# A feasibility study on the reintroduction of Industrial Hemp, as an arable break-crop, in the United Kingdom

by

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# Summary

Industrial hemp is cultivated on an increasing scale in Europe, with large markets driven by demand in hemp seeds, flowers and leaves. However, the cultivar is grown on a very small scale in the UK, despite a long history of cultivation and increasing demand for hemp-derived products. The cultivar is also beneficial agronomically and makes a suitable break-crop in conventional cereals-dominated crop rotations. Therefore, this project explores the reasons why industrial hemp production has not increased in the UK, in the same way it has done in other parts of Europe. It also reviews the current European industrial hemp industry to identify key markets and products, before discussing the agronomic considerations for growing the cultivar. Subsequently, independent market research data is analysed, firstly to identify value chain structures, growth trends, opportunities and threats across various European industrial hemp supply chains, and secondly to consult UK farm businesses on their cropping practises, break-crop choices, decision factors, cropping concerns, drivers for change, and knowledge and perceptions on industrial hemp. Finally, the perceived barriers to growing industrial hemp as a break-crop in the UK are identified, and it is concluded that; if understanding of the crop amongst UK farmers can be improved, and investments can be made in infrastructure, machinery and equipment, then industrial hemp can become a viable arable break-crop in the UK.

# Contents

*"In the face of great global challenges in the area of climate change, food security and diminishing reserves of fossil fuels, the role of a low-input high yielding crop able to provide a range of high-quality renewable materials and chemicals, such as hemp, could not be more timely."*

Stefano Amaducci, 2017

Scientific Coordinator
Department of Sustainable Crop Production
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# Chapter 1: Introduction

Industrial hemp production is a complicated, diverse and variable subject. There is a century-long international controversy attached to the cultivar, and the disgrace caused by political and legislative turbulence remains. Nevertheless, research on the cultivar endures at a global scale and goes back hundreds of years, but is often contradictory, incomplete and disconnected. Whilst the cultivar is once again being grown in many countries around the world commercially, markets have generally only very recently become re-established, since political reform in the 1990's. Furthermore, whilst markets are somewhat volatile and difficult to predict in the long term, some are also extremely promising for the future of the agricultural industry.

The cultivar has thousands of uses, and innovative applications for the plants constituents have evolved within many different industries, from pharmaceuticals to plastic alternatives. The methods of processing the various plant components are equally diverse, and the desired physical and biochemical properties of the plant can vary significantly based on the end application. Such properties are strongly influenced by cultivar variety and climate, as well as agronomic management, from sowing through to harvest, and indeed post-processing. As such, during this work it was soon realised it would be impossible to review every potential application, process and marketplace for the cultivar. Instead, the most promising applications were analysed in detail, as well as the methods and requirements for successful crop growth, to establish the most likely potential pathways for UK farmers to grow and market it successfully.

In chapter 2, literature including; peer-reviewed journals, press releases, books, market reports, academic reports, statistical data, archive information, blog posts and information from personal contacts were reviewed based on the history, core applications and key markets for industrial hemp. Firstly, in section 2.1, the Cannabis genus is described, detailing the taxonomy of the species and setting out how *hemp* is classified and the nomenclature that is most commonly used. *Industrial hemp* is then defined based on current law and regulation, and the complex evolution of the industry is reviewed up to the present day. This sets a foundation to analyse the most recent European hemp industry data and specifically discuss the on-going work by various UK hemp companies and institutions on the development of industrial hemp value chains, before reviewing the most promising contemporary applications for the cultivar. Modern applications and processes for hemp fibres are discussed, such as biocomposites and insulation materials, which are relatively under-utilised, but show strong potential for growth, as well as industrial hemp *shives* and their applications for building materials and animal bedding. Subsequently, hemp seeds, and the food products and various oils they produce, as well as Cannabis extract products, such as cannabinoids, derived from the plants leaves and flowers are discussed, all of which are applications of tremendous current interest, within markets showing particularly strong growth in Europe.

In section 2.3, the agronomic aspects of industrial hemp are discussed. Like any modern-day cultivar, industrial hemp thrives under certain conditions and there are many varieties bred for different climates and applications. For any cultivar to be grown at scale by UK farm businesses, it must firstly be agronomically viable and beneficial. Thankfully, despite prohibition for much of the last century, agronomic research on the cultivar has advanced sufficiently it to be grown successfully, and at scale, throughout large parts of Europe, China and North America, both indoors and as part of conventional outdoor rotational agriculture. Furthermore, whilst a comparatively miniscule acreage of industrial hemp is currently grown in the UK, companies GW Pharmaceuticals and British Sugar, both with close ties to government, recently became the largest producer and exporter of legal cannabis in the world (Jackman, 2019; Prohibition Partners, 2019; TDPF, 2018). Whilst somewhat promising, this lead many recent articles and reports to criticise the UK government for continued disparity and confusion in cannabis legislation. In any case, it is realised that the industrial-type cultivar has considerable untapped agronomic potential for UK farmers, particularly as a sustainable and environmentally beneficial break-crop in conventional cereals-based crop rotations.

Drawing on the initial research and review of literature, in section 2.4 the proposal for conducting the feasibility study is outlined, including the overall aims and objectives of the study. It was subsequently realised that in order to assess the feasibility of large-scale adoption of the cultivar, as a break-crop in the UK, it was necessary to acquire specific, current market data and direct industry insight, related to both the industrial hemp market and the UK agricultural community. Subsequently, independent research was conducted, of which the methods and data analysis for the European industrial hemp industry are given in Section 3.1 and the methods and data analysis for the UK agricultural community are given in Section 3.2. Finally, discussion of results and final conclusions are made in Chapter 4.

# Chapter 2: Literature Review

## 2.1 The Cannabis Genus

*Cannabis* is an annual, naturally dioecious[1] plant genus, belonging to the family *Cannabaceae (*Gloss, 2015*).* The family is known for its unusual and often highly beneficial ingredients, such as biologically-active terpenophenolic metabolites, including humulone, which is found in Hop plants (*Humulus lupulus*), a genus belonging to the same family (Page and Nagel, 2006). Hops flower cones have been used in beer making for thousands of years as an anti-bacterial and bittering agent, thanks to a complex chemical structure containing resins and essential oils, which themselves consist of hundreds of different compounds (Parker, 2012). *Cannabis* has a similarly complex structure and the taxonomy of the *Cannabis* genus is widely disputed due to the biological complexity of the plants, human cultivation dated to thousands of years ago, a long history of plant-breeding and various contradictory research into the plant genetics (Small and Cronquist, 1976). As such, *Cannabis Sativa L.* remains the only officially accepted species in the genus, although there are a further 31 scientific species names listed on The Plant List with 'synonym' status (Theplantlist.org, 2018).

Commonly, plants referred to as s*ativa,* are characterised by tall stems (usually 8 to 12 ft) with long branches and relatively spread out, thin leaves (Thomas and Elsohly, 2016). Whilst the most referred variations, or sub-species, include C. *indica* Lam., characterised by shorter, bushier plants with large, wide and often purple leaves, and C. *ruderalis* Janisch., a much shorter, hardier and rarer plant with fewer leaves, typically found in Russia and the Himalayas (Thomas and Elsohly, 2016). See figure 1.

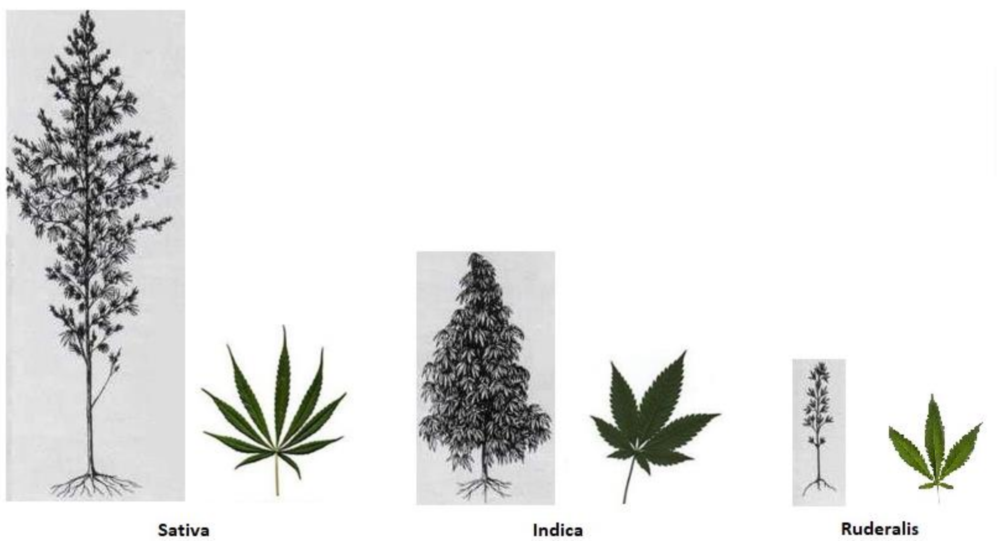


Figure 1: Cannabis Sativa L. Sub-species

Sources: (Cannabis-Education.org, 2018), Commons.wikimedia.org. (2006). *File:Cannab2.jpg - Wikimedia Commons*. [online] Available at: https://commons.wikimedia.org/wiki/File:Cannab2.jpg

[1] Monoecious cultivars of the Cannabis Sativa L. species have been bred.

*Hemp* usually refers the *sativa* sub-species of the c*annabis* genus, bred for its biomass constituents, such as natural textile fibres, and for the seeds, used as a source of nutrition, which have been harvested by humans for thousands of years (Thomas and Elsohly, 2016). S*ativa and indica* plants have also been cultivated extensively as recreational and medicinal drugs, often through selective cross-breeding to create 'hybrids' with enhanced psychoactive and therapeutic properties, in which case the plants are often referred to simply as *cannabis,* or more controversially *marijuana* (Halperin, 2018).

The most widely accepted differentiation between modern hemp and drug-type cultivars are based on different concentrations of the psychoactive cannabinoid compound, $\Delta^9$ -tetrahydrocannabinol (THC) (Hartsel et al., 2016). However, there are hundreds of cannabinoids and other phytochemicals found in *cannabis*, which have complex biosynthetic pathways and a vast array of secondary metabolite compounds (Andre et al, 2006). The most abundant compounds are phytocannabinoid acids; $\Delta^9$ -tetrahydrocannabinolic acid (THCA), cannabidiolic acid (CBDA) and cannabinolic acid (CBNA) (Elsohly and Slade, 2005, as cited by Andre et al, 2006). These compounds are subsequently 'non-enzymatically decarboxylated into the corresponding neutral forms [THC, cannabidiol (CBD) and cannabinol (CBN)], which occur both within the plant and, to a much larger extent upon heating after harvesting' (Andre et al, 2006, pp 3).

It follows that establishing simple yet robust methods to differentiate between cultivar types has proven difficult. For example, Hartsel et al (2016) refer to chemical phenotype (chemotype) classifications between 'drug-type' and 'fibre-type' varieties, as given by the United Nations Office on Drugs and Crime (United Nations Office on Drugs and Crime, 2009), whereby the ratio (X) of the sum of cannabinoids THC and CBN, to CBD are used to differentiate chemotypes (>1 is type 1 - *drug-type, <1 is type 3 - fibre-type and 1:1 is type 2 intermediate)*. It is stated CBN is included because 'THC is oxidised partly to CBN after cutting and drying' (United Nations Office on Drugs and Crime, 2009, pp 20). However, Hartsel et al (2016) cite Hillig and Mahlberg's (2004) work which found that the thresholds are more accurately 'chemotype 1 (X>10), chemotype 2 (0.2<X<10) and chemotype 3 (X<0.2).

Subsequently, international law and regulation classifications are varied, but are usually based solely on THC / THCA content of plant dry matter, under specified conditions, regardless of CBD content. For example, EU regulations allow, and subsidise, the industrial cultivation and use of approved cannabis varieties so long as THC content is limited to 0.2%. Furthermore, 'several directives and regulations' govern the sale of different products, which, dependent on the country, may be classified as a medicines, foods or consumer product (Emcdda.europa.eu, 2019). It follows that there are fundamental differences in the definition of low-THC industrial hemp products at a national level, which are further explained in Section 2.2.1.

The industrial-type cultivar has been predominantly used for the high-strength fibres found in the stem of the plant, which have vast applications. However, the non-psychoactive cannabinoid, CBD is also the subject of intensive research and increasing demand, due to the health and therapeutic benefits it offers (Mechoulam, Parker and Gallily, 2002). Again, regulations of CBD and other cannabinoids are complex and vary depending on the country, however, breeders have responded to increasing international demand by developing modern hemp varieties which contain relatively high concentrations of CBD in the flowers and leaves, whilst retaining the required low concentrations of THC (Bielecka et al., 2014; Hartsel et al., 2016). This has resulted in the development of non-psychoactive cultivars with leaves and flowers rich in potentially therapeutic compounds, seeds high in nutritional value and stems and cores containing biomass constituents harnessing the potential to transform various environmentally damaging industries.

## 2.2 Industrial Hemp Production

### 2.2.1 Definition, Law and Regulation

There is currently no internationally unanimous definition, or subsequent regulatory regime for 'low-THC' industrial hemp cultivars. In US law, section 10113 of the Agriculture Improvement Act of 2018 defines hemp as; 'the plant Cannabis Sativa L. and any part of that plant, including the seeds thereof and all derivatives, extracts, cannabinoids, isomers, acids, salts and salts of isomers, whether growing or not, with a delta-9 tetrahydrocannabinol concentration of not more than 0.3 percent on a dry weight basis' (115th Congress of United States of America, 2018). Whereas, a 2018 report by the EMCDDA states that 'in the European Union, it is legal to cultivate and supply cannabis plants for hemp fibre if they have low levels of THC'. And, 'the granting of payments under the Common Agricultural Policy is conditional upon the use of certified seeds of specified hemp varieties; only varieties with a THC content not exceeding 0.2% may be used (EU Regulation 1307/2013)' (European Monitoring Centre for Drugs and Drug Addiction (EMCDDA, 2018).

Furthermore, in the EU regulations have recently become more complicated, as fibre production or industrial uses are specified, such that grey areas have arisen surrounding the production and 'open sale' of industrial hemp flower and leaf derivatives, including low-THC cannabinoid-based products. Currently, national regulatory bodies can classify such products independently and enforce their own conditions, meaning that licensing and regulations are quite different in many Member States (Emcdda.europa.eu, 2019).

In the UK, regulatory information was repeatedly updated in early 2019. At present there is one license policy for production of so-called low-THC 'industrial hemp', which is typically valid for three growing seasons and costs £580, and another for so-called high-THC cannabis cultivation which is 'individually considered on its merits and in accordance with the general drug licensing risk assessment process' and costs £4700 (GOV.UK, 2019). The low-THC license enforces the 0.2% THC limit, and is only granted for approved varieties and 'production of hemp fibre for industrial purposes or obtaining of seeds which are then pressed for their oil', thus only permitting use of the 'seeds and fibre/mature stalk', but not the flowers or leaves (Home Office, 2019). Whilst, the high-THC license would be issued to 'cultivate, produce and supply high THC cannabis (the controlled parts of the cannabis plant; leaves and flowers) for research purposes and to enable the lawful extraction of controlled cannabinoids' (Home Office, 2019). This effectively means that regardless of THC content, use of the flowers and leaves, including for the extraction of cannabinoids and other compounds, is not permitted under an industrial hemp license, even though it is stated that CBD 'as an isolated substance, in its pure form, would not be controlled under the MDA 1971 / MDR 2001', referring to The Misuse of Drugs Act 1971 and Misuse of Drugs Regulations 2001 (Home Office, 2019).

Whilst law and regulation for fibre and seed production are relatively stable, those surrounding the production and sale of low-THC plant derivatives are changeable, and CBD regulations have become notoriously complex and unpredictable. There are signs of progress and stability however; for example, in early 2019, following pressure by the European Industrial Hemp Association (EIHA), the World Health Organisation (WHO) proposed that the United Nations (UN) make 'unprecedented changes to international control of cannabis and cannabis-related substances', such that 'preparations containing predominantly cannabidiol and not more than 0.2 percent of delta-9-tetrahydrocannabinol are not under international control', which according to the EIHA 'will fully legitimize [the] industrial hemp-derived CBD sector worldwide' (EIHA, 2019a). The EIHA also prompted the European Commission (EC) to 'recognise hemp extracts with naturally occurring CBD levels as traditional in food' (EIHA, 2019b) and both the EIHA and the British Hemp Association (BHA) are actively lobbying for reformed licensed use of the whole plant, under low-THC regulations, which would significantly increase the viability of the cultivar for European farmers (EIHA, 2019a ; British Hemp Association, 2019).

### 2.2.2 Evolution of the Industrial Hemp Industry

Hemp has been grown as a fibre crop for hundreds of years in Europe and, along with Flax, was one of the most important fibre crops between the 16th and 18th centuries (Struik et al., 2000). According to the nova-Institut GmbH, several hundreds of thousands of hectares were grown in Europe during the 17th Century (Bio-based News, 2018). Predominantly used in ship building, hemp fibre was a core material for sails and ropes, but also cargo, fishing nets, flags, shrouds, oakum (waterproofing), paper, maps, logs and bibles (Hemptastic, n.d.). However, there was gradual, yet significant, decline in production throughout the 19th century due to; the invention of steam ships, the labour-intensive process of extracting hemp fibres, increased imports and product substitution for other resources, such as cotton, jute and wood (Roulac, 1997). Labour intensity was due to the fact that hemp stems consist of a hollow inner core, surrounded by woody 'hurds' or 'shives', themselves surrounded by the sought-after bast fibres (see Figure 2), which had to be separated out using various predominantly manual and very physically demanding processes, (Clarke, 2010).

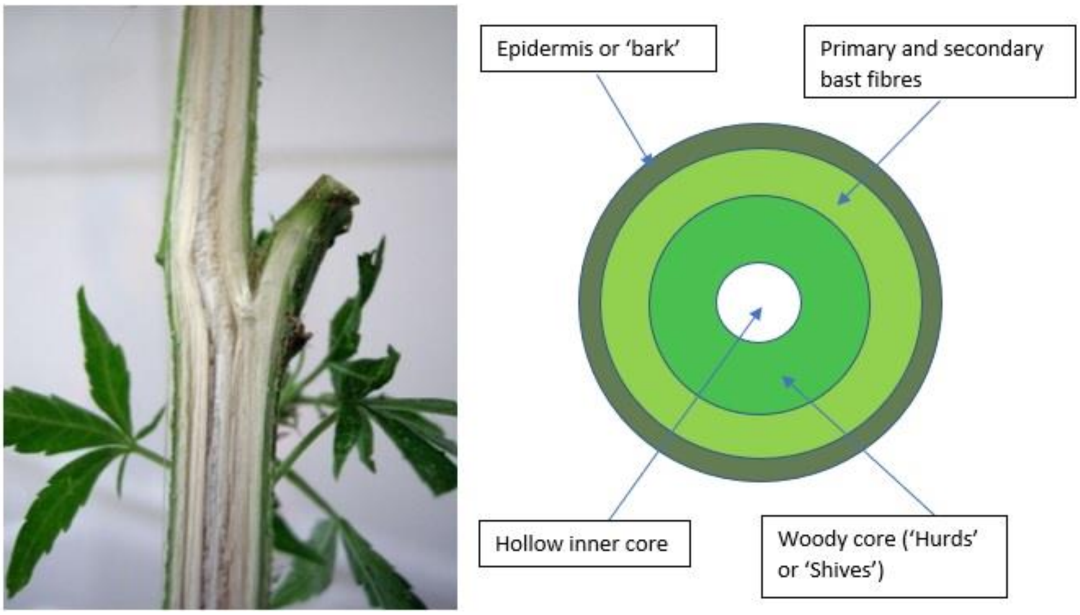


Figure 2: Hemp stem structure

Source: https://s3.amazonaws.com/mtv-main-assets/files/pages/768px-cannabis_sativa_querschnitt.jpg.

In the early 20$^{th}$ century, however, demand for domestic hemp fibre increased briefly during the First World War (Roulac, 1997) and mechanised processing machines called decorticators, designed to significantly improve the efficiency of extracting fibres, were under development both in the US and in Europe (Revolvy, 2019). Early hemp decorticators proved promising, as described in an extract from a report by the Wisconsin Agriculture Experiment Station in 1918 (cited by Global Hemp, 2019), which stated:

*'Nearly every kind of hemp machine was studied and tested. The obstacles were great, but through the cooperation of experienced hemp men and one large harvesting machinery company, this problem has been nearly solved. The hemp crop can now be handled entirely by machinery'*

Furthermore, discoveries were being made for many different applications of the plant, which included biofuels and natural fibre composites. The founder of Ford Motor Company, Henry Ford not only pioneered development of a vehicle with hemp-derived bioplastic body panels, but also developed a facility in Michigan to produce biofuels from plant ingredients, which included the extraction of ethanol from hemp (The Global Hemp Renaissance, 2013). Ford inevitably became a supporter of the concept of 'chemurgy' in the 1930's (Global Hemp, 2019), a term created by William Hale, an associate of Dow Chemical Company (William J. Hale Papers, n.d.). The catchphrase for the scientific concept was 'anything that can be made from a hydrocarbon, could be made from a carbohydrate' (cited by Global Hemp, 2019 and Roulac, 1997). Subsequently, Hale and his associate Wheeler McMillan 'joined forces to promote the vision of farm products replacing imported oil' (Global Hemp, 2019).

Whilst these developments of the 1920's and 30's were encouraging for the hemp industry; timing was unfortunate, as it coincided with increased political tension on recreational cannabis use as well as development of the fossil-derived synthetic fibre industry. Recreational cannabis use had been under debate since the early 1900's and would eventually lead to the prohibition of 'marijuana' (Musto, 1972). Prior to the 1912 Hague Convention, a delegate of the California Board of Pharmacy 'wished to draw attention to the dangers of cannabis' and requested control of the world cannabis traffic (Musto, 1972). However, it was only at the Second Opium Convention in Geneva 1925, where cannabis was referred to as 'Indian hemp', that international control was agreed (EMCDDA, 2018). Whilst cannabis and hemp were not officially banned in the US at this point, the convention led to a ban in many other countries, including Britain, under the Dangerous Drugs Act 1928 (BMA Board of Science, n.d.).

Around the same time (late 1920's), American chemical company DuPont started developing fossil-derived synthetic materials (in 1937 they patented Nylon, and in 1941 they patented the plastic Teflon, or PTFE) (DuPont Company films and commercials, n.d.). At the time, DuPont were financially backed by Andrew Mellon (Knight, 2003); who was US secretary of the Treasury, Bank owner (Federalreservehistory.org, 2019), and creator of the Federal Bureau of Narcotics (FBN) (addiction.com, 2019; Knight, 2003). In 1936 the FBN launched a ruthless nation-wide media campaign, in collaboration with William Randolph Hearst (a logging company owner, paper manufacturer and media tycoon) against what they saw as a dangerous drug 'marijuana' (Boeri, 2018).

The resulting political demonization of cannabis transpired to the 1937 Marijuana Tax Act, which whilst still not entirely prohibitive, had massive impacts on the North American hemp industry, as 'all types of cannabis [were] labelled drug plants' (Global Hemp, 2019), and subsequently placed under strict federal control (Musto, 1972). However, the US was still dependent on hemp imports and during the Second World War such imports were disrupted, and farmers were subsequently encouraged to grow as much hemp as possible. Taxes were temporarily lifted, and the US government issued a 'Hemp for Victory' news campaign (Mit.edu, 2019). Similarly, in Europe, with hemp production also in decline, natural fibre supplies were dependent on imports from other parts of the world, including increased use of imported cotton (UK Hemp Association, 2019). In Ireland, 'high demand for hemp, the difficulty in obtaining it from traditional sources and the trade difficulties imposed by war' resulted in shortages, which were frequently reported to politicians (Houlihan, 2018). In Germany, domestic hemp production was subsequently reconsidered on a massive scale, as governments 'supported improvements to cultivation, harvesting and processing technologies', but despite great promise and around 21,000ha under cultivation, production quickly receded to 'insignificant levels, mainly due to competition from imported natural fibres and the newly developed synthetic fibres' (Carus and Leson, 1994).

The promotion of hemp during World War II was short lived, however. As Shahzad (2011) reported, glass fibre production increased, and with various fossil-derived synthetic resins in development, mass production of synthetic composites was initiated, resulting in natural fibre demand, and use, declining. Ranalli and Venturi (2004) also stated that 'decline occurred after World War II for several reasons: high-labour cost, introduction of synthetic fibres, association of the plant with illegal narcotics, and the large-scale production of cotton' (Ranalli and Venturi, 2004, pp4). In any case, the loss of the hemp industry in the US became inveterate due to the effective prohibition of all types of Cannabis Sativa L., under the Controlled Substances Act of 1970 (Johnson, 2014). Similar laws were subsequently introduced around the world, such as the UK Misuse of Drugs Act 1971, section 6 of which made it unlawful 'for a person to cultivate any plant of the genus *Cannabis*' (Legislation.gov.uk, 2019).

In the 1990's 'a sustained resurgence of interest in allowing commercial cultivation of industrial hemp began in the United States', which eventually led to the 2013 Industrial Hemp Farming Act and legislative separation of low-THC hemp from marijuana, which facilitated state law to permit growing industrial hemp (Johnson, 2014, *Summary*). However, federal legalisation of industrial hemp only came about in 2018 under the Agricultural Improvement Act (115th Congress of United States of America, 2018). In the UK, the ban on hemp cultivation was over-turned in 1993, when campaigners argued that hemp 'could be grown as a legitimate crop as it contained practically no THC' (Shahzad, 2011, pp 974). UK legalisation of industrial hemp production was subsequently closely followed by the Netherlands, Germany and later throughout Europe (European Industrial Hemp Association (EIHA), 2018).

Ranalli and Venturi (2004) reported that European cultivation subsequently increased from 2762 ha in 1989, to 41,682 ha in 1998 due 'revived interest in hemp as a renewable resource' (Ranalli and Venturi, 2004, pp 4). Furthermore, Shahzad (2011) stated 'ecological concerns of society in issues such as sustainability, recyclability, and environmental safety in the 1990s resulted in the renewed interest in natural fibre composites' (Shahzad, 2011, pp5). However, some sources argue that European Commission subsidies played an inadvertent role in the revival of the industry (Vantreese, 2002). EC subsidies for hemp had been available since 1970 in countries where it was still legal, such as France and Spain, under Regulation (EEC) No 1308/70, from which support was paid per hectare of area sown and cultivated for fibre production (European Commission (EC), 1970).

According to EIHA data (figure 3), as was expected following legalisation in specific countries, total cultivation area increased gradually between 1993 and 1997; with France reaching just over 10,000 ha, Germany reaching around 3000 ha and UK cultivation peaking at around 3000 ha. However, whilst it is not shown in the latest EIHA data, earlier sources support Ranalli and Venturi's (2004) claims, showing that cultivation in Spain increased significantly between 1996 and 1998, peaking at over 16,000 ha (Carus and Sarmento, 2016; Gorchs and Lloveras, 2003). Around the same time, Karus, Kaup and Lohmeyer (2000) stated that 'the industrial demand for hemp and flax fibres is higher than ever', particularly within the automotive industry, reporting an increase in automotive use from 4000-5000 tonnes in 1996 to over 21000 tonnes in 1999 (Karus, Kaup and Lohmeyer, 2000, pp 4). The same authors also stated that 'within a suitable framework, there is a real chance to guarantee an ecological and sustainable supply of technical natural fibres' but warned 'this chance should not be imperilled by the wish for short-term subsidy savings' (Karus, Kaup and Lohmeyer, 2000, pp 5).

Nevertheless, in 1998 the EC had suspected large-scale 'speculative cultivation' was resulting in unintended over-funding of the industry, and so initiated various reforms on hemp and flax subsidies (Vantreese, 2002). In 1999 Minimum Fibre Yields were established with an aid penalty of 65% for low yields, and processing subsidies were introduced (Vantreese 2002). Further reform in 2000/2001 initiated; a reduction in the THC limit from 0.3% to 0.2%, incremental reductions in area payments to that of cereal crops and Maximum Guaranteed Quantities limiting the tonnage eligible for aid (Vantreese, 2002). Overall, 'the total support and the aid paid directly to the farmer decreased', although the introduction of processing aid resulted in increased straw prices offered to producers (European Commission (EC), 2006). Despite increased prices, gross margins for hemp subsequently declined rapidly, and only 900 ha was subsequently grown in Spain in 2002 (Gorchs and Lloveras, 2003). Furthermore, whilst the UK had cultivated a large share of the EU's hemp in the late 90's and early 2000's, cultivation area gradually declined from around 2001, and has since never recovered, as shown in Figure 3.

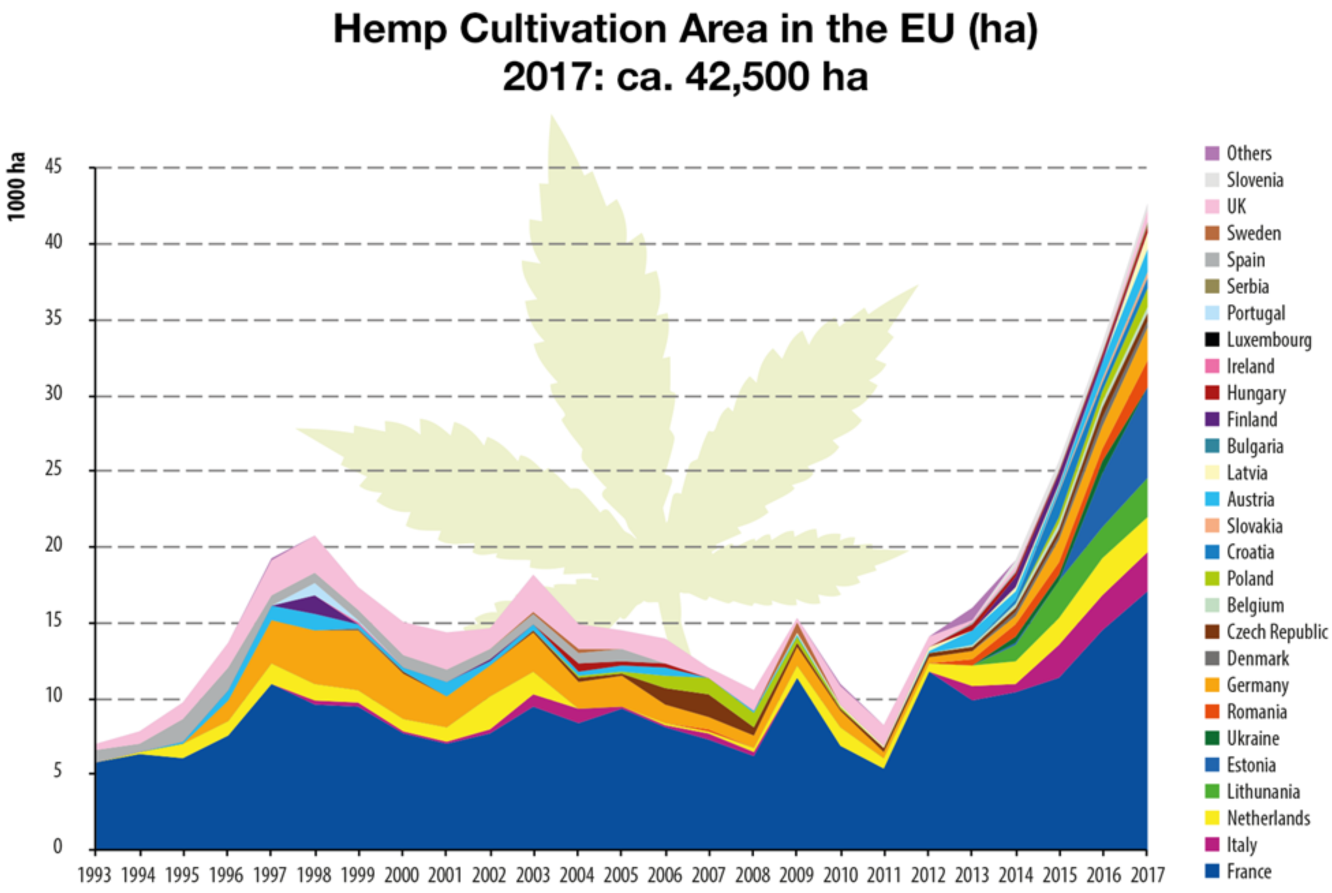


Figure 3: Industrial Hemp Cultivation Area in the European Union, 1993-2017 Source: http://eiha.org/document/eu-hemp-cultivation-area-2017/

In the last 7 or so years, the EU industrial hemp industry has entered a period of somewhat remarkable growth, mainly due to new entrants in emerging markets. Figure 3 shows that between 2011 and 2017 total cultivation area increased by over 500% to exceed 40,000 ha, with an internationally diverse industry, importantly not driven by subsidies. Figure 3 shows that cultivation area growth has mainly occurred in France, Italy, Netherlands, Lithuania and Estonia. In France, growth has been gradual and in fact, growth has not been spectacular in any one country. However, total cultivation area in Italy, Netherlands, Lithuania and Estonia grew from almost nothing in 2012 to an area comparable with France by 2017. Carus (2017) compared production data from 2010 and 2013, and concluded that straw production (for fibres, shives and dust) was not significantly different, at just over 80,000 tonnes, whereas seed production increased 92% to 11,500 tonnes and flower and leaf production increased 3000% to 240 tonnes. This data quite clearly indicates demand for seeds, flowers and leaves as the triggers for market growth.

Nevertheless, fibre has remained the most utilised raw material of the hemp plant in Europe, with production dominated by France, of which the most important market was pulp and paper in both 2010 and 2013, with a share of 55% and 57% respectively (Carus, 2017; Carus et al., 2013). Insulation materials and automotive biocomposites were the second and third most important fibre markets, accounting for approximately 26% and 14% respectively in both years (Carus, 2017; Carus et al., 2013). The data therefore indicates that fibre markets were stable and did not contribute to industry growth post 2011.

It follows that the most recent market trends, indicated by the increase in European cultivation area between 2015 (26,000 ha) and 2017 (43,000 ha), were the result of a continued increase in demand for hemp seeds in the food sector, and the introduction of CBD products to the health supplement market (European Industrial Hemp Association (EIHA), 2018). Furthermore, outside of Europe, hemp markets in Canada are thriving, particularly in the dynamic food industry with 56,000 ha cultivated, predominantly for seed, in 2017. Also, the textile industry in China, alongside the automotive industry, accounted to a further 47,000 ha grown in 2017. Furthermore, since the 2018 reform in the USA, 50,000 ha are predicted to be cultivated there in the next ten years (European Industrial Hemp Association, 2018).

Lastly, it is noted that whilst the demand for hemp seeds, and emerging markets for hemp extracts have undergone particularly strong recent growth in Europe, the political environment still presents a significant risk, particularly as CBD markets hinge on regulatory development over the next few years. Of most concern is that whilst the UK Home Office currently permit the import, export and use of CBD products on the open market, the use of industrial hemp leaves and flowers grown in the UK, for any reason, is prohibited, meaning they are effectively wasted. It seems, then, that there is significant opportunity in the UK to revoke previous political errors and make proactive decisions to license use of the whole hemp plant, which would significantly increase the viability of the cultivar for UK farmers, promoting increased cultivation, and subsequently aiding development of the whole market, including domestic fibre and seed production.

### 2.2.3 European Industry Analysis and UK Industry Potential

Whilst undertaking the literature review it was found that recent industry data was not easily obtained, and although commercial industry reports were available, it was not reasonable to acquire them due to high purchase fees. Therefore, in order to gain further insight into the current status of European industrial hemp markets, as well as the potential for UK hemp value chains to develop; data and further information were obtained from EIHA members, The European Cannabis Report (4th Edition), Google Trends, and information from personal contacts of the British Hemp Association (BHA) and the company Vitality Hemp. Furthermore, information was reviewed from studies related to potential external market factors, such as environmental, ecological and social factors, which may affect the development of the hemp industry in the UK.

Firstly, data was obtained from the EIHA list of suppliers (EIHA European Industrial Hemp Association, 2019). There were 29 suppliers (regular members) listed from across Europe and each company profile lists the range of products and/or services provided by the company as well as the country in which they are based. The data was subsequently copied to Microsoft Excel and graphed, as shown in Figure 4. Whilst the data may not represent the whole European industry accurately, it does provide insight into the diversity of EIHA suppliers and gives an indication of the main products and services currently offered.

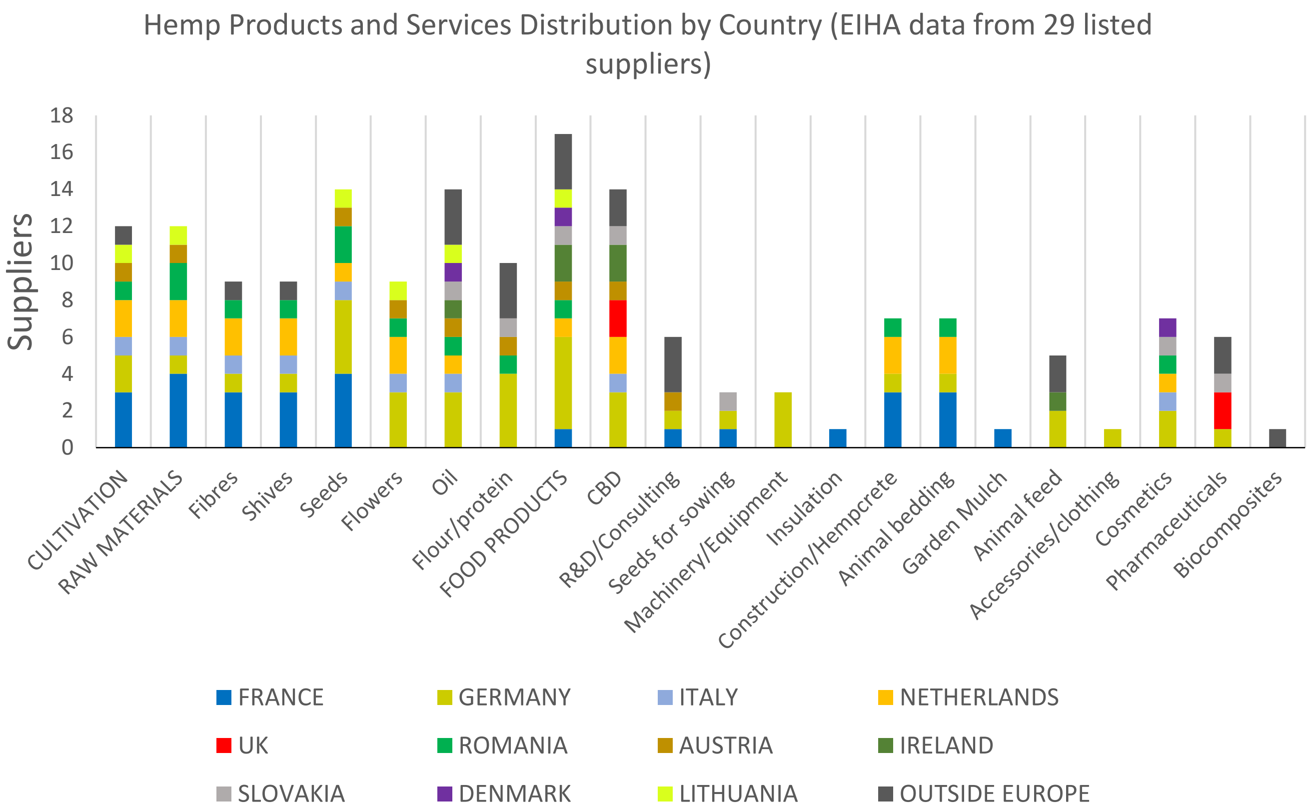


Figure 4: Hemp Products and Services Distribution by Country (EIHA data from 29 listed suppliers)

Source: http://eiha.org/suppliers/

Figure 4 shows that 'food products' was the most common, listed by 16 suppliers (59% of the sample). 'Oil' and CBD products, and supply of seeds were the second most common within the sample, being listed by 14 suppliers each (48%). Third most common, listed by 12 suppliers (41%) were cultivation and supply of raw materials, with the number of suppliers for raw fibres and shives, and flowers being equal in this case. Notably, whilst construction materials, animal bedding and cosmetics were relatively common, being listed by almost a quarter of the suppliers, insulation materials and biocomposites were the least common, listed by only one supplier in each case. This is most likely because these are specialised industries, requiring specialist equipment. Furthermore, whilst the data shows some suppliers listed cultivation, supply of raw fibres and construction materials or animal bedding, it does indicate whether they also supply raw or semi-processed fibres to other businesses, for manufacture of biocomposites or insulation materials. Significantly, the data supports that the European industry is now diverse, with 11 suppliers in 7 different European countries listing hemp cultivation and supply of raw materials.

Four out of five French suppliers were involved in the supply of raw materials, but do not produce flowers for oils or CBD products, which is unsurprising, as like in the UK, it is illegal to grow hemp for use of the flowers and leaves in France (Prohibition Partners, 2019). It is noted however that 3 of the French businesses supply fibres, and all four supply seeds, although it was slightly unclear what products the seeds are used in, as only one supplier listed 'food products', and another 'seeds for sowing'. Four of the German suppliers on the list supply raw seeds, and all five supply hemp food products, whilst four also listed 'flour/protein'. Three of the five German suppliers also listed supply of flowers for oil and CBD products, whilst very few listed cultivation and supply of raw materials. There were only 2 suppliers listed from the Netherlands, however both listed cultivation and supply of fibres, shives, and flowers, whilst one listed cultivation and supply of the whole plant. Finally, two suppliers from the UK were listed, both of which only supply CBD and pharmaceutical products.

Therefore, based on 29 members (suppliers) of the EIHA, it seems that three European market indicators can be identified; the first is that there are vertically integrated businesses cultivating and processing hemp in at least 7 European countries, the second is that French producers are fibre and seed suppliers, whilst German suppliers are more likely to be focussed on the food, oil and cannabinoid sectors, and the third is that seeds, food products, oils and CBD products are potentially the strongest markets. It follows that in order to specifically review market trends in the other countries identified earlier, namely; the Netherlands, Italy, Lithuania and Estonia, The European Cannabis Report (Prohibition Partners, 2019) was consulted.

The report states that in the Netherlands 'one potentially lucrative route to market is hemp'. 'It is completely legal to cultivate and process industrial hemp containing less than 0.3% THC' (Prohibition Partners, 2019, pp 79). Perhaps the best example of a vertically integrated hemp company is Hempflax, which was established there in 1994 and has since expanded into Germany and Romania, alongside increasing domestic cultivation, towards an anticipated minimum of 3500 ha in 2020 (Hempflax.com, 2019). Hempflax cultivate and process the entire hemp plant, for products such as; nutraceuticals including CBD products (flowers and leaves), seeds for cultivation, seeds for food products including raw seeds and protein powder, animal care products including high quality bedding products (shives), 'semi-finished' fibre-based products for specialised industrial applications including bioplastics, building products including hemp felt insulation and lime hemp blocks, and horticultural products including garden mulch and compostable fibre matting (Hempflax.com, 2019). Furthermore, Hempflax developed their own harvesting and processing technology, which are detailed in section 2.3.5.

In Italy, hemp flowers, with a THC content of less than 0.2%, are known as 'Cannabis Light', which have been legal since 2018 (Prohibition Partners, 2019, pp 56). The market is subsequently under-growing strong growth, and from a relatively strong prior position in terms of area under cultivation, as was shown in figure 3. The report stated that 'farmers associations are viewing wide-scale hemp production as a possible solution to Italy's agricultural slump' (Prohibition Partners, 2019, pp 56). In Lithuania, hemp oils and CBD products are illegal, however, the hemp industry is still thriving, as the report describes that in 2018 Aurora Cannabis, a Canadian company, purchased both the Lithuanian seed contractor and processor Agropro UAB and the Lithuanian hemp-based food company Borela UAB. As such, the group has approximately 4000 acres of hemp under contract for seed production and processing (Prohibition Partners, 2019, pp 192). Whereas, in Estonia, 'CBD and all hemp-derived non-medical products are legal', and 'focus is on the hemp market, cultivating over 3500 hectares of the plant in 2016, a marked increase from 900 hectares grown in 2015' (Prohibition Partners, 2019, pp 173-174). The report puts the growth in Estonia down to the 'unprecedented growth in the CBD market in Europe, and Estonia 'flexing its entrepreneurial muscle' to become the second largest industrial hemp producer in Europe, within less than 2 years (Prohibition Partners, 2019, pp 174).

On the UK market, the European Cannabis Report described the complex and changeable political situation surrounding medicinal cannabis, as well as hemp oil and CBD products. However, most significantly for the UK hemp industry, the report states that 'the cannabis investment sector is beginning to gain traction in London' and 'pharmaceutical and cosmetic industries have started to embrace and capitalise on the myriad applications of cannabis'. Furthermore, the report states that 'British high-street mainstays Body Shop and Holland and Barrett both stock hemp-based cosmetic products, either imported or grown on British soil' (Prohibition Partners, 2019, pp 87). Therefore, it is the low-THC, high-CBD extracts that seem to be driving large scale consumer interest in hemp in the UK, and particularly the demand for CBD extracts. Therefore, to assess consumer-interest over the last 5 years in the UK, Google Trends was used with search terms; 'CBD', 'Cannabis' and 'Hemp'. The results are shown in figure 5.

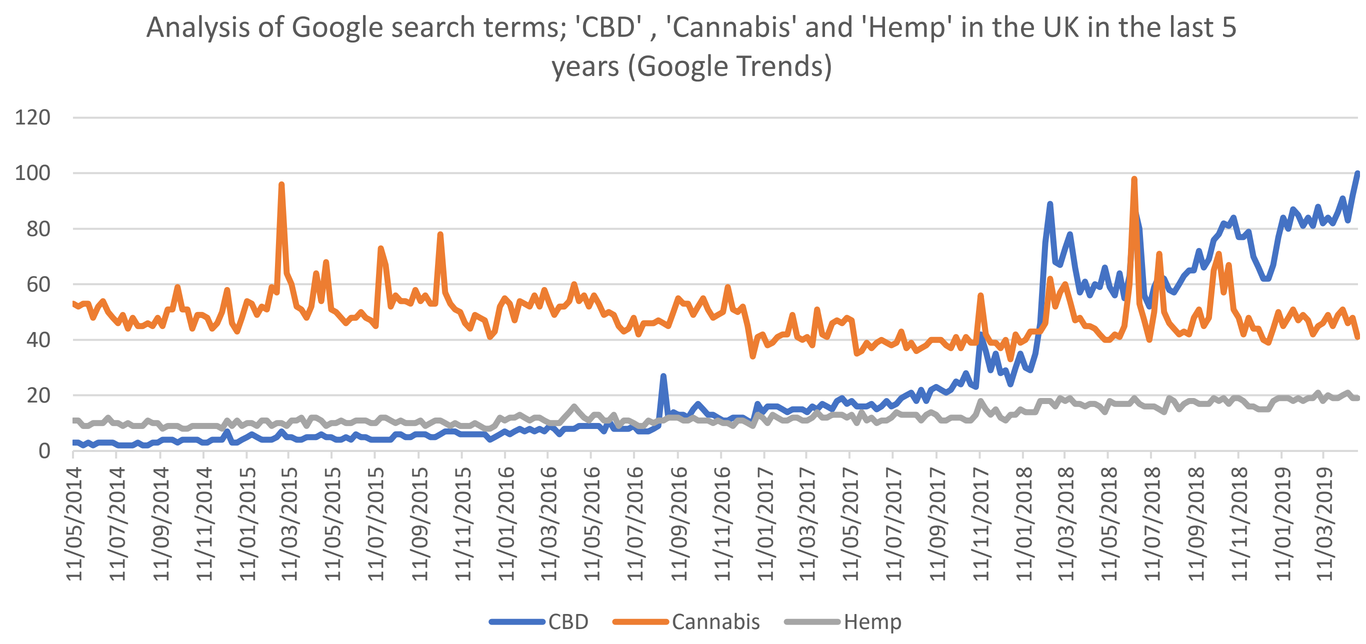


Figure 5: Analysis of Google search terms; 'CBD', 'Cannabis' and 'Hemp' in the UK (Google Trends)

Source: trends.google.com

The Google Trends normalised data indicates that on average, google searches in the UK for 'cannabis' have been relatively consistent over the 5-year period, albeit with brief 'spikes' in interest. Google searches for 'hemp' have been comparably low but show a gradual upward trend, whilst searches for the term 'CBD' were the lowest of the 3 search terms until mid-2016, when interest began to build. The data shows there was a significant spike in the number of searches for CBD around February 2018, followed by relatively consistent and significant growth ever since.

Whilst the CBD market in the UK has potential to aid development of the hemp industry, there are examples of vertically integrated companies already cultivating industrial hemp in the UK and marketing various hemp products in other sectors. East Yorkshire Hemp is one example, who focus on hemp fibre production and on-site fibre and shive processing. They manufacture and market their own briquettes, which can replace logs in wood burning stoves, as well as a range of animal bedding products. The company also supply raw shives to the building industry and semi-processed fibre bales (Eastyorkshirehemp.co.uk, 2019). Another company Good Hemp, founded in North Devon in 1998, began growing hemp to produce fibre, which was sold to BMW for natural fibre composites, but later switched to a focus on seed production, initially to manufacture oil which was sold by high street retailers such as Waitrose. Subsequently Good Hemp began producing hemp seed milk products which are now widely sold within the health food sector (Good Hemp, 2019). Thirdly a company called Vitality Hemp, based in the West Sussex also grow industrial hemp primarily for seed production, to produce their own hempseed-based food products such as extra virgin oil, seed snacks and protein powder, with a new product range due to launch in May 2019 (vitality-hemp, 2019).

Whilst there are success stories, the BHA estimated that the maximum of 810 hectares is currently under cultivation (British Hemp Association, 2019). And with such a small cultivation area in comparison to the rest of Europe, it is difficult to analyse current market stance for domestic hemp products in the UK. Therefore, it is more effective to analyse potential value chains assuming that cultivation area could be rapidly increased under the right market conditions. For example, the UK food industry is under-going a significant transition, with plant-based diets becoming mainstream. The Waitrose Food and Drink Report 2018/2019 states that 'almost 13% of the population is now vegetarian or vegan, with a further 21% identifying as 'flexitarian'', as a result retailers are under pressure to produce meat and dairy alternatives and provide healthy and interesting meat-free products for this demographic. This includes alternatives to dairy milk, and 25% of the 'milk' range at Waitrose are now non-dairy options (Waitrose and Partners, 2019, pp 7).

Research by health institutions and environmental scientists support that consumers should reduce meat and dairy consumption, for benefits to their own health, to reduce their carbon-footprint and to reduce loss of biodiversity and ecological habitat (Machovina, Feeley and Ripple, 2015; Sadler, 2004). However, the environmental and ecological impact of the food industry is complex, and very much related to where, and how, food products (including plant-based foods) are produced. Purchase decisions made by consumers are also based on many different factors and often consumers are ill-informed as to the wider impact of their decision making. For example, Feldmann and Hamm (2015) found that consumers attitudes relating to food purchases were very much dependent on their knowledge and interest of specific foods, including origin and production methods. Furthermore, the purchase of local food products was mostly related to food quality and taste, but also; personal health, food safety, environmental care and supporting the local economy (Feldmann and Hamm, 2015). Whilst it is clear that locally-sourced, or at least sustainably-sourced, low-carbon footprint food products are becoming increasingly sought-after, research has shown that consumers are also often limited by a perceived lack of information, knowledge and choice for sustainable products (Vermeir and Verbeke, 2006). Therefore, it seems that plant-based, protein rich and domestically grown food sources, such as hempseed, can potentially have significant positive impact on both the food industry and UK farm businesses, given the right market conditions and consumer knowledge.

Consumer behaviour is also changing rapidly surrounding the use of plastics, and particularly single-use plastics. For example, The Waitrose Food and Drink Report found that since the 2017 television series Blue Planet II, which exposed the significance of plastic waste in the world's oceans, 88% of Brits have changed how they use plastics. The report states that 'a new era of environmentalism has taken hold, and attitudes towards single-use bags, disposable plastic straws and packaging will never be the same' (Waitrose and Partners, 2019, pp 4). The synthetic plastic market in the UK is responsible for an estimated 3.7 million tonnes of waste each year, of which 'packaging' accounts for 69% (Resource Futures and Nextek, 2018). As such the Government, under significant pressure to make unprecedented changes to the way plastics are produced and utilised, have stated 'ambition to eliminate avoidable plastic waste by the end of 2042' in the 25-year Environment Plan (Resource Futures and Nextek, 2018). Significantly, 'drop-in' or direct replacement bio-based plastics are 'anticipated to have a 75% share of the total bio-based plastics market by 2021', although the report also states that 'novel biodegradable plastic food packaging products have the potential to radically change the way that waste is processed as a feedstock to be mixed with food and composted in one of the UK's 50+ composting facilities' (Resource Futures and Nextek, 2018, pp 61). Therefore, it seems likely that the demand will increase for bio-based plastics, such as drop-in alternatives, or short lifespan compostables, which can both be made from industrial hemp (Hemp Plastic, 2019).

Increases in demand for synthetic plastic alternatives will also inevitably coincide with increased demand for natural fibre composites. As pressure builds on large corporations, such as automotive manufacturers and construction companies, to reduce use of fossil-derived materials and carbon-intensive production processes, it seems likely that an increasing amount of naturally-derived materials will be used. Dunne et al (2016) gave a comprehensive review of a range of natural fibres specifically in relation to the automotive industry and found that there is a current trend towards replacing synthetic fibres and 'high energy consuming products' with natural fibre products (Dunne et al., 2016). They also stated that the transition to natural fibres is not only due to environmental concerns, but also due to the beneficial properties of the natural fibre composites and relatively low costs. In the study, 14 different natural fibre resources were reviewed, and the authors stated that the advantages of hemp fibre include; it's high fibre strength, no requirement for pesticides and little requirement for fertiliser, fast growing and relatively drought and frost resistant. Whereas the only disadvantages listed by Dunne et al (2016) were that the separation of the fibres is labour intensive and there are cultivation restrictions in many countries. The findings are significant, as the UK automotive industry is worth £82 billion to the UK economy, with 6 mainstream manufacturers, over 60 specialist car manufacturers, 20 research and development centres and 2500 suppliers (SMMT, 2019). Furthermore, most of those businesses are practically surrounded by highly productive farmland and large infrastructure, such as business parks and warehousing.

Overall, whilst consumer interest for CBD products is gathering momentum in the UK, legislation is the limiting factor. Also, hemp seeds are not yet widely known or appreciated for their nutritional value, and whilst available (mostly from imports), products are not yet in significant demand with retailers or consumers. However, it has been shown that consumer behaviour is changing rapidly in the food market, and through effective education and marketing of the benefits of hempseed products, it seems likely that such products could become well-placed mainstream options. Similarly, in terms of the market for hemp fibre in the UK, value chains are currently poorly developed, as; there is a lack of supply, fibre applications are poorly understood and there is a lack of processing infrastructure. Yet, external factors such as climate change, changing consumer behaviour and industry pressure, mean that demand for hemp-derived fibre products can conceivably increase significantly in the UK, and the UK automotive industry, in particular should be well placed to take advantage of the potential large-scale supplies of hemp fibre.

Based on these factors, the EIHA and BHA are lobbying the UK government for changes to industrial hemp licensing, which would permit the use of the whole hemp plant, including the flowers and leaves, from cultivation through to processing for hemp extracts (British Hemp Association, 2019; EIHA European Industrial Hemp Association, 2019). Furthermore, the company Vitality Hemp, founded by Nathaniel Loxley, are working closely with the BHA and EIHA, as well as the National Non-Food Crops Centre (NNFCC) under the BioBase4SME project. The project offers 'training, innovation bootcamps and innovation vouchers' to support proof of concept delivery as well as development and launch of business plans (Nnfcc.co.uk, 2019). This includes scaling to 'pilot scale, Life Cycle Assessment, techno-economic evaluation, market research, feedstock analysis, social acceptance, business planning and business plan support' (Nnfcc.co.uk, 2019). In conversation with Mr Loxley as part of this project, he stated that the major barrier to valorising the hemp crop is the poorly developed value chain, despite interest amongst farmers to cultivate it in the UK. He also points to 'a lack of knowledge across the sector, on what processes are the most commercially promising, as well as a lack of good quality processing equipment'. Through the project, Vitality Hemp's aim is to support increased cultivation of the crop, by setting up supply chains for 'material processing and route to market'. Potential markets are stated as 'food, textiles, construction, bioplastics and new materials derived from hemp plant valorisation'. Finally, through working with the BHA, the company plan to 'develop a UK hemp industry roadmap, which can be used across the industry to identify market opportunities, R & D needs and policy action points'. (Information provided privately by Nathaniel Loxley, Vitality Hemp, 2019).

The data and information obtained indicates that UK farmers could be well placed in the next few years to exploit potentially strong domestic markets for the entire hemp plant, perhaps initially for food products, by harvesting hempseed and processing for flours, protein products, oils and dairy replacements, among others. Straight-forward changes in regulation could also theoretically permit hemp farmers to utilise the whole plant and subsequently offer domestic supplies of low-THC flowers and leaves to licensed processing companies, although quality control and compliance measures could mean that conventional rotational farming may be restricted to certain products, and organic or even indoor growing, under controlled conditions could be more feasible in that case. Finally, examples were found, such as Hempflax, of well-established, vertically integrated companies, operating in strong European markets, that are cultivating raw materials and 'part-processing' the fibres on-site, or in local facilities, before supplying the semi-finished products to external companies for processing into the specialist products. Therefore, it seems reasonable that similar businesses can be developed in the UK, through the construction of on-farm, farm-shared, or local independent hemp fibre processing facilities, which could be viable under farm diversification schemes, or other rural investment projects, to develop robust hemp value chains.

### 2.2.4 Applications for Hemp Straw

The process of extracting fibres and shives from hemp straw is known as *decortication* (Clarke, 2010), which uses either mechanical or chemical methods, and usually follows *retting* of the straw, which describes the removal of the bark from the stem by 'dissolving various adhesive compounds that preserve the structural integrity of the hemp stalk during its rapid growth' (Clarke, 2010). There are now many different mechanical, biological and technological processes used in the extraction of fibres, depending on the intended applications and required fibre quality. Such processes are further described in section 2.3.5. In any case, retting, decortication and fibre separation processes turn hemp straw into hemp fibres, hemp shives, dust and waste products. Figure 6 shows a basic schematic of the process.

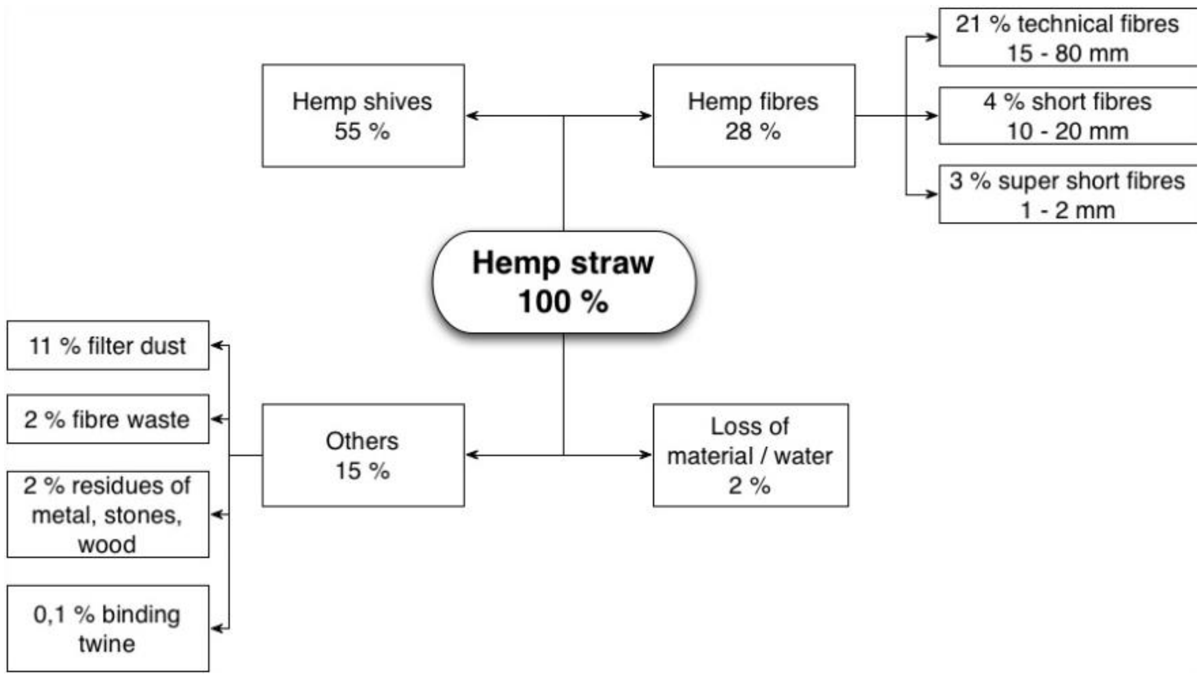


Figure 6: Schematic of hemp straw processing outputs

Source: http://www.fibrafp7.net/Portals/0/Michael_Carus_Day_1.pdf

Carus (2013) gave a comprehensive analysis of the 2010 European hemp harvest, which showed that over 76000 tonnes of hemp straw were harvested, producing 25,589 tonnes of fibres, 43,621 tonnes of shives and 11,439 tonnes of dust. The main applications were; pulp and paper, agrotextiles, automotive natural fibre composites (NFCs) and textiles, insulation and non-automotive composite applications (Carus, 2013). Most significantly, Carus (2013) reported that in 2012 the European automotive industry used 30,000 tonnes of natural fibres in 60,000 tonnes of biocomposites, 12% of which was hemp fibre (Carus, 2013). Carus (2017) stated that 'hemp fibres have some of the best mechanical properties of all natural fibres', which along with relatively low costs, has made them increasingly popular with automotive manufacturers. It follows that the main applications for automotive NFCs and natural textiles, based on a review by Dunne et al (2016) are; body panels and liners, cladding, seat back liners, boot liners, carpets, seats, parcel shelves and headliners.

The benefits of using natural fibres in the production of advanced materials are both their sustainability and mechanical properties. Shahzad (2011) conducted a comprehensive review of hemp fibre composites in relation to alternative materials. It was reported that there are both advantages and disadvantages of using industrial hemp in composite materials, based on its material properties. Firstly, all natural fibres have quite variable fibre compositions, which result in variable physical properties. Fibre composition depends on factors including; 'source, age, retting, separating techniques, geographical origin, rainfall during growth and constituents content' (Shahzad, 2011, pp2). This means that the mechanical properties of the product may be variable and difficult to predict.

Furthermore, natural fibres generally have 'non-uniform' and 'non-smooth' surfaces and low resistance to water absorption and decay (Shahzad, 2011). Therefore, 'poor fibre/matrix interfacial bonding can be an issue while using natural fibres' and as a result, physical or chemical surface modification processes are required to achieve strong adhesion with the matrix (Shahzad, 2011, pp7). On the other hand, hemp fibres have high tensile strength, stiffness, length/diameter (aspect ratio) and low density (Shahzad, 2011). In comparison to other natural fibre composites, hemp has also been shown to have the highest tensile and flexural strength. In fact, hemp composite was shown to have higher specific flexural strength than glass fibre composite (Shahzad, 2011).

As well as the beneficial mechanical properties, sustainability is one of the most important factors promoting the use of natural fibres. Whilst synthetic fibres may be more easily manufactured, and have better performance in various applications, it is the sustainability credentials that are most likely to result in further expansion of the hemp fibre market. Regrettably, the mass production of synthetic materials since the mid-20$^{th}$ century has had devastating effects on the environment, due to the extremely poor biodegradability and lack of recycling. The University of Georgia reported that between 1950 and 2015, humans had produced 8.3 billion metric tons of plastics, of which 6.3 billion tons was waste, with 9% recycled, 12% incinerated and the 79% remainder accumulating in the natural environment (University of Georgia, 2017).

However, 'natural fibres reinforced with biodegradable polymers result in completely 'green' composites', and according to Shahzad (2011, pp 6), in recent years research in this area has substantially increased. Examples of such biodegradable composites include matrix made from Cashew nut shell liquid, Cellulose ester, Polyactic acid or Euphorbia oil, reinforced with hemp fibres, as well as other hybrids of various natural fibres and alternative matrix materials (Shahzad, 2011, table 6, pp 9). The higher cost of such materials is highlighted as the main drawback, although properties of such composites have been promising (Shahzad, 2011).

Whilst the sustainability benefits of natural fibres have been known since before the arrival of synthetic polymers, there was no official measure or recognition of it. However, in 2016, the EIHA reported that European hemp fibre had become the first sustainably certified natural fibre, receiving ISCC PLUS certification (European Industrial Hemp Association, 2016). They stated that 'for the first time, the automotive industry can gain access to a sustainably certified natural fibre for producing light weight biocomposites, mainly for interior applications. Now the sustainability can be traced and confirmed in the value chain from its agriculture source to the final car component' (European Industrial Hemp Association, 2016, pp1).

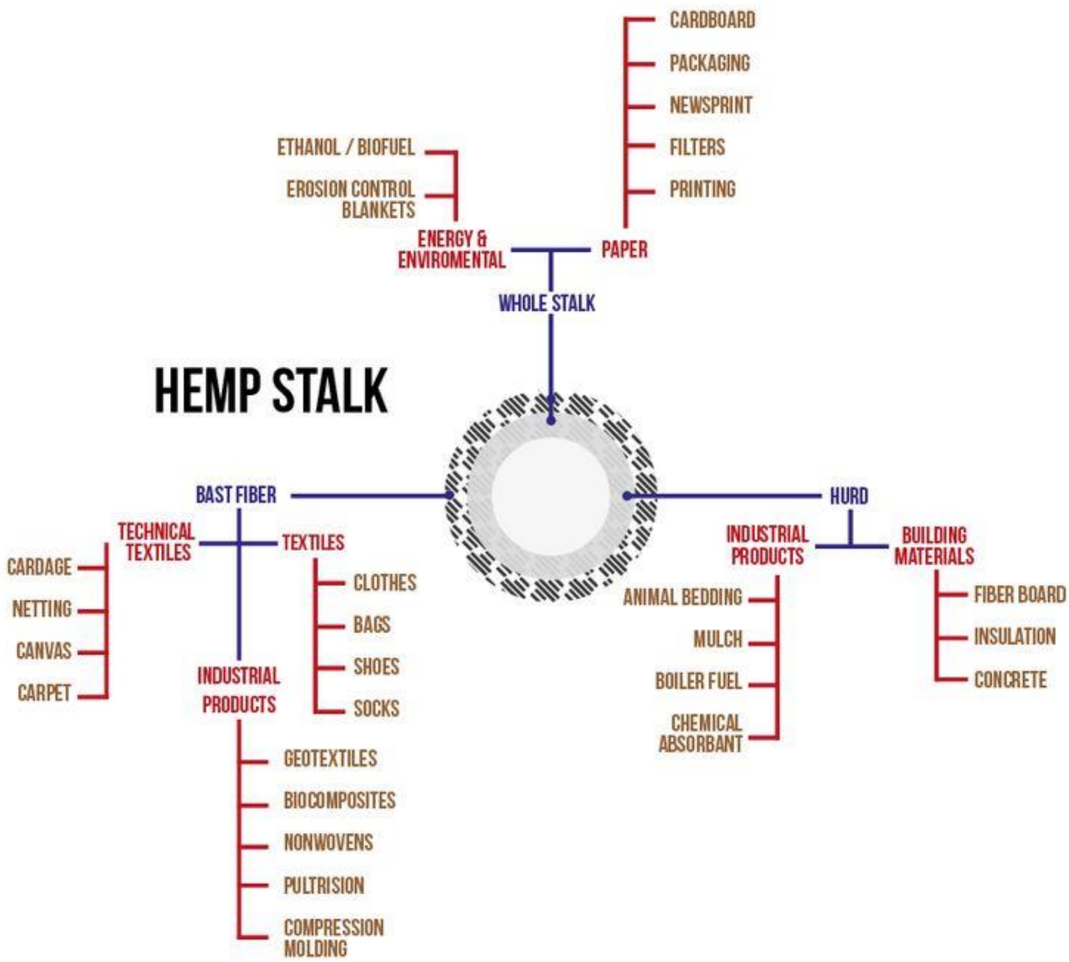


Figure 7: Schematic of hemp straw applications

Source: https://www.stexfibers.com/hemp

Furthermore, whilst natural composites and bioplastics are key potential markets for UK grown industrial hemp, the fibres and shives (or hurds) have several other high potential applications, as indicated in figure 7 above, including; animal bedding, advanced insulation materials, a variety of construction materials, energy products. Firstly, the construction industry accounted for approximately 16.5% of European hemp straw production in 2010; 25.9% of fibres were used in the production of insulation materials and 15% of hemp shives were used in construction, mainly for production of Hempcrete (Lekavicius et al., 2015). Carus (2013) states that hemp-derived insulation materials result in both lower CO2 emissions and reduced costs when applied in construction. Mahapatra (2018) stated that 'Hemp has the best ratio of the heat capacity of all fibres giving it superior insulation properties' with many superior qualities to cotton, and significantly better sustainability. The most common hemp insulation products are hemp wool insulation blankets, and insulation boards, which are recyclable, anti-irritant, protected against moulds and bacteria, scent free, thermal and acoustic insulators, low energy to manufacture and sustainable, however, it is also noted that hemp wool insulation is susceptible to damp and is not suitable for damp spaces (Insulation-info.co.uk, 2019).

Apart from fibre, figure 6 showed that during the process of fibre separation, more than half of hemp straw biproducts by mass, are in the form of hemp shives. Hemp shives were originally seen as a waste product in the fibre extraction process (Mahieu et al., 2015), but they are now part of large markets, such as bedding products for pets, horses and chicken farms. EIHA data reported by Carus (2017) showed that the market for high performance animal bedding accounted for 63% of the total market share for hemp shives, in both 2010 and 2013 European harvest years. Horse bedding alone accounted for a 45% market share. Furthermore, based on the number of products available, it seems that hemp shive bedding remains one of the most important and stable markets for hemp straw. East Yorkshire Hemp is just one of many suppliers of hemp shive derived horse bedding in the UK, who state that advantages such as; better absorbency than wood shavings or straw, cost effective, low dust, easy to handle, labour saving, environmentally friendly and low odour (Eastyorkshirehemp.co.uk, 2019).

Hemp shives also have great potential in industries such as construction (Lühr, Pecenka and Gusovius, 2015). Lühr, Pecenka and Gusovius (2015) stated that 'there is an increasing demand for high-grade hemp and flax fibres', and '[approximately] 50% of the income of a hemp fibre processor is generated by marketing quality shives'. They subsequently discuss details on the development of a machine, designed by Agricultural Engineering Potsdam-Bornim (ATB), which is described as a 'simple but efficient technology for cleaning of shive-fibre mixtures' (Lühr, Pecenka and Gusovius, 2015, pp 130). Importantly, the development of such machines means that the efficiency of processing systems is improved, costs are reduced, and hemp shives can be effectively used for a range of products, including particle boards, as replacement to wood shavings (Lühr, Pecenka and Gusovius, 2015). Furthermore, in a study of the properties of particle boards made from agricultural biproducts; hemp and flax shives, sunflower bark and oilseed rape straw, Mahieu et al (2015) stated that 'hemp shives are clearly the best agricultural waste raw material for manufacturing of 100% biobased particle boards'.

A similarly important, and promising, application for hemp shives is Hempcrete, which is a relatively new material used within the construction industry. Lekavicius et al (2015, pp 39) defined Hempcrete as 'a lightweight insulating material produced by mixing hemp chaffs [shives] with a lime base binder and water', which produces a strong and lightweight material, with highly beneficial properties, such as breathability and 'extraordinary thermal performance' (UK Hempcrete, 2019). The material is also considered to be 'better than zero carbon', as higher amounts of carbon are effectively locked up within the material, for the life of the product, than was generated during production and use (UK Hempcrete, 2019). The material is also reported to be non-toxic, fire-resistant and affordable and can be used in renovation, restoration, new-build walls and garden studios (Hemplimespray.co.uk, 2019). Furthermore, Lekavicius et al (2015, pp 39) also noted that as demand and supply of hemp fibres increase, the supply of shives also increase, therefore 'hemp chaffs [shives] have a big potential for improving the construction business in terms of sustainability'.

Industrial hemp straw can also be converted into a range of bioenergy products, such as biomass pellets or liquid biofuels. Lekavicius et al (2015, pp 40) reported that production of hemp pellets suited to domestic systems may be limited, but large-scale boilers 'for industrial heating or power generation are seen as a promising option for hemp utilisation'. Most promising is a low potential field-dried moisture content of 20%, and subsequent net calorific values higher than alternatives, including wood residues and other straw (Lekavicius et al., 015). Furthermore, Cherney and Small (2016) report that whilst most European hemp varieties have been bred for fibre production, rather than biomass, hemp is still rated as one of the best crops available for energy production. Hemp shives can be burned directly, or used to produce 'charcoal, methanol, methane or gasoline through pyrolysis (destructive distillation)' (Cherney and Small, 2015). However, the same authors stated that 'conversion of hemp biomass into fuel or alcohol is impractical in areas where there are abundant supplies of wood, and energy can be produced relatively cheaply from a variety of sources'. Citing Prade et al (2012), Cherney and Small (2015) also reported that the main competitors for hemp as an energy crop are maize and sugar beet for biogas, and willow, reed canary grass and Miscanthus for production of solid biofuel, but concluding 'hemp is an above average energy crop with a large potential for yield improvements' (Cherney and Small, 2015 citing Prade et al., 2012).

### 2.2.5 Applications for Hemp Seeds

Like hemp straw, the seeds of the hemp plant have a wide variety of beneficial applications. Figure 8 shows a schematic of some of the most common, which are mostly food products. The most important, and promising, application for the seeds is in human food products, which is largely thanks to their high nutritional value. The seed contains about 30% oil, which is rich in fatty acids, with very high 90% unsaturated fat content, including; 'Linoleic acid (omega 6, essential), Alpha-linoleic acid (omega-3, essential), [and] Gamma-linoleic acid (omega-6)' (Carus, 2017, pp 7). The ratio contained of omega-6 to omega-3 is 'between 2:1 and 3:1, which is considered optimal for human health' (Callaway, 2004, pp 65). The seed also contains a relatively high 25% protein content, which is 'balanced and easily digested' (Carus, 2017, pp 7). Callaway (2004) also describes two main proteins in hempseed, edestin and albumin, stating they are 'high-quality storage proteins [that] are easily digested and contain nutritionally significant amounts of all essential amino acids' (Callaway, 2004, pp 65). Furthermore, the seeds are high in dietary fibre, vitamins and minerals (Callaway, 2004).

It seems that hempseed food products are only just beginning to enter mainstream retail chains in western Europe, as the EIHA (EIHA, 2018) stated 'Healthy hemp seeds have arrived in the mainstream and can be found today in almost all European supermarkets pure, in muesli, in chocolate and many other products'. 'Hemp seeds can be processed into drinks and yoghurts like soy', and 'there is no end in sight to the rising demand' (EIHA, 2018, pp1). Although Callaway (2004) argues that the nutritional properties of hemp seeds have been recognised for hundreds of years, and have become valued in many parts of the world, stating that 'in China, roasted hempseed is still sold as snacks by street venders' and 'in Russia 'black' oil has been pressed from hempseed and used as a substitute for more expensive (and less healthy) sources of dietary fat, such as butter and hydrogenated margarines' (Callaway, 2004, pp 67).

Callaway (2004), compiled nutritional data on the Northern climate adapted seed variety of hemp, called Finola, which were compared with several other food crops including; potato, wheat and rapeseed. It was found that hempseed oil contains the essential fatty acids (EFAs) and polyunsaturated fatty acids (PUFAs), that have health benefits such as; lower levels of LDL-cholesterol, lower blood pressure and reduced clotting (Callaway, 2004). Furthermore, proteins albumin and legumin are abundant in hempseed, in similar quantities to other protein food foodstuffs such as egg white and soybean. Finola was found to be particularly high in vitamin E compared with other hemp varieties (Callaway, 2004). It is such nutritional qualities which make hempseed a valuable source of plant-based protein, in the form of raw seeds, protein powder supplements, snack bars, hempseed butter, flours and cereals among others. As well as cold pressed hemp seed oils, which are used in similar ways to conventional extra-virgin oils, and hemp milks, which are good substitutes for dairy milk (Ministry of Hemp, 2019).

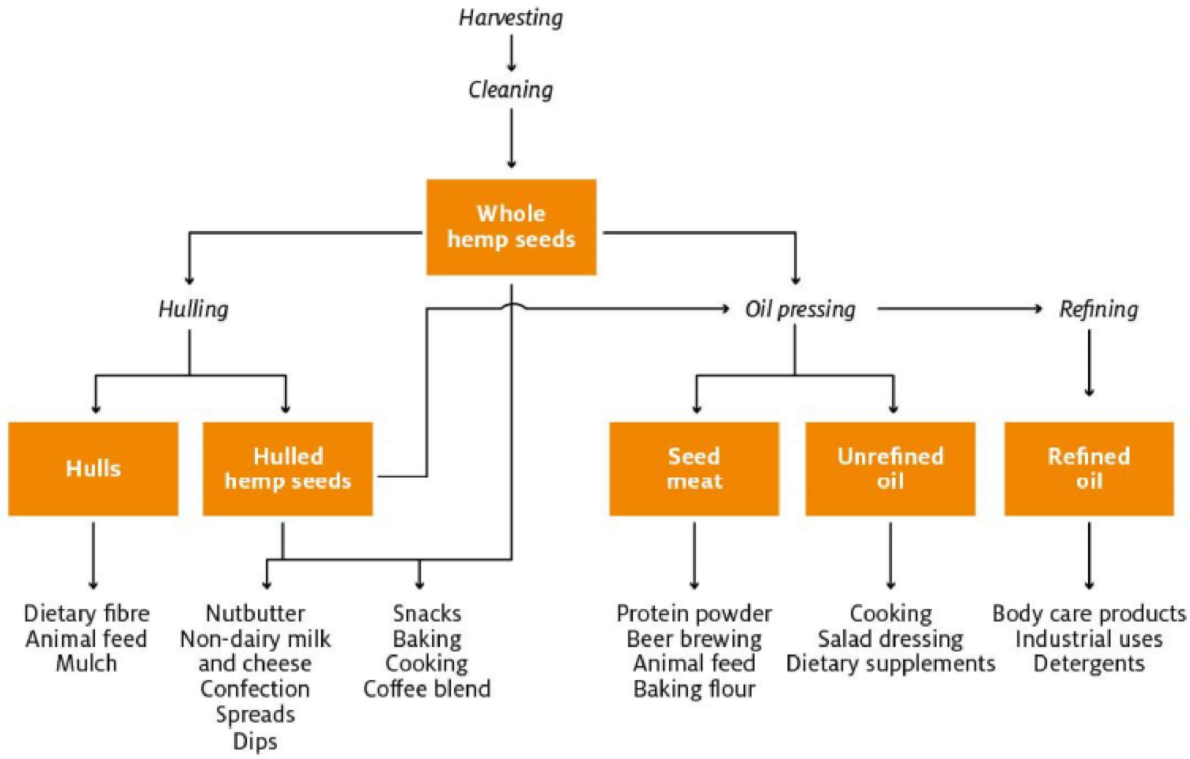


Figure 8: Schematic of hemp seed processing and products

Source: (North American Industrial Hemp Council), https://www.foodstandards.gov.au/code/applications/documents/A1039_SD2_a.pdf.

Whilst food products are an important, and growing market, until quite recently seed demand in Europe was driven by animal feeds, and as seen in Figure 4, a similar number of business were supplying feed products, as were supplying cosmetics and pharmaceuticals. Carus (2017), showed that approximately 60% of seeds are used in human food products, and 40% in animal feeds. Carus (2017, pp 7) stated that 'bird and fish feed is the main market for hemp seeds in animal nutrition'. 'Both birds and fish need fatty acids with a high share of omega-3 and omega-6 fatty acids for optimum development' (Carus, 2017, pp 7). Callaway (2004) also discussed the use of hemp seeds as animal feed and stated 'recent feeding trials with chickens have confirmed that hempseed is an excellent source of nutrition for laying hens, where the omega fatty acid profile in egg was favourably influenced after feeding hempseed meal (Silversides et al., 2002)'. Furthermore, 'another study on hempseed found it to be an excellent source of rumen undegraded protein in cows and sheep' (citing Mustafa et al., 1999) (Callaway, 2004, pp 70).

## 2.3 Industrial Hemp Agronomics

The National Non-Food Crops Centre (NNFCC) 'recognises hemp as an established minor crop' (Shahzad, 2011) and provide a Crop Fact Sheet on growing industrial hemp in the UK, in which it is described as a fast growing, competitive, spring-sown cultivar which has a low input requirement and makes a good alternative to more conventional break-crops, such as oilseed rape, peas and beans (NNFCC, 2006). Similarly, Andre et al (2016) stated the crop has 'quite good resistance to drought and pests, well-developed root system preventing soil erosion, and lower water requirement with respect to other crops' (Andre et al, 2016, pp 2).

Additionally, Piotrowski and Carus (2011) showed that industrial hemp, along with Flax, were good candidates for direct financial support under Regulation (EC) Nr. 73/2009, based on protection or enhancement of the environment and additional agri-environment benefits, through diversification of crop rotations. Notably, whilst flax is a better established resource of natural fibres in Europe, Piotrowski and Carus (2011) showed that hemp is in many ways more ecologically sound than flax, being more effective based on the beneficial effects of crop rotation, effects on soil and pest management, and equally effective based on agro-biodiversity and products/LCA. The only ecological assessment hemp seemed less effective than flax was fertilisation requirement (Piotrowski and Carus, 2011).

### 2.3.1 Variety, Climate, Soil Type and Seedbed Preparation

Industrial hemp varieties grown in Europe must be registered on the EC plant variety database and registered under the common catalogue status. These are the varieties which have been verified to comply with EU THC restrictions (Ec.europa.eu, 2019). At the time of writing there were 66 varieties listed. There are two broad categories of industrial hemp, namely monoecious and dioecious cultivars. Most cultivars are dioecious and have both female and male plants and require wind for pollination (Hemptrade.ca, 2019), whereas monoecious cultivars have both male and female flowers on the same inflorescence, and partially self-pollinate and are considered better suited for multipurpose use, as they are generally more uniform, easier to harvest and produce higher seed yields (Baldini et al., 2018). Furthermore, hemp is naturally photoperiodic, meaning that flowering is initiated as the day length reduces, prior to Autumn (in the northern hemisphere), which can result in later than optimal harvest timing (Hemptrade.ca, 2019). So-called auto-flowering cultivars have been bred, however, which are not photoperiodic and instead flower after a set period of time, dependent on the variety (Finola.fi, 2019). Timing of flowering is a key consideration, as it has been shown to be a key determining factor of hemp yield and quality, and short uniform flowering duration is desirable, for crop uniformity and harvest timing (Amaducci et al., 2008). Therefore, the main considerations for varietal selection should be based on vegetative cycle, uniformity, plant height, climate and intended applications.

Examples of common hemp varieties grown in Europe include; Fedora 17, Futara 75 and Felina 32 and Finola. Fedora 17 is monoecious, easy to harvest and suitable for cultivation in North-western (Atlantic) parts of Europe, it has a relatively short height and short average vegetative cycle of 135 days, meaning it flowers early and is suitable for grain, fibre and cannabinoids (Enecta, 2019). Futara 75 is also monoecious and grown in Atlantic climates, but is a taller cultivar with a longer vegetative cycle, meaning it is better suited to fibre and biomass production, but can also produce relatively good yields of seed and oil, and has a higher CBD content than Fedora 17 (Enecta, 2019). Felina 32 is a third variety which is monoecious and well adapted to Atlantic climates, it has similar characteristics to Fedora 17, such as short vegetative cycle and grain yields, but the mature plants have similar CBD content and are similar in height to Futara 75, so slightly higher biomass yields are possible (ihempfarms.com, 2019). Finola is quite different in that it is dioecious, but auto-flowering, and is described as 'the shortest and fastest auto-flowering variety of hemp' (Finola.fi, 2019). Finola is best suited to northern latitudes and produces the best seed yields around latitude 50, under irrigated conventional farming methods, making it well-suited to UK climates (Finola.fi, 2019). Furthermore, Struik et al (1999) showed that fibre yields in the UK were consistently lower than those in Italy and the Netherlands, and it has been demonstrated in this work that the most promising initial markets for hemp in the UK are likely to be for hempseed. Therefore, modern 'dual hemp' varieties, such as Fedora 17 or Felina should be considered, which are short, easier to harvest and best suited for grain production, although the smaller yields of straw can still be used for applications such as manufacture of natural fibre composites in the automotive and construction industries (NNFCC, 2006).

The mature hemp plant has a dominant tap root with side roots and tolerates dry conditions, but does not thrive in them (McPartland, Clarke and Watson, 2000). Root system development can depend on soil type and condition, for example in poorer soils the tap root may be less developed and the side roots more so (Province of Manitoba - Agriculture, n.d.). The cultivar grows best in soils with high moisture levels (approximately 80% soil field capacity), although it does not tolerate saturated soil or permanent wetlands (McPartland, Clarke and Watson, 2000). Therefore, good soil drainage is important to avoid uneven growth or crop failure (Vessel and Black, 1947). Based on European studies, Ehrensing (1998) suggested optimum moisture levels (rainfall and soil moisture) of 250-300mm during the vegetative growth stage and 500-700 mm in total for optimal yield. This varies with soil, climate and culture, but generally, in non-irrigated crops, the amount of rainfall during June and July in Europe can have a large effect of hemp yield (Bócsa and Karus, 1998).

Industrial hemp can tolerate and germinate at relatively low soil temperatures, as low as 0 $^{o}$C (Mediavilla et al., 1998), but the suggested optimum soil temperature is 10 $^{o}$C (Ukcia.org, n.d). McPartland, Clarke and Watson (2000) cite Duke (1982) who showed optimum growing conditions at an average daily temperature of 14.3$^{o}$C with a range of 5.6 $^{o}$C to 27.5 $^{o}$C (McPartland, Clarke and Watson, 2000). Similarly, Ehrensing (1998) suggested optimum daily temperatures between 13 $^{o}$C and 22 $^{o}$C, but also stating 'hemp grows well at relatively low temperatures, and young seedlings will tolerate some exposure to frost (Ehresing, 1998, pp11). The tolerance of hemp for varied climates does not hinder its ability for vigorous early growth, as long as moisture levels are suitable. Ehrensing (1998) and Struik et al (2000) stated that hemp can develop a closed canopy in early spring, thus becoming a good competitor with weeds. The rapid growth brought on by increasing light interception subsequently produces full ground cover after only 400 to 450 $^{o}$C days thermal time, which compares well in comparison to Sugarbeet (600-700 $^{o}$C days) (citing Smit and Struik, 1995).

Optimum soil types and texture for industrial hemp are 'well aerated loams with high fertility and high organic matter' (Cherney and Small, 2016) as opposed to unproductive, poor draining or compacted soils. Struik et al (2000) found hemp to be 'very sensitive to soil structure, especially in a very wet or dry year', leading to non-uniform emergence or crop failure in extreme cases. Ehrensing (1998) stated that whilst hemp grows on a variety of soils, it has been shown to be 'practically impossible' to cultivate good crops with high quality fibres on heavy low-lying soils. On the other hand, it seems light sandy soils prone to drought are equally undesirable without sufficient fertilisation and moisture (Ehrensing, 1998). Optimum soil pH was suggested as 5.8 to

6.0 (Bócsa and Karus, 1998), whilst van der Werf (2002, pp3) stated 'hemp will perform well on many types of soil, as long as pH is not below 5', but also stating it 'can be impaired by water logging and by compaction of the tilled layer'. Furthermore, the MultiHemp project stated that a suitable pH is between 6 and 7.5 (MultiHemp, 2017). To summarise, it seems as long as the soil has good drainage, aerated uniform sub-structure, and is not too acidic, hemp should perform well, given suitable availability of nutrients, moisture and sunlight.

It follows that, where there are compaction issues, and risk or water logging or drought, deep soil working such as ploughing or subsoiling at 30-40cm in depth, is recommended, perhaps followed by an effective winter cover crop to maintain a good soil structure and promote deep and effective hemp tap root growth (Ehrensing, 1998; MultiHemp, 2017). Application and incorporation of organic manure, or Phosphorous (P) and Potassium (K) fertilisers are also recommended, prior to finishing preparation of the seedbed, with Nitrogen (N) fertiliser applied either during, or just prior to, sowing (MultiHemp, 2017). A Nitrogen fertiliser rate of 100 kg/ha for typical fibre crops in France is suggested by van der Werf (2002), and Ehrensing (1998) reported Nitrogen fertiliser rates in various countries since the 1950's ranging from 40 kg/ha to 150 kg/ha. Ehrensing (1998) also noted that caution should also be taken when considering very high fertilisation rates, as although yield responses may be realised, fibre quality can be seriously affected. For the Finola variety of hemp, fertiliser applications like those recommended for Oilseed rape are suitable, but with 15% additional N recommended (Finola.fi, 2019). Finally, industrial hemp is a small seed (1,000 grain weight (TGW), between 10-25 grams), so final soil preparation to create a fine, uniform seed bed, allows for shallow sowing and promotes high establishment rates and uniform emergence (Finola.fi, 2019).

### 2.3.2 Sowing Parameters and Timing

Sowing of industrial hemp seeds for commercial activities is done with a conventional seed drill in most cases (MultiHemp, 2017). Optimum plant spacing and seed depth varies depending on variety and application, but generally for fibre type crops a row spacing between 9 and 17 cm is suggested, at a seed depth of between 2 and 3 cm depending on timing and conditions (MultiHemp, 2017). Cherney and Small (2016) suggested planting in rows 7 cm to 20 cm apart for fibre crops and 15 cm to 18 cm apart for seed crops, at depths not exceeding 3 cm. For short dual hemp and predominantly seed/grain varieties, densities in the region of 100 plants/m$^2$ are recommended, by sowing at a rate of 25-30 kg/Ha (Finola.fi, 2019). Also, for the Finola variety it is stated that seed depth should ideally be at 1cm and not exceed 2cm, as crop failures are often due to sowing too deep (Finola.fi, 2019).

Struik et al (2000) found that stem dry matter yields were not significantly affected by plant density except at extremes, although they reiterated plant density is crucial for quality, due to enhanced ratio between cortical surface and volume (bark to fibre ratio). Plant densities below 90 plants/m$^2$ maintained density and crops with plant densities of 180 and 270 plants/m$^2$ showed self-thinning. Therefore, intended plant densities should be high to improve fibre qualities, as well as keeping plants shorter and canopies thicker, but not so high to result in a largely uneven canopy and excessive self-thinning (Ehrensing, 1998). The MultiHemp project suggested seed rates of between 40 and 65 kg/Ha to reach 200-300 plants/m$^2$ for fibre hemp (MultiHemp, 2017).

Regarding sowing timing, Amaducci et al (2008) reported that emergence timing has a large effect on flowering duration, crop uniformity and yield, which is largely dependent on whether the variety is monoecious or dioecious. Amaducci et al (2008, pp 15) stated that for dioecious varieties, 'time from emergence to 50% flowering decreased when postponing sowing, because of the long basic vegetative period (BVP) and the high sensitivity to the photo period'. In other words, the later-sown photoperiodic dioecious varieties completed BVP more quickly, and the progressively shorter photoperiod resulted in a shorter time to flowering. Although, this is clearly affected by climate (latitude N) and the specific variety and could still result in late harvests. Whereas, the same varieties sown early and at low temperatures, have a BVP which ends when the photoperiod is long, which does not favour flowering. On the other hand, Amaducci et al (2008, pp 16) subsequently stated that for monoecious varieties, namely Felina and Futura, 'a shorter BVP and a lower sensitivity to the photo period results in early flowering in early sowings because BVP is completed when the photo period is still short and inductive'. Whereas for later sown monecious varieties, flowering is delayed, due to increasing photoperiod, 'until a maximum time from emergence to flowering is reached' (Amaducci et al., 2008, pp 16). It follows that, for the dioecious, but auto-flowering, variety Finola, it is stated that a suitable sowing window is between mid-May (near 60$^{o}$N latitude) and late May or Early June (near 50 $^{o}$N Latitude) (Finola.fi, 2019).

The MultiHemp project (2017) stated that 'sowing date is usually defined on the basis of soil temperature and water availability to guarantee a prompt germination and a rapid crop establishment, and on the basis of the photoperiod that defines the length of the vegetative phase and ultimately stem and seed yield' (MultiHemp, 2017).

### 2.3.3 Crop Rotation

Curl (1963) defined crop rotation as 'the growing of economic plants in recurring succession and in definite sequence on the same land as distinguished from a one-crop system usually lacking a definite plan' (Curl, 1963). Continuous cropping of modern conventional broad-acre cultivars is now rare, due to the build-up of soil-borne diseases, pests and weeds, over-reliance on fertilisation and loss in yields (Conserve Energy Future, 2019). Most recently in Europe, cropping practises such as; longer rotations, a mixture of winter and spring cropping, inclusion of cover crops and intercropping, have been encouraged, as many farmers move towards sustainable cropping systems, which improve organic matter, allow better control of weeds, pests and disease and support reduced tillage and pesticide use (Conserve Energy Future, 2019). It follows that Ranalli (2004, pp 2) stated that hemp 'provides many opportunities, i.e weed control, pest and disease resistance, pesticide elimination without disadvantages, [and] soil improvement by means of crop rotation'.

Furthermore, the MultiHemp project (2017) reported that hemp can be important in crop rotations as it has been shown to improve yields in the following crops, such as wheat and soybean. Similarly, Gorchs and Lloveras (2003) stated that in Spain 'hemp is grown in rotation with winter wheat and farmers consider it an excellent break crop to wheat for several reasons', particularly as yield increases in the following wheat crop, as well as in sunflower, oilseed rape and peas (Gorchs and Lloveras, 2003, pp 50). They suggested that the yield effect was due to good weed suppression, and that the cultivar also left the soil with improved structure, ventilation and moisture balance. Furthermore, hemp is not only a superb rotation crop, based on conventional measures, but also 'hemp promotes environmental-friendly agricultural methods (through improvement of rotation), which might secure a long-term land management strategy; a strategy that might be even more significantly improved, if hemp was used as a key bioremediation crop to restore unproductive land into agricultural use' (Ranalli and Venturi, 2004, pp 3). Hemp has been shown to have characteristics very suited to effective phytoremediation, which refers to ability of plants to remove heavy metal pollutants from water and soil (Ahmad et al., 2015). The high biomass potential, long root growth and short life cycle of hemp, along with the plants ability to absorb and accumulate heavy metal toxins faster than the soil, means it has been described as a hyperaccumulator, highly suited to soil remediation (Ahmad et al., 2015).

Break-crops are key crops within a commercial rotation which can be defined as 'a secondary crop grown to interrupt the repeated sowing of cereals as part of a crop rotation' (Oxford Dictionaries | English, 2019). Such crops are often grown only once in the rotation, and utilised mainly to improve disease and weed control, as they are often a different plant species (for example broad-leaved cultivars, within a rotation of grass-species cultivars), are therefore susceptible to different pathogens, and so create a break in the lifecycle, and subsequent build-up of soil-borne diseases and pests (Ag.ndsu.edu, 2019; Sare.org, 2019). In many cases break-crops also allow for more effective use of selective herbicides to control problematic weeds (Ag.ndsu.edu, 2019; Sare.org, 2019). Additionally, many break-crops are spring sown, such as in the case of hemp, allowing weed control measures and seedbed preparation to be conducted in the autumn or early spring, prior to sowing the break-crop (Sare.org, 2019).

Furthermore, break-crops can be selected to help improve soil structure and organic matter levels, as they can support different soil organisms, and particularly in the case of hemp, may have deep rooting plants which break up soil structure and aerate soils at depth (MultiHemp, 2017). However, timing of the break-crop and the selection of other crops in the rotation is important as MultiHemp (citing Rivora, 2001) stated, 'it is in fact advisable to avoid [crops] in the same rotation with hemp species, that are susceptible to Pythium, Sclerotinia and Piralide'. Furthermore, 'Hemp has proved to be highly sensitive to the residue of herbicides in the soil, therefore it is advisable to avoid the cultivation after maize, if atrazine and simazine are used, or after tomato treated with specific herbicides for Solanaceae' (MultiHemp, 2017).

### 2.3.4 Weeds, Pests and Diseases

When provided adequate early growing conditions, weeds are naturally suppressed by the rigorous growth of the hemp crop (van der Werf, 2002). The use of herbicides is not required and in fact, currently there are none with approval for use on industrial hemp in Europe (Finola.fi, 2019). Van der Werf (2002) also stated 'pests and diseases are extremely rare, so no pesticides are used. In some cases, however, 'spots of broomrape (a parasitic plant feeding on the roots) may pose a problem, and here the only remedy is in crop rotation.' (van der Werf, 2002, pp 108). Although well-established hemp plants are highly competitive with weeds, it is still important to maintain control. The MultiHemp project (2017) states that 'In China, hand or chemical weeding is carried out when necessary. Especially in Southern China, chemical weed management is preferred. Herbicides are spread on the soil after sowing and before seedling emergence' (MultiHemp, 2017). Similarly, NNFCC advice is to apply a pre-emergence broad-spectrum herbicide following sowing, to promote early establishment of the hemp crop by limiting early weed competition (NNFCC, 2010). The advice for Finola is that pesticides and herbicides should not be used, and weeds should be controlled in the autumn if possible, or at least through spring cultivation (Finola.fi, 2019). Problem weeds are cited as ‘black bindweed or wild buckwheat (Fallopia convolvulus), wild oat (Avena fatua), pigweed (Amaranthus species), fat hen (Chenopodium album), rapeseed, caraway, coriander and other volunteer crops’ (finol.fi, 2019).

The Finola website also states that ‘Hemp has very few disease and pest problems in most places’. But ‘under wet conditions, Sclerotinia Sclerotiorum (stem rot) and Botrytis Cinera (grey mould/ bud blight) can be a problem’. ‘Early harvest is recommended to avoid fungal damage. Grasshoppers, gophers, the Bertha Army Worm, the Hemp Borer and Lygus plant bugs have been known to attack hemp in some regions’, and, ‘flocking migratory birds will be attracted to the mature seed in late autumn. Ideally, hempseed should be harvested just before birds begin to visit the field’ (Finola.fi, 2019). Furthermore, McPartland, Clarke and Watson (2000) provide a comprehensive overview of the range of diseases and pests which can adversely affect industrial hemp crops. The book also lists ‘top 10’ common disease and pest problems for; seeds and seedlings, stems and branches, roots, flowers and leaves, whole plant and indoor plants. Notably, Integrated Pest Management (IPM) strategies are discussed, from identification and monitoring of; insect pests (many of which can be identified by their damage), fungi and bacteria, nematodes and viral and nutritional disease, through to implementation of control methods, categorised as; cultural and mechanical methods, biological controls and biorational chemical control (organic pesticides) (McPartland, Clarke and Watson, 2000).

### 2.3.5 Harvesting and Processing Technology

THC sampling of the crop depends on variety and is carried out post onset of flowering and prior to harvest. For example, in the case of Finola, which is very quick to maturity, sampling timing is highly important, as late sampling can result in THC levels exceeding the threshold (Finola.fi, 2019). Sampling under EU regulations is conducted 10 days after the onset of flowering at the earliest, and 10 days after the end of flowering at the latest. Therefore, in the case of Finola, it is suggested that field sampling is started at around 40-50 days after sowing (Finola.fi, 2019).

Gorchs and Lloveras (2003) reported that hemp grown for fibre is harvested when male flowers or plants have completed pollen shed, and early seeds from female flowers begin to mature. Although (citing Bocsa and Karus, 1998), it is also stated that earlier harvest may result in better fibre quality. In terms of the machinery used, Gorchs and Lloveras (2003, pp 52) describe cutting the crop with ‘a simple bar mower (reciprocating cutter bar) which lays the plants down in rows to be ret by dew or rain for a period of 10 to 20 days’. This sounds similar to the technique employed currently by the company East Yorkshire Hemp (eastyorkshirehemp.co.uk, 2019), whereby the crop is cut in early August using a custom built machine which cuts the tall stems into several lengths that are left to ret for around 5 weeks, before the straw is baled and stored.

Whereas for short seed crops, the crop is harvested at seed ripeness, which Gorchs and Lloveras (2003) stated is usually mid-late September, although for a variety such as Finola, it is recommended to harvest around 100-130 days after sowing (dependent on climate) with the top third harvested for grain whilst the plant is still green (70-90% seed head maturity) (Finola,fi, 2019). It is stated that harvesting while the plants remain partially green reduces cutting and wrapping problems and fire hazards (Finola,fi, 2019). Optimum grain moisture at harvest is around 10-15% moisture (Finola,fi, 2019). A standard combine header can be used, with the straw chopped, or swathed (if conditions allow) for baling. With a pure hempseed harvest from Finola, a standard combine is recommended to thresh the grain and chop the straw, adding the biomass back to the field. Furthermore, caution must be taken to avoid significant wrapping with frequent checks of the intake components recommended (Finola.fi, 2019). Lastly it is stated that Claas and New Holland combines work well and straw walker systems are recommended rather than rotary systems (Finola.fi, 2019).

For harvesting the whole crop, Hempflax (hempflax.com, 2019) have designed and produced a 'double cut combine' header-system for John Deere machines, which allows harvesting the entire plant, even with tall varieties. The system harvests seed, stem and leaf and results in cost savings, greater capacity, higher yield recovery and environmental benefits due to lower CO2 emissions per hectare. It is also stated that the system can be rebuilt in a day for harvesting other more conventional cereal crops and oilseed rape. Hemp seeds and flowers can be harvested directly and straw swathed, for retting and further processing (hempflax.com, 2019).

Clarke (2010) described that traditional, labour intensive straw fibre extraction processes nearly always involved *retting.* In Europe, field retting or dew retting is typical, whereby microbial processes degrade the stem after cutting in the field, depending on moisture levels and air temperature. Traditionally, after weeks of field retting, hemp is then gathered for further processing to extract the fibres (Clarke, 2010). Regardless of the retting techniques used, without sophisticated machinery, manual labour was subsequently required to break, crush or peel the stems, to separate the outer bark and bast fibre material from the 'woody core'. One early invention, the 'hemp breaker', was a wooden scissor-type device invented in Holland, which enabled 'one person to do the work of several' but it was described as 'extremely brutal work' (Clarke, 2010, pp143).

As described in Section 2.2.2, developments were subsequently initiated on processing machines called decorticators in the early 20$^{th}$ century, but development was somewhat hampered by the onset of prohibition and the decline in the hemp market. Nevertheless, there are now many modern techniques for retting and decortication, with various advantages and disadvantages associated with cost, complexity, quality, speed and application. Modern decorticators are now widespread, and various companies have advanced processing lines for high quality and efficient extraction of each biomass component. Hempflax state that they have subsequently developed the 'most efficient production line in the world' (hempflax.com, 2019). Additionally, Austrian company Hanfland (hanfland.at, 2019) have developed a 'mobile hemp conditioner', which breaks the swathed straw in the field, 'resulting in fibres and shives'. 'The broken straw is picked up with the field harvester and separated into shives and fibres'. Finally, 'the shives are bunkered in a grain tank and the fibres are made transportable by means of a baler' (hanfland.at, 2019).

## 2.4 Feasibility Study Proposal, Aims and Objectives

It has been shown that there is strong potential for industrial hemp to be cultivated and marketed at scale in the UK, to introduce domestic supplies for a variety of environmentally and economically important products. It has also been shown that the cultivar has the potential to be agronomically beneficial to farmers, particularly as a break-crop within a cereal-dominant rotation, through its beneficial effects on soils, competition with weeds and low input requirements. However, it has also been identified that the UK currently cultivates a very small percentage of the industrial hemp produced in Europe, and value chains are subsequently poorly-developed and reliant on imports. Furthermore, recent, detailed and reliable market data for industrial hemp products were not freely available, meaning that it is currently difficult to accurately evaluate the most beneficial markets for hemp-derived products. Due to the long period of prohibition of the cannabis species and the resultant demonization of hemp, there are also questions surrounding the current perceptions and knowledge of UK farmers on the industrial cultivar. It is realised that even if the cultivar has high potential both in terms of UK demand for its product derivatives, as well as agronomically, it does not necessarily mean that farmers will be capable, or willing to grow it.

It follows that independent market research was necessary to establish or verify the key market trends in Europe, as well as gain insight into market health and market growth. Furthermore, by analysing the opportunities and threats of various European businesses in the industry, it would provide insight into how vertically integrated businesses in the UK may best develop. It was also realised that independent market research would be required to analyse UK farm businesses, to find out what the current cropping habits are, how crop rotations are being managed and what the perceptions are on industrial hemp, as well as to gauge current knowledge and interest levels. Ultimately, combining the two datasets should allow the feasibility to be assessed and theories to be formed on the most likely pathways for the reintroduction of industrial hemp, as a wide scale break-crop, in the UK.

Therefore, the overall aim of the project can be summarised as;

- To assess the economic and practical feasibility for large-scale reintroduction of industrial hemp as a break-crop in the UK.

Furthermore, the objectives of the project can be stated as;

- Review literature related to industrial hemp production in Europe to identify key markets and products, barriers to entry and potential opportunities for UK farming systems.
- Conduct independent market research to analyse European industrial hemp markets and product supply chains.
- Conduct independent market research to analyse the practises and positions of UK farm businesses, in relation to potential industrial hemp cultivation.
- Analyse both independent data sets, alongside information obtained in the Literature Review, to discuss the most viable potential pathways and frameworks for the reintroduction of the cultivar.

# Chapter 3: Market Data Analysis

Independent market research was conducted by designing