety and convenience claims are the least common across all companies. Labelling products with hemp ingredients as sustainable especially those that use little or no fertiliser and pesticides would encourage environmentally conscious consumers to patronise the crop.

Figure 10 shows the top five companies in the UK and the number of products launched under different product categories. First, for Naturya, healthcare products are the main type of products containing hemp ingredients. Snacks are the second most launched products, whereas breakfast cereals have the least number of products launched. For Braham and Murray, sauces and seasoning products containing hemp ingredients constitute the majority, followed by dairy. Snacks and bakery are the categories with the least number of products to be launched. Wholebake and 9Brand Foods launched only snack products with hemp ingredients. The majority of products launched by Food Doctors are snacks. Savoury spreads, and meal and meal centres have the fewest products launched. In summary, healthcare, dairy and snacks represent the largest categories of products with hemp ingredients launched by the top five manufacturers in the UK.

Supply chain development

Hemp seed growers

Production The supply chain map for Scottish hempseed growers is a basic map (see Fig. 11). The seeds for cultivation are imported and not produced in the UK. From Fig. 13, this is a major drawback to the sectors

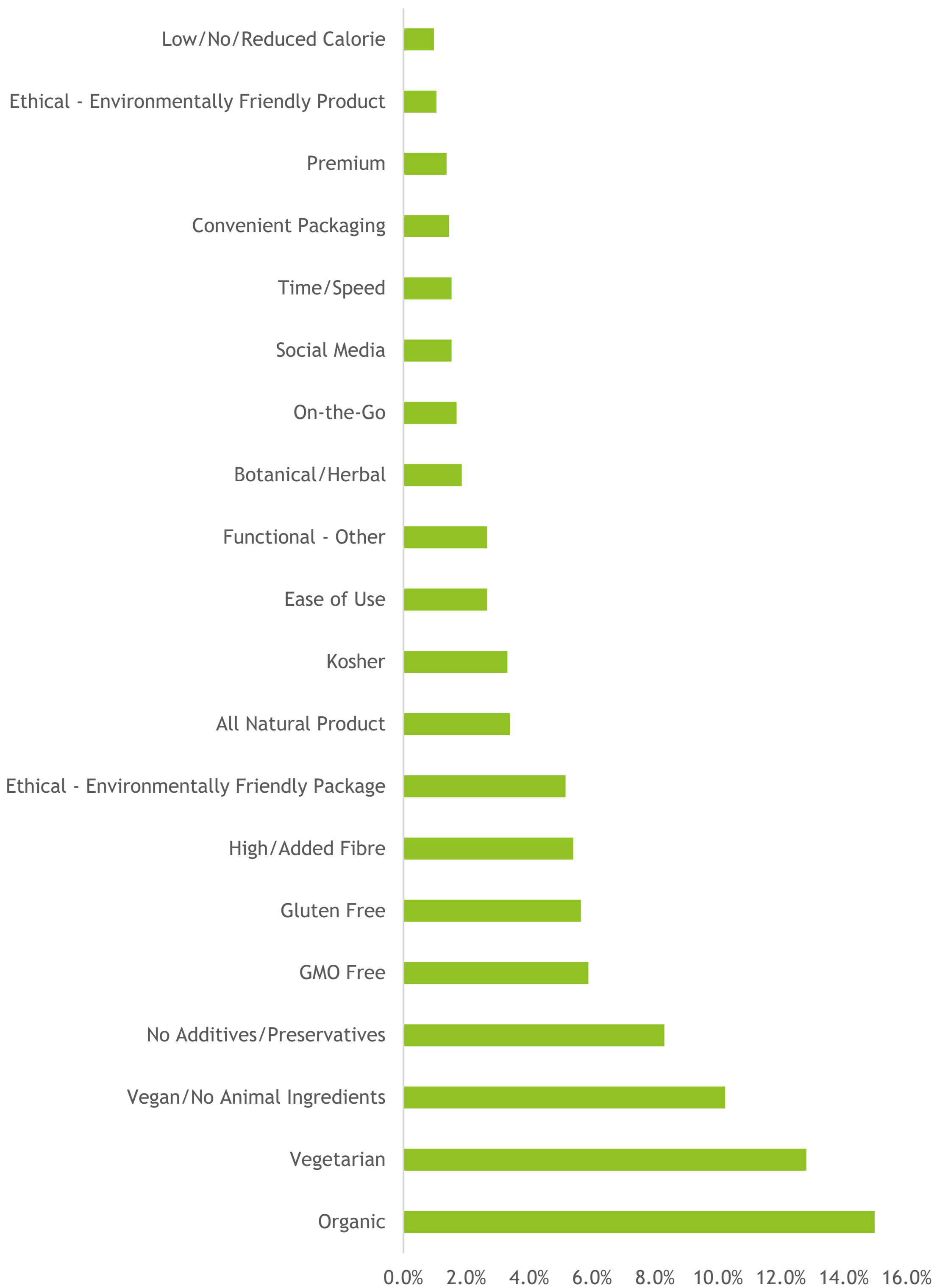

Fig. 8 Top 20 claims launched with hemp-based products from 1997–2020. Source: Authors' own computation on the basis of the Global New Product Database (2022)

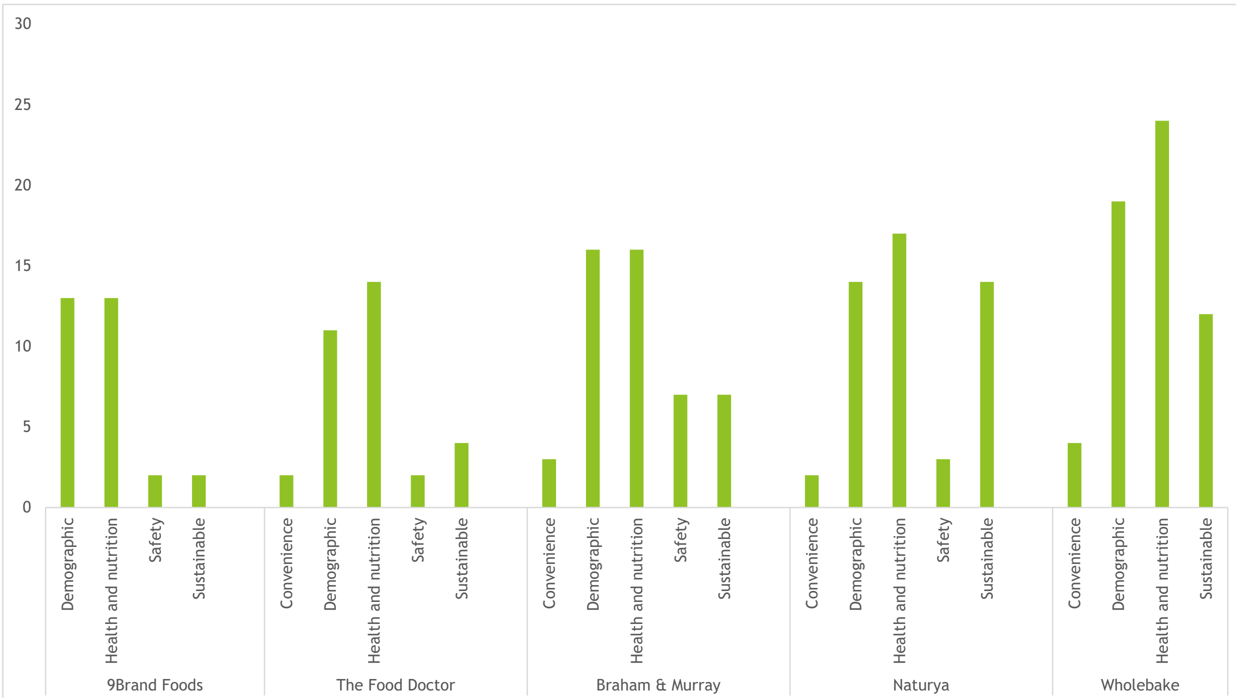

Fig. 9 Top five companies in the UK and the number of products launched by claims category 1997–2021. Source: Authors' own computation on the basis of the Global New Product Database (2022)

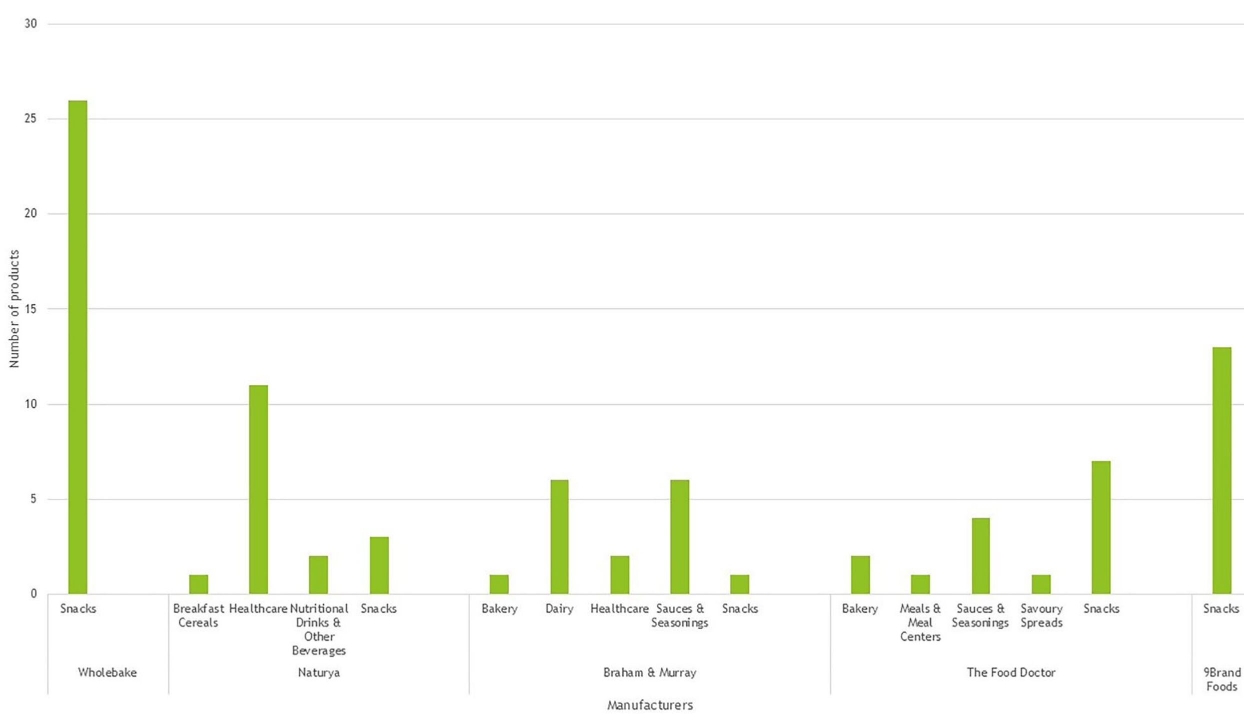

Fig. 10 Supply chain map for hemp seed. Source: Own computation

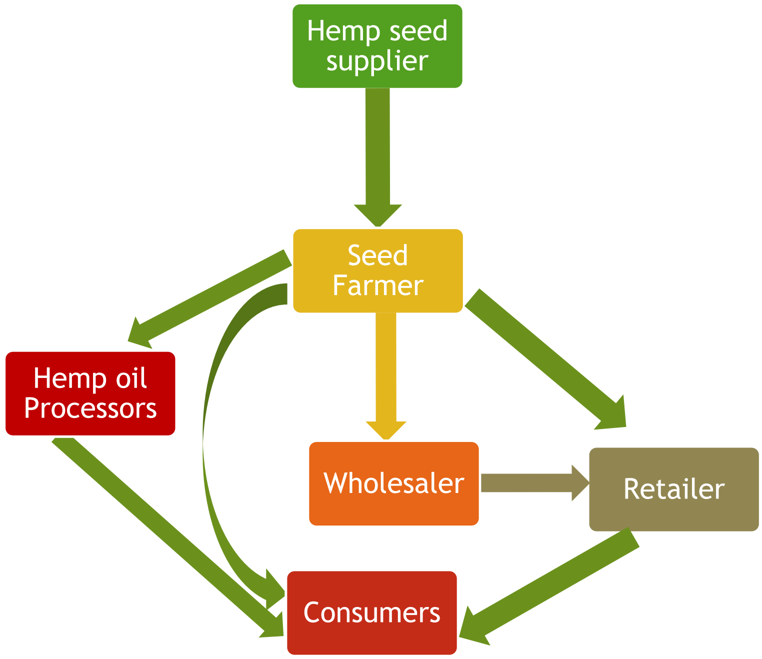

Fig. 11 Supply chain map for hemp seed. Source: Own computation

development. Based on the small number of responses to the questionnaire, most farmers grow hemp for seeds. Together, these cultivated a total of 17 hectares. The seeds are sown outdoors in the spring and germinate for approximately 3 to 7 days. The crop is cultivated once annually because of the weather conditions in Scotland.

The farmers outlined various reasons for cultivating hemp. From Fig. 13, these benefits include the following: (1) environmental benefits resulting from improved biodiversity of farmlands and the low input requirement for the crop; (2) diversification benefits—most farmers regard planting hemp as a safety net; it is risky to produce only one type of crop; (3) crop rotation—instead of leaving the land idle for years due to deterioration, most farmers prefer to cultivate hemp to take advantage of its role in soil remediation and improve soil biodiversity; and 4) health benefits—farmers who are motivated to grow hemp are driven by the potential health benefits of hempseed oil. Other farmers grow hemp because they want to try a new crop or produce their own food.

Processors In June 2022, the first commercial production of cold-pressed hemp oil was initiated in Scotland [76]. This is a strong motivation for the commercial production of hempseed in Scotland. Our data show that there are rapeseed oil processors who have expressed an interest in pressing hempseed into oil. However, these processors are unable to purchase from Scottish hempseed growers because of the lower output and the high cleaning cost required to alternate between hempseed and rapeseed oil processing. Three out of seven farmers intend to sell their output to processors. They cultivate 11 hectares of hempseed, which will produce an optimal output of 82.5 tonnes of hempseed. According to the farmers, the lack of processing facilities for their produce is a major limitation to the commercial production of hempseed in Scotland. Figure 13 highlights this as one of the major weaknesses of the current hemp sector in Scotland.

Wholesalers and retailers Some farmers listed wholesalers and retailers as potential buyers of their output. This aspect of the supply chain is underdeveloped because there are currently no official wholesalers of hempseed nor futures contract with retailers. However, interim farmers can sell their output to the British Hemp Alliance and the Scottish Hemp Farmers Association to increase their bargaining power. The data analysis from the GNP database suggests that retailers such as Sainsbury's, Aldi, Lidl and M&S are potential buyers of hemp seeds. It is important for farmers to consider futures contracts with these retailers before starting to plant hemp seeds. This is necessary considering the fluctuation of hempseed prices and to hedge themselves against potential price shocks.

Consumers Approximately three out of seven farmers intend to sell their outputs directly to consumers. The nature of marketing is not fully understood. However, farmers are required to clean the seeds of debris and package them before offering them for sale. While this will increase profit margins for farmers, as there are no middlemen, farmers are required to develop their own marketing channels and skills to ensure that they reach a large group of consumers. From Fig. 13, lack of established market route is considered as a setback to the sector. Another major limitation is the prejudices that people have toward hemp. Some farmers suggested educating the public to distinguish between industrial hemp and marijuana.

Hempseed and fibre growers

The supply chain map of hempseed and fibre is simpler than that of hempseed described above (see Fig. 12). The same explanation for hempseed can be given for hempseed and fibre growers. However, a major distinction is that the supply chain of hempseed and fibre growers does not consider retailers and wholesalers.

The farmers intend to sell their outputs directly to consumers, the construction sector and processors. Therefore, the potential buyers of hempseed in this map are processors and consumers. The construction sector (indirectly) uses hemp fibre for insulation materials and wood for buildings. Figure 13 shows that there is the need to establish a strong market link between hemp farmers and manufacturers/processors (Fig. 13).

SWOT analysis of the Scottish hemp sector

To understand the strengths, weaknesses, opportunities and threats (SWOT) that influence the success of the Scottish hemp sector, the farmers were asked to answer a series of questions. A summary of the results can be found in Fig. 13.

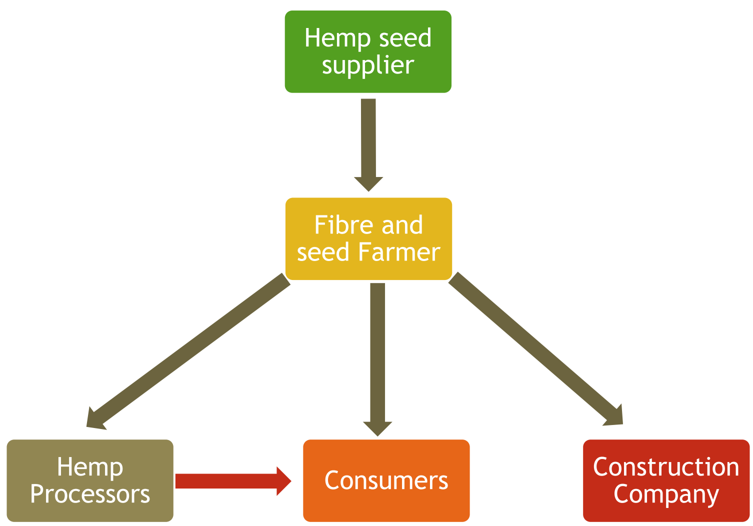

Fig. 12 Supply chain map for hemp fibre. Source: Own computation

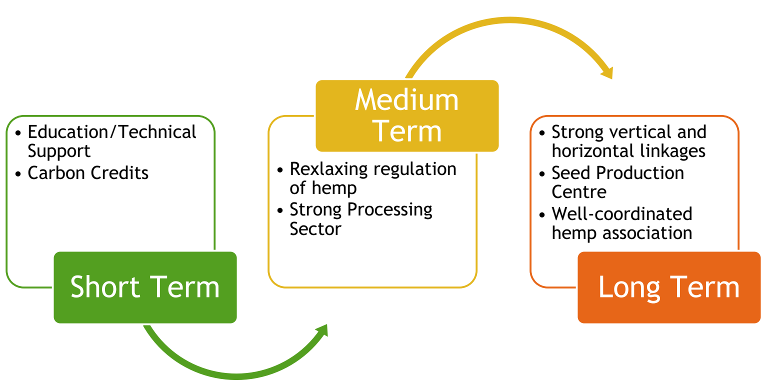

Fig. 13 Summary of SWOT analysis. Source: Own computation

Strengths

Environmental benefits of the crop A major motivation or strength of the hemp sector is the environmental benefits attributed to the hemp crop. All the farmers agreed that the crop is a low-input crop and has a low climate impact. This finding is confirmed by the literature above, which suggests that hemp crops have low inputs and numerous environmental benefits, including improved biodiversity of the soil, improved soil remediation, and improved carbon storage potential. This suggests that hemp crops are important for crop rotation and marginal agricultural lands contaminated with pesticides and fertiliser residues.

High yield or returns Most farmers agree that the strength of the hemp sector is based on the high yield of the crop and maturity within a short period of time. The hemp crop can be grown for both fibre and seed for increased profitability. A small field could produce a large amount of hemp fibre, as little spacing is needed. The crop also requires little or no pesticides or insecticides, making it less capital intensive. However, most farmers prefer to grow the crop for its seeds. Table 1 provides details of the economic returns of the crop. The crop has been shown to be profitable irrespective of the country or continent in which it is grown. Although hemp fibre and seed prices are unstable due to competition from other arable crops, farmers could harness their profitability by using the futures market to hedge themselves against price fluctuations.

Diversification/crop rotation It is important to consider hemp crops in crop diversification. Crop diversification allows farmers to spread both production and economic risk over a broader range of crops. The crop improves both the soil and the environment, as well as generating profits when the seed or fibre is sold. The risk of growing hemp is low due to its low input requirements and the usefulness of each part of the crop: flowers, leaves, stalks and seeds (see Sect. "Literature review"). The crop is also essential to include in crop rotation, as it can improve the soil for subsequent crops. It is able to absorb toxins and contaminated ions from the soil structure, improve the soil ecosystem, loosen the soil, etc. These benefits, coupled with the ability of the crop to grow in all types of soil, make it essential to include in arable cropping systems as well as grasslands to feed livestock.

Health benefits of the crop As discussed in Sect. "Literature review", hemp has many health benefits. Hempseed is a potential source of gluten-free flour for people diagnosed with celiac diseases; it is also a rich source of essential amino acids for vegans or people who do not consume animal proteins. Its fibre is essential for producing allergen-free clothes, making it an excellent substitute for cotton and synthetics. Furthermore, hemp seed oil is used in pharmacology to produce many drugs to treat diseases. It is also used in cosmetics to produce products that improve the skin and treat a variety of skin conditions. The health benefits of hemp crops are important and strong for the hemp sector.

Weaknesses

Difficult to obtain a licence A major challenge faced by all hemp growers, especially in Scotland, is the process required to obtain a licence for production. Most farmers describe the process as cumbersome, and the licence fee is too expensive. As discussed above, the hemp crop is classified under regulated drugs requiring approval from the UK Home Office prior to cultivation. Without relaxing the regulations, it will be difficult for interested farmers to pursue the cultivation of hemp.

Low profitability of the crop Although hemp is traditionally believed to be a highly profitable crop, Scottish growers tend to disagree. This could be due to many local factors affecting commercial production of the crop. First, farmers are unable to sell their output due to low acreage under cultivation. Most processors who import hempseed or fibre are unable to purchase hempseed or fibre from these farmers because of their low tonnage. These processors consider changing suppliers to be a large risk if these farmers are unable to meet their monthly or annual demand for production. There are also certain criteria that seeds or fibres must meet before they can be sold to these processors/manufacturers/wholesalers. As a result, most farmers process their own products via inefficient technologies. Second, the highly distributed and small number of farmers does not give Scottish hemp growers market power to influence the price they attract from potential buyers.

Lack of technical support Another major weakness of the Scottish hemp sector is the lack of extension or technical support. Farmers do not receive agronomic and marketing support from government-trained agencies because of the prejudice attached to the crop. This has resulted in farmers using trial and error techniques that affect their output and profit margins.

Lack of processing facilities The lack of processing facilities for hemp seed and fibre is a major limitation to the growth and development of the Scottish hemp sector. This has implications for value addition and profit margins. Farmers are forced to sell raw produce since they are unable to add value to the products. As a result, a major share of the profit is lost to either the processer or the retailer. The product is also disposed of soon after harvesting at lower prices because farmers are unable to process it to extend its shelf life.

No established market routes Another major barrier to the success of the Scottish hemp sector is the lack of well-established market routes. Farmers are unsure of who their potential buyers are even though most have proposed selling their products to consumers, retailers and wholesalers. There are no clearly defined marketing channels or established agents who are readily available to purchase their output. As a result, farmers have to market the product themselves to be able to continue producing each year. Well-established wholesalers, processors and retail centres are essential for the growth of the Scottish hemp sector.

High seed cost and weather limitations There are no established seed growers in Scotland or the UK. As a result, farmers must ensure that 100% of the seeds they grow are important. This imposes a significant financial burden on the farmers since they do not have the market power to affect the price they pay for the seeds. The constant fluctuation in the hempseed price also affects the price they pay each year. Therefore, there is a need to establish a hempseed production farm to eliminate this barrier. Another important limitation is the weather, which does not allow farmers to grow hemp all year round.

Opportunities

Financial support The first important opportunity mentioned by farmers is providing financial support to ensure the viability of the sector. Each part of the hemp crop provides the opportunity for financial growth. However, this is only possible if farmers are able to receive financial support to build infrastructure to process and add value to the raw output. Hemp processing machinery requires significant financial commitment and serves as an opportunity to develop and expand the sector. A well-established processing facility extends the shelf life of hempseed or fibre until it moves along the next link in the supply chain. Farmers also mentioned the need for financial assistance to fund more trials of different varieties of hemp seeds in Scotland. While this is important, establishing a seed centre where farmers can buy their seeds for cultivation will also reduce the cost and difficulties they face in importing hempseed.

Market routes The farmers identified that the lack of established market routes for both hempseed and fibre was a challenge. Several interviewees suggested that a well-developed market route will enhance the development of the Scottish hemp sector. Therefore, stakeholder support is necessary to assist growers in obtaining marketing routes within Scotland, the UK and international markets. The GNP database suggests that many hemp-based products are produced each year by food and drink manufacturers. A strong link between Scottish farmers and these manufacturers or processors is necessary for a thriving hemp sector.

Carbon credits The cultivation of hemp enhances carbon sequestration, which should be considered an opportunity for hemp farmers to receive carbon credits. The hemp plant can also store most of the carbon it takes from the atmosphere during its lifecycle. Farmers could be rewarded for allocating land to the production of hemp and improving the natural ecosystem. Rewards in the form of carbon credits encourage other farmers to incorporate hemp into their farming system.

Relax the licencing process The current legislation regarding the growth of hemp in Scotland does not encourage farmers to produce on a large scale. This prevents farmers from venturing into hemp production. Farmers are unable to sell leaves and flowers, which have important pharmaceutical benefits. The required *tetrahydrocannabinol* (THC) level of less than 0.2% is a major limiting factor since it has been raised to approximately 2% in Uruguay [48]. Switzerland and Australia allow their farmers to grow hemp varieties with a THC level of 1%. By relaxing the current regulations on the cultivation of hemp, many farmers will take advantage of the conducive environment to expand production and attract new farmers.

Threats

There are several internal and external factors that have the potential to harm the development of a sustainable hemp supply chain. To identify these factors, the farmers were asked to select the hemp legislation that they considered a threat to the hemp sector among several factors.

The following factors were identified as threats to the development of the hemp sector in Scotland:

1) *Difficulty obtaining a licence*—Currently, licences for industrial hemp are valid for three growing seasons, after which the farmer needs to go through the same process to have the licence renewed. A one-time licence for industrial hemp cultivation could encourage farmers to make long-term plans regarding the cultivation of the crop.

2) *Destruction of the leaves and flowers* of industrial hemp prior to cultivation represents a loss of additional revenue to the hemp sector considering the importance of these two parts of the crop. As described above, the leaves and flowers are of both cosmetic and medicinal value.
3) *High licensing* costs—According to the Home Office, a new licence application to cultivate cannabis with a THC content of 0.2% or lower will cost £580. Farmers are also required to pay a compliance visit fee of £1371 and a licence renewal fee of £326. These costs may disincentivise new farmers, as the sector does not have strong market routes for outputs.
4) *Labelling hemp as a restricted crop*—Categorising industrial hemp under controlled drugs has created an image that undermines the acceptance of the crop and its parts for domestic and industrial use. The UK government could consider listing the crops under tree crops planted in the UK.

Other factors, such as difficulty getting the farmers to work together and restrictions on the type of fields used to grow the hemp crop, were also considered threats to the success of the sector.

Policy recommendations

Figure 14 presents the roadmap for developing a strong and resilient supply chain for hemp in Scotland. The recommendation is divided by timescale. Short-term recommendations can be achieved with minimal resources in a period of 1–5 years. Medium-term measures are those that require some amount of planning and commitment from policymakers and stakeholders in the hemp sector. These could be achieved within a timeframe of 6–10 years. Finally, long-term recommendations are expected to be achieved after 10 years, when the supply chain is well developed. A brief description of the recommendations is provided below.

Education/technical support

This study suggests that farmers believe that there is prejudice against hemp crops. In collaboration with the British Hemp Alliance, the Scottish Hemp Association could develop a programme through educational resources, such as a podcast and/or video series, to educate the population about the benefits of industrial hemp and explain the differences between industrial hemp and marijuana. This will help garner support from the grassroots community to advance the call for relaxation of the legislation, help eliminate the prejudice the public has toward the crop and gain support from the population to

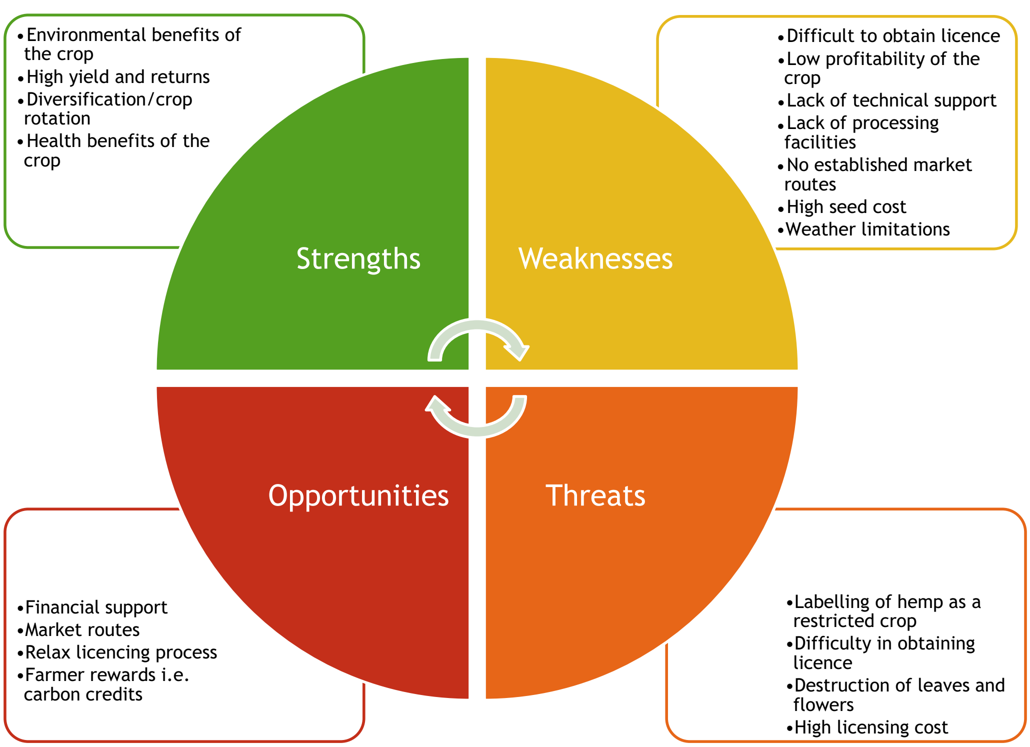

Fig. 14 A roadmap for developing a supply chain for Scottish hemp. Source: Own computation

advance the goal of developing a supply chain for hemp in Scotland.

The Scottish Agricultural College, which delivers extension services to farmers in Scotland, could also develop programmes to provide both agronomic and technical support to hempseed and fibre farmers. There is a need to inform hemp farmers about the number of seeds needed to grow hemp and fibre per acre of land, the depth to sow the seed, the cultural practices to carry out before and after planting and how to harvest their products to minimise postharvest losses. This will be crucial to developing a strong production chain in the supply channel.

Carbon credits

The Scottish Government aims to reach net-zero emissions of all greenhouse gases and emissions by 2045. Hemp cultivation could be a cost-effective means of contributing to a net zero goal. This study therefore recommends including hemp cultivation as a strategy to decarbonise the agricultural sector. Hemp has environmental benefits, i.e. carbon sequestration and the ability of the crop to store approximately 45% of the carbon it takes from the atmosphere during photosynthesis [13]. However, a greater evidence base is needed to ascertain the extent of the carbon sequestration potential of hemp and how this potential compares with that of other crops. The provision of permits to sell the carbon credits generated from planting hemp could support hemp farming. Businesses looking to offset their carbon footprint could be linked with these Scottish hemp farmers through the Woodland Carbon Guarantee4F.[4] Farmers not only benefit from the economic value of hempseed and fibre, but also contribute to their sector and wider society, becoming net zero.

Removal/relaxation of restrictions on hemp

A review of restrictions on places where hemp can be grown would assist the sector and create the opportunity to grow hemp on marginal lands. The UK government (Home Office) could also ensure that the number of days it takes for farmers to obtain a licence is reduced since the crop can be grown only once a year. Licencing cost and processing time are major deterrents for new entrants; new farmers will be unable to benefit from the environmental impact of the crop if this limitation is not lifted.

Strong horizontal and vertical linkages

One major setback identified in the Scottish hemp sector is weak horizontal and vertical linkages. It is recommended that farmers develop strong horizontal linkages among themselves to give a strong voice to the sector. Horizontal linkages refer to collaboration between farmers, either formally or informally. Strong coordination and communication are necessary to build a strong and resilient hemp sector, reduce transaction costs and enhance the competitiveness of the industry. Farmers must agree on what type of hemp variety to grow, the quality and price to offer for sale, etc. Vertical linkage refers to the relationship between firms at different levels of the supply chain, i.e. between farmers and processors, processors and retailers, retailers and consumers, etc. Strong coordination between marketing channel members is necessary for the development of the Scottish hemp sector. Farmers must understand what processors want and how to meet their needs; processors must understand the needs of retailers; and retailers must understand what consumers want. The existence of a strong vertical linkage between processors and consumers will enable retailers to better communicate the health and environmental benefits of hemp products to consumers and receive appropriate feedback to give to processors. This will facilitate the development of innovative, affordable and appealing products that meet the tastes and preferences of consumers. In summary, a strong vertical link will likely reduce waste and inefficiency in the supply chain.

Development of a strong processing sector

The Scottish hemp sector cannot achieve both national and international impact without a thriving hemp processing sector within the supply chain. Although new products containing hemp ingredients are developed each year in the UK food and drinks sector, other avenues, such as the construction sector; livestock, poultry and aquatic feed sector; and the cosmetic, textile, and automotive industries, should be brought into the loop. Hemp processing machinery requires significant financial investment and therefore stakeholder support. A strong manufacturing/processing sector will enhance the hemp supply chain in Scotland, as this is the main limitation to the development of the hempseed and fibre sector. Farmers need to reduce the risk of their investment and commit to large production only when there is a ready market for their output.[5]

[4] The Woodland Carbon Code is a government scheme administered by Scottish Forestry but applicable across the UK.

[5] According to a news item by *The Press and Journal*, cold pressed hemp oil was commercially produced in Scotland in June 2022. This is a breakthrough for hemp seed farmers in Scotland.

In the short term, the Scottish Hemp Association can act as a middle person to develop links with hemp processors such as Good Hemp and IndiNature. Farmers will be required to meet the quality requirements and supply demand of these major processors to become their suppliers. This could be achieved by working together with academic sector/extension services to develop innovative and higher-value products that meet the demands of processors.

Scottish seed production centre

Currently, two types of hemp varieties are being tested in Scotland: Finola and Henola. These products are imported from outside the UK and may not be productive in Scottish conditions. To establish a strong Scottish hemp sector, it is recommended that the sector that supports organisations and research institutes explore the potential to establish a hemp seed production centre. This will enable the centre to breed seeds that are suitable for the Scottish climate and soils and meet the quality requirements of UK-based processors. This will potentially reduce the reliance on foreign partners such as Germany and France for seeds. A strong Scottish seed production sector will also enhance the sustainability of the sector by limiting the impacts of external market shocks on growers.

Strong and well-coordinated hemp growers' associations

Finally, the SHA should work to develop a strong and well-coordinated hemp growers' association for Scotland. This could be accomplished by holding regular meetings to educate farmers on happenings in the sector and address challenges faced by farmers. Working together as a farmer group can increase the capacity of farmers, give them market power to buy seeds and market their outputs, and provide a strong voice to influence policy. Farmers can also pull resources together to establish a strong processing sector to extend the shelf life of their products and increase their profit margins. The association could also rely on the expertise of researchers working for the SEFARI and on SG-funded research programmes on hemp. This will help bridge the knowledge gap.

Conclusion

The growing demand for eco-friendly food and industrial products have renewed interest in industrial hemp which is a low-cost, biodegradable, sustainable, and multi-purpose plant. Hempseeds are high in protein, omega-3 and omega-6 fatty acids, and hemp fibre is a sustainable alternative to cotton, fossil fuel, and current synthetic insulation material. Many countries in Europe and Asia have changed their laws to take advantage of the tremendous benefits that industrial hemp present. However, the development of the sector in Scotland is very slow. The goal of the present work is to provide objective insights into the current and potential market opportunities, supply chain profile, and trends in new product development involving industrial hemp to develop a roadmap for hemp production in Scotland.

The study is based on desk research, primary and secondary data analysis. The literature review summarises, collates and synthesises the results from existing research on hemp production worldwide. It gathers online data on published scientific and gray literature, as well as government-published data such as FAOSTATS, EUROSTAT and HMRC data. The results are based on the analysis of secondary data from the Global New Product Database (GNPD), which contains information on products launched from 1997 to 2021 containing industrial hemp as an ingredient. This information was used to assess trends in new product development in the hemp market. The second section of the results is based on the analyses the supply chains for hemp seed and fibre in Scotland using primary data collected from farmers in Aberdeen, Aberdeenshire and Scottish Borders.

The results of the study show that the potential opportunities for hemp seed and fibre are vast: hemp can sequester more carbon dioxide than traditional crops can, improve soil biodiversity, extract toxins from soil through phytoremediation, can be used as an eco-friendly insecticide and pesticide, and provide an excellent source of protein, fibre and micronutrient vitamins and minerals, as well as a range of bioactive phytochemicals. More than 4076 hemp-based products have been launched worldwide. However, the supply chain for Scottish-grown hemp is still underdeveloped. Farmers have faced many setbacks, including a lack of well-established market routes, high licensing costs and a lack of a hemp-seed-pressing centre. The study concludes with strong and time-bound recommendations that are necessary to advance hemp production and in countries considering hemp production. In summary, these structures have to be in place to develop a strong hemp sector: regular extension services, easy access to licences for production, established hemp seed and fibre processing plant, and seed production centre.

Despite the contribution of the work to the discussion on the topic, there are certain limitations that would influence the generalisation of the results. First, the number of farmers that were sample are few. Unfortunately, there are few farmers who are currently trying the crop as a result we were unable to sample a number that would increase the precision and generalisability of our results. Future research can consider interviewing farmers outside of Scotland to increase the sample size and the precision of the results. Also, the study relied heavily on secondary data and literature which may not be fully accurate and/or up to date. This could also affect the reliability of the findings. A consumer and market analysis of the use of hemp as food and fibre in Scotland will provide a more accurate information about the market potential for the crop.

Third, scope of the study was limited to farmers based in specific regions of Scotland, such as Aberdeen and Aberdeenshire. This may not fully represent the entire country's potential. Third, the GNPD does include the type and quantity of hemp ingredients in the products launched. This makes it difficult to ascertain the extent to which the product can be considered as hemp-based. Finally, the economic potential of the crop may be significantly different for Scotland due to weather conditions, seed type and geographical differences. Future research could perform a cost–benefit analysis to ascertain the economic viability of the crop in Scotland.

Acknowledgements
The authors wish to acknowledge the contributions of the following people: Helen Glass, Charles Bestwick, Kyle Esplin, Andrew Kelloe, and Julia Mitchell.

Author contributions
WD: methodology, formal analysis, validation, writing- original draft preparation, visualisation. CRG: data curation, supervision, writing- reviewing and editing. WR: conceptualisation, supervision, reviewing and editing.

Funding
This research received financial support from the Scottish Environment and Food and Agriculture Research Institutions.

Availability of data and materials
The authors do not have permission to share the primary data used in the analysis. The secondary data are publicly available.

Declarations

Ethics approval and consent to participate
The study received ethics approval from the Rowett Institute's Ethics Approval Committee. Informed consent was given to and signed by the participants before the data collection.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Received: 25 April 2024 Accepted: 30 October 2024
Published online: 20 January 2025

References

1. Abé H, Foko Dadji AF, Nkondjio CA, Awono-Ambene PH, Tamesse JL. Insecticidal activity of *Cannabis sativa* L. leaf essential oil on the malaria vector *Anopheles gambiae* sl (Giles). Int J Mosq Res. 2018;5:65–74.
2. Adams R. Marihuana: harvey lecture, February 19, 1942. Bull N Y Acad Med. 1942;18(11):705.
3. Ahmad M, Ullah K, Khan MA, Zafar M, Tariq M, Ali S, Sultana S. Physicochemical analysis of hemp oil biodiesel: a promising non edible new source for bioenergy. Energy Sourc Part A Recov Utiliz Environ Effects. 2011;33(14):1365–74. https://doi.org/10.1080/15567036.2010.499420.
4. Amaducci S, Gusovius HJ. Hemp--cultivation, extraction and processing. Industrial applications of natural fibres: structure, properties and technical applications, 2010, 109–134.
5. Arnall B, Bushong J, Lofton J. Agronomic Considerations for Industrial Hemp Production . Oklahoma State University. 2019. https://extension.okstate.edu/fact-sheets/agronomic-considerations-for-industrial-hemp-production.html
6. Arnaud L. Mechanical and thermal properties of hemp mortars and wools: experimental and theoretical approaches. Bioresource Hemp. 2000
7. Barberà L, Pèlach MA, Pérez I, Puig J, Mutjé P. Upgrading of hemp core for papermaking purposes by means of organosolv process. Ind Crops Prod. 2011;34(1):865–72. https://doi.org/10.1016/J.INDCROP.2011.02.005.
8. Baxter WJ. Growing Industrial Hemp in Ontario. 2000. http://www.omafra.gov.on.ca/english/crops/facts/00-067.htm
9. Bedini S, Flamini G, Cosci F, Ascrizzi R, Benelli G, Conti B. *Cannabis sativa* and *Humulus lupulus* essential oils as novel control tools against the invasive mosquito *Aedes albopictus* and fresh water snail *Physella acuta*. Ind Crops Prod. 2016;85:318–23. https://doi.org/10.1016/J.INDCROP.2016.03.008.
10. Benelli G, Pavela R, Petrelli R, Cappellacci L, Santini G, Fiorini D, Sut S, et al. The essential oil from industrial hemp (*Cannabis sativa* L.) by-products as an effective tool for insect pest management in organic crops. Ind Crops Prod. 2018;122:308–15. https://doi.org/10.1016/J.INDCROP.2018.05.032.
11. Bertoli A, Tozzi S, Pistelli L, Angelini LG. Fibre hemp inflorescences: from crop-residues to essential oil production. Ind Crops Prod. 2010;32(3):329–37. https://doi.org/10.1016/J.INDCROP.2010.05.012.
12. Bos H. The potential of flax fibres as reinforcement for composite materials. Wageningen University and Research. 2004
13. Bouloc P. Hemp: industrial production and uses. CABI. 2013.
14. Brugère C, Ridler N. Global aquaculture outlook in the next decades: an analysis of national aquaculture production forecasts to 2030 (0429–9329). 2004. https://www.fao.org/publications/card/en/c/6bc7993d-f86d-5d55-bbf1-aa398b71ff65/
15. Bugnet J, Morin-Crini N, Cosentino C, Chanet G, Winterton P, Crini G. Hemp decontamination of poly-metallic aqueous solutions. Environ Eng Manag J (EEMJ), 2017;16(3).
16. Burczyk H, Grabowska L, Koodziej J, Strybe M. Industrial hemp as a raw material for energy production. J Indus Hemp. 2008;13(1):37–48. https://doi.org/10.1080/15377880801898717.
17. Callaway JC. Hempseed as a nutritional resource: an overview. Euphytica. 2004;140(1):65–72.
18. Ceyhan V, Türkten H, Yıldırım Ç, Canan S. Economic viability of industrial hemp production in Turkey. Indus Crops Prod. 2022;176:114354. https://doi.org/10.1016/j.indcrop.2021.114354.
19. Cigasova J, Stevulova N, Schwarzova I, Sicakova A, Junak J. Application of hemp hurds in the preparation of biocomposites. IOP Conf Ser Mater Sci Eng. 2015;96(1): 012023. https://doi.org/10.1088/1757-899X/96/1/012023.
20. Clarke RC. Botany of the genus Cannabis. Binghamton: Haworth Press; 1999.
21. Crini G, Lichtfouse E, Chanet G, Morin-Crini N. Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: a review. Environ Chem Lett. 2020;18(5):1451–76.
22. Crini G, Lichtfouse E, Chanet G, Morin-Crini N. Traditional and new applications of hemp. Sustain Agric Rev. 2020;42:37–87.
23. Crini G, Lichtfouse E, Chanet G, Morin-Crini N. Traditional and new applications of hemp. Sustain Agric Rev. 2020;42:37–87. https://doi.org/10.1007/978-3-030-41384-2_2.

24. Das L, Liu E, Saeed A, Williams DW, Hu H, Li C, Ray AE, Shi J. Industrial hemp as a potential bioenergy crop in comparison with kenaf, switchgrass and biomass sorghum. Biores Technol. 2017;244:641–9.
25. Deferne J-L, Pate DW. Hemp seed oil: a source of valuable essential fatty acids. J Int Hemp Assoc. 1996;3(1):1–7.
26. Dempsey JM. Hemp. In: Fiber crops. University of Florida Press. 1975
27. der Werf HMG. Life cycle analysis of field production of fibre hemp, the effect of production practices on environmental impacts. Euphytica. 2004;140(1):13–23.
28. Du Bois WF. Hennep als grondstof voor de papierindustrie. 1982
29. Dunford NT. Hemp and flaxseed oil: Properties and applications for use in food. Specialty oils and fats in food and nutrition: properties, processing and applications, 2015, 39–63. https://doi.org/10.1016/B978-1-78242-376-8.00002-8
30. Dutt D, Singh V, Ray AK, Mukherjee S. Development of specialty papers is an art: electrical insulation paper from indigenous raw materials—part IX. 2003
31. Dutt D, Tyagi CH, Upadhyay JS. Hygienic and cost efficient technology for the development of tea bag paper from indigenous raw materials. Cellul Chem Technol. 2007;41(4):291.
32. Dutt D, Upadhyaya JS, Ray AK, Malik RS, Upadhyaya MK. Development of specialty papers is an art: wax match tissue paper from indigenous raw materials—part I. 2002
33. Dutt D, Upadhyaya JS, Tyagi CH, Malik RS. Studies on pulp and paper making characteristics of some Indian non-woody fibrous raw materials-Part II. 2004
34. Edwards KJ, Whittington G. Palynological evidence for the growing of *Cannabis sativa* L (hemp) in medieval and historical Scotland. Trans Inst Br Geogr. 1990. https://doi.org/10.2307/623093.
35. Euromonitor International. Beauty and personal care—market size data. 2020. https://www.euromonitor.com/beauty-and-personal-care
36. Euromonitor International. Alcoholic & soft drinks and packaged food—market size data. 2020. https://www.euromonitor.com/industries
37. Farrokhnia M, Banihashem SK, Noroozi O, Wals A. A SWOT analysis of ChatGPT: Implications for educational practice and research. Innov Educ Teach Int. 2024;61(3):460–74. https://doi.org/10.1080/14703297.2023.2195846.
38. Faruk O, Bledzki AK, Fink H-P, Sain M. Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci. 2012;37(11):1552–96.
39. Faruk O, Bledzki AK, Fink HP, Sain M. Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci. 2012;37(11):1552–96. https://doi.org/10.1016/J.PROGPOLYMSCI.2012.04.003.
40. Figueiredo JA, Ismael MI, Anjo CMS, Duarte AP. Cellulose and derivatives from wood and fibers as renewable sources of raw-materials. Carbohydr Sustain Dev. 2010;I:117–28.
41. Fortune Business Insights. *Hemp Seeds Market. Fortune Business Insights*. 2022. https://www.fortunebusinessinsights.com/hemp-seeds-market-103478
42. Galasso, I., Russo, R., Mapelli, S., Ponzoni, E., Brambilla, I. M., Battelli, G., & Reggiani, R. (2016). Variability in seed traits in a collection of Cannabis sativa L. genotypes. *Frontiers in Plant Science*, 688.
43. Gibson K. Hemp in the British Isles. J Indus Hemp. 2006;11(2):57–67.
44. Girouard P. Insights of the French hemp program. In *REAP Canada*. 1994. https://eap.mcgill.ca/MagRack/SF/Fall.94 K.htm
45. Görener A, Toker K, Ulucay K. Application of combined SWOT and AHP: a case study for a manufacturing firm. Procedia Soc Behav Sci. 2012;58:1525–34.
46. Hanson J. An outline for a UK hemp strategy. The Ecologist. 1980;10:260–3.
47. Home Office. *Factsheet- Cannabis, CBD and other cannabinoids*. Drugs and Firearms Licensing – Crime, Policing and Fire Group. 2022. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/825872/factsheet-cannabis-cbd-and-cannabinoids-2019.pdf
48. Hudak J, Ramsey G, Walsh J. Uruguay's cannabis law: pioneering a new paradigm. Washington: Center for Effective Public Management at Brookings; 2018.
49. Hullar I, Meleg I, Fekete S, Romvari R. Studies on the energy content of pigeon feeds I. Determination of digestibility and metabolizable energy content. Poultry Sci. 1999;78(12):1757–62. https://doi.org/10.1093/PS/78.12.1757.
50. Ingrao C, Lo Giudice A, Bacenetti J, Tricase C, Dotelli G, Fiala M, Siracusa V, Mbohwa C. Energy and environmental assessment of industrial hemp for building applications: a review. Renew Sustain Energy Rev. 2015;51:29–42. https://doi.org/10.1016/J.RSER.2015.06.002.
51. Ionescu N, Popescu M, Bratu A, Istrati D, Ott C, Meghea A. Valuable Romanian vegetable oils and extracts with high pharmaco-cosmetic potential. Rev Chim. 2015;66:1267–72.
52. Iványi I, Izsáki Z. Role of fibre hemp (*Cannabis sativa* L.) in sustainable agriculture. Cereal Res Commun. 2007;35(2):509–12.
53. Jeyasingam JT. Smokers take in the benefits of hemp pulp. Pulp Paper Int. 1994;36(3):45–7.
54. Jianyong F, Jianchun Z. Preparation and oil/air filtration properties of hemp paper. J Ind Text. 2015;45(1):3–32.
55. Karus M, Ortmann S, Gahle C, Pendarovski C. Se of natural fibers in composites for the German automotive production from 1999 till 2005. In: *Hurth im Rheinland: Nova Institute GmbH*. 2006. https://doi.org/10.1177/0021998311413623
56. Khoathane MC, Vorster OC, Sadiku ER. Hemp fiber-reinforced 1-pentene/polypropylene copolymer: the effect of fiber loading on the mechanical and thermal characteristics of the composites. J Reinf Plast Compos. 2008;27(14):1533–44.
57. Knight K. EU hemp industry welcomes novel foods update but Sweden refuses to give green light. *Vitafoods Insights*. 2023. https://www.vitafoodsinsights.com/regulation/eu-hemp-industry-welcomes-novel-foods-update-sweden-refuses-give-green-light
58. Kocić A, Bizjak M, Popović D, Poparić GB, Stanković SB. UV protection afforded by textile fabrics made of natural and regenerated cellulose fibres. J Clean Prod. 2019;228:1229–37.
59. Kolodziejczyk P, Ozimek L, Kozłowska J. The application of flax and hemp seeds in food, animal feed and cosmetics production. Handbook Nat Fibres. 2012. https://doi.org/10.1533/9780857095510.2.329.
60. Kostic M, Pejic B, Skundric P. Quality of chemically modified hemp fibers. Biores Technol. 2008;99(1):94–9.
61. Kozlowski R, Baraniecki P, Barriga-Bedoya J. Bast fibres (flax, hemp, jute, ramie, kenaf, abaca). *Biodegradable and Sustainable Fibres*, 2005; 36–88.
62. Kreuger E, Sipos B, Zacchi G, Svensson SE, Björnsson L. Bioconversion of industrial hemp to ethanol and methane: the benefits of steam pretreatment and co-production. Biores Technol. 2011;102(3):3457–65. https://doi.org/10.1016/J.BIORTECH.2010.10.126.
63. Lamberti DD, Sarkar AK. Hemp fiber for furnishing applications. IOP Conf Ser Mater Sci Eng. 2017;254(19): 192009.
64. Li SY, Stuart JD, Li Y, Parnas RS. The feasibility of converting *Cannabis sativa* L. oil into biodiesel. Bioresour Technol. 2010;101(21):8457–60. https://doi.org/10.1016/J.BIORTECH.2010.05.064.
65. Linger P, Müssig J, Fischer H, Kobert J. Industrial hemp (*Cannabis sativa* L.) growing on heavy metal contaminated soil: fibre quality and phytoremediation potential. Indus Crops Prod. 2002;16(1):33–42.
66. Loiacono S, Crini G, Martel B, Chanet G, Cosentino C, Raschetti M, Placet V, Torri G, Morin-Crini N. Simultaneous removal of Cd Co, Cu, Mn, Ni, and Zn from synthetic solutions on a hemp-based felt. II. Chemical modification. J Appl Polym Sci. 2017;134(32):45138. https://doi.org/10.1002/APP.45138.
67. Mackinnon L, Mcdougall G, Aziz N, Millam S. Progress towards transformation of fibre hemp: Annual Report of the Scottish Crop Research Institute. In *Annual Report of the Scottish Crop Research Institute*. 2001. https://scri.webarchive.hutton.ac.uk/scri/files/annualreports/2001/11HEMP.PDF
68. Macpherson D, Anderson A. Annals of Commerce, Manufactures, Fisheries, and Navigation: With Brief Notices of the Arts and Sciences Connected with Them. Containing the Commercial Transactions of the British Empire and Other Countries, from the Earliest Accounts to the Meeting of th (Vol. 1). Nichols. 1805.
69. Malachowska E, Przybysz P, Dubowik M, Kucner M, Buzala K. Comparison of papermaking potential of wood and hemp cellulose pulps. Annals of Warsaw University of Life Sciences-SGGW. Forestry and Wood Technology, 2015:91
70. McKay MM. The Rev. Dr. John Walker's report on the Hebrides of 1764 and 1771. Edinburgh: John Donald; 1980.

71. Mechoulam R, Gaoni Y. The absolute configuration of $δ$1-tetrahydrocannabinol, the major active constituent of hashish. Tetrahedron Lett. 1967;8(12):1109–11.
72. Mediavilla V, Steinemann S. Essential oil of *Cannabis sativa* L. strains. J Int Hemp Assoc. 1997;4:80–2.
73. Meena SR, Meena SD, Pratap S, Patidar R, Daultani Y. Strategic analysis of the Indian agri-food supply chain. Opsearch. 2019;56(3):965–82.
74. Miao C, Hui L-F, Liu Z, Tang X. Evaluation of hemp root bast as a new material for papermaking. BioResources. 2014;9(1):132–42.
75. Mikulec A, Kowalski S, Sabat R, Skoczylas Ł, Tabaszewska M, Wywrocka-Gurgul A. Hemp flour as a valuable component for enriching physicochemical and antioxidant properties of wheat bread. LWT. 2019;102:164–72.
76. Milne E. Aberdeen University research inspires first commercial production of cold pressed hemp oil in Scotland. The Press and Journal. 2022. https://www.pressandjournal.co.uk/fp/news/aberdeen-aberdeenshire/4430688/aberdeen-university-research-inspires-first-commercial-production-of-cold-pressed-hemp-oil-in-scotland/
77. Montford S, Small E. A comparison of the biodiversity friendliness of crops with special reference to hemp (*Cannabis sativa* L.). J Int Hemp Assoc. 1999;6(2):53–63.
78. Moujalled B, Aït Ouméziane Y, Moissette S, Bart M, Lanos C, Samri D. Experimental and numerical evaluation of the hygrothermal performance of a hemp lime concrete building: a long term case study. Build Environ. 2018;136:11–27. https://doi.org/10.1016/J.BUILDENV.2018.03.025.
79. Mukhtar T, Kayani MZ, Hussain MA. Nematicidal activities of *Cannabis sativa* L. and *Zanthoxylum alatum* Roxb. against Meloidogyne incognita. Indus Crops Prod. 2013;42(1):447–53. https://doi.org/10.1016/J.INDCROP.2012.06.027.
80. Multari S, Neacsu M, Scobbie L, Cantlay L, Duncan G, Vaughan N, Stewart D, Russell WR. Nutritional and phytochemical content of high-protein crops. J Agric Food Chem. 2016;64(41):7800–11.
81. Muzyczek M. The use of flax and hemp for textile applications. In: Handbook of natural fibres (pp. 147–167). Elsevier. 2020.
82. Neacsu M, Vaughan NJ, Multari S, Haljas E, Scobbie L, Duncan GJ, Cantlay L, Fyfe C, Anderson S, Horgan G, Johnstone AM, Russell WR. Hemp and buckwheat are valuable sources of dietary amino acids, beneficially modulating gastrointestinal hormones and promoting satiety in healthy volunteers. Eur J Nutr. 2022;61(2):1057–72. https://doi.org/10.1007/s00394-021-02711-z.
83. Omnes M-A. Industrial Hemp in France. 2021.
84. Pavlovic R, Panseri S, Giupponi L, Leoni V, Citti C, Cattaneo C, Cavaletto M, Giorgi A. Phytochemical and ecological analysis of two varieties of hemp (*Cannabis sativa* L) grown in a mountain environment of Italian Alps. Front Plant Sci. 2019;10:1265.
85. Pejic B, Vukcevic M, Kostic M, Skundric P. Biosorption of heavy metal ions from aqueous solutions by short hemp fibers: effect of chemical composition. J Hazard Mater. 2009;164(1):146–53. https://doi.org/10.1016/J.JHAZMAT.2008.07.139.
86. Pernevan MS, Marsavina L, Pernevan I, Popescu M. Comparative analysis regarding the mechanical properties of polymer matrix based biocomposites reinforced with hemp scraps - proquest. In: *International Multidisciplinary Scientific GeoConference* (Vol. 4, pp. 667–674). 2012. https://www.proquest.com/docview/1444046704/abstract/78D82498984446D5PQ/1?accountid=8155#
87. Pihlanto A, Mattila P, Mäkinen S, Pajari A-M. Bioactivities of alternative protein sources and their potential health benefits. Food Funct. 2017;8(10):3443–58.
88. Pimentel D, McLaughlin L, Zepp A, Lakitan B, Kraus T, Kleinman P, Vancini F, Roach WJ, Graap E, Keeton WS, et al. Environmental and economic impacts of reducing US agricultural pesticide use. Pesticide Quest Environ Econ Ethics, 1993;223–278.
89. Pretot S, Collet F, Garnier C. Life cycle assessment of a hemp concrete wall: Impact of thickness and coating. Build Environ. 2014;72:223–31. https://doi.org/10.1016/J.BUILDENV.2013.11.010.
90. Rehman M, Fahad S, Du G, Cheng X, Yang Y, Tang K, Liu L, Liu FH, Deng G. Evaluation of hemp (*Cannabis sativa* L.) as an industrial crop: a review. Environ Sci Pollut Res. 2021;28(38):52832–43. https://doi.org/10.1007/S11356-021-16264-5/FIGURES/7.
91. Rehman MSU, Rashid N, Saif A, Mahmood T, Han JI. Potential of bioenergy production from industrial hemp (*Cannabis sativa*): Pakistan perspective. Renew Sustain Energy Rev. 2013;18:154–64. https://doi.org/10.1016/J.RSER.2012.10.019.
92. Research Dive. Global Aquaculture Market Predicted to Generate a Revenue. Globe News Wire. 2021. https://www.globenewswire.com/news-release/2021/09/01/2290138/0/en/Global-Aquaculture-Market-Predicted-to-Generate-a-Revenue-of-310-291-7-Million-at-a-CAGR-of-3-9-during-the-Forecast-Period-2020-2027-Exclusive-Report-241-Pages-by-Research-Dive.html
93. Riddlestone S. Hemp Textiles in Britain-Opportunities for bioregional development. 1996; 1–9.
94. Roulac JW. Hemp horizons: the comeback of the world's most promising plant. 1997
95. Schofield JE, Waller MP. A pollen analytical record for hemp retting from Dungeness Foreland, UK. J Archaeol Sci. 2005;32(5):715–26.
96. Shahzad A. Hemp fiber and its composites–a review. J Compos Mater. 2012;46(8):973–86.
97. Shannon WD. Hemp cultivation and processing in North-West England. North Hist. 2024;61(2):202–25.
98. Shinde PA, Abbas Q, Chodankar NR, Ariga K, Abdelkareem MA, Olabi AG. Strengths, weaknesses, opportunities, and threats (SWOT) analysis of supercapacitors: A review. J Energy Chem. 2023;79:611–38. https://doi.org/10.1016/j.jechem.2022.12.030.
99. Sinclair J. Statistical accounts of Scotland: Vol. VII (p. 293). 1793 https://stataccscot.edina.ac.uk/static/statacc/dist/home
100. Sinclair J. General report of the agricultural state, and political circumstances of Scotland.: Vol. I (p. 590). 1814. https://stataccscot.edina.ac.uk/static/statacc/dist/home
101. Sipos B, Kreuger E, Svensson SE, Réczey K, Björnsson L, Zacchi G. Steam pretreatment of dry and ensiled industrial hemp for ethanol production. Biomass Bioenerg. 2010;34(12):1721–31. https://doi.org/10.1016/J.BIOMBIOE.2010.07.003.
102. Small E, Marcus D. Hemp: a new crop with new uses for North America. In J. Janick & A. Whipkey (Eds.), Trends in new crops and new uses (pp. 1–43). ASHS Press. 2002. https://tmozart.com/hthemp/docs/hemp.pdf
103. Smith-Heisters S. Environmental costs of hemp prohibition in the United States. J Indus Hemp. 2008;13(2):1–22. https://doi.org/10.1080/15377880802391308.
104. Stanković SB, Novaković M, Popović DM, Poparić GB, Bizjak M. Novel engineering approach to optimization of thermal comfort properties of hemp containing textiles. J Text Inst. 2019;110(9):1271–9. https://doi.org/10.1080/00405000.2018.1557367.
105. Tallon MJ. *Cannabis sativa* L. and its extracts: regulation of cannabidiol in the European Union and United Kingdom. J Diet Suppl. 2020;17(5):503–16. https://doi.org/10.1080/19390211.2020.1795044.
106. Technavio. Global Textile Market 2019–2023. 2019
107. Teoli D, Sanvictores T, An J. SWOT analysis. 2019.
108. Misuse of Drugs Act 1971, Pub. L. No. 38 1971.
109. Thomas TG, Sharma SK, Anand P, Sharma BR, et al. Insecticidal properties of essential oil of *Cannabis sativa* Linn. against mosquito larvae. Entomon. 2000;25(1):21–4.
110. Thompson EC, Berger MC, Allen SN. Economic impact of industrial hemp in Kentucky. Citeseer. 1998
111. United Nations. Conversion on psychotropic substances. In: United Nations. 1971. https://www.unodc.org/pdf/convention_1971_en.pdf
112. United Nations. Commentary on the single convention on narcotic drugs, 1961. 1973. https://www.unodc.org/pdf/convention_1961_en.pdf
113. van der Werf H. The role of hemp in sustainable development. CABI. 2013.
114. Vukčević MM, Kalijadis AM, Vasiljević TM, Babić BM, Laušević ZV, Laušević MD. Production of activated carbon derived from waste hemp (Cannabis sativa) fibers and its performance in pesticide adsorption. Microporous Mesoporous Mater. 2015;214:156–65. https://doi.org/10.1016/J.MICROMESO.2015.05.012.
115. Vukcevic M, Pejic B, Lausevic M, Pajic-Lijakovic I, Kostic M. Influence of chemically modified short hemp fiber structure on biosorption process of Zn^{2+} ions from waste water. Fibers Polymers. 2014;15(4):687–97. https://doi.org/10.1007/S12221-014-0687-9.

116. Wambua P, Ivens J, Verpoest I. Natural fibres: can they replace glass in fibre reinforced plastics? Compos Sci Technol. 2003;63(9):1259–64.
117. Wang Q, Xiong YL. Processing, nutrition, and functionality of hempseed protein: a review. Compreh Rev Food Sci Food Safety. 2019;18(4):936–52.
118. van der Werf HMG, Mathussen E, Haverkort AJ. The potential of hemp (*Cannabis sativa* L.) for sustainable fibre production: a crop physiological appraisal. Ann Appl Biol. 1996;129(1):109–23.
119. Whittington G, Edwards KJ. The cultivation and utilisation of hemp in Scotland. Scott Geogr Mag. 1990;106(3):167–73. https://doi.org/10.1080/00369229018736795.
120. Wrangham AH, SRUC A. A feasibility study on the reintroduction of Industrial Hemp, as an arable break-crop, in the United Kingdom. Scotland's Rural College. 2019.
121. Yano H, Fu W. Hemp: a sustainable plant with high industrial value in food processing. Foods. 2023;12(3):651.
122. Yao Y, Jian-Bo Z, Hao W, Ying Z, Li-Wei L, Jiang Y, Ting-Ting Y, Jiao X, Bao-Shan Y. Manufacturing technology and application of hemp cigarette paper with dense ash integration. IOP Conf Ser Earth Environ Sci. 2017;61(1): 012078. https://doi.org/10.1088/1755-1315/61/1/012078.
123. Zhang H, Zhong Z, Feng L. Advances in the performance and application of hemp fiber. Int J Simul Syst Sci Technol. 2016;17(9):11–8.
124. Zou X, El Fallah J, Goupil J-M, Zhu G, Valtchev V, Mintova S. Green removal of aromatic organic pollutants from aqueous solutions with a zeolite–hemp composite. RSC Adv. 2012;2(7):3115–22.

Publisher's Note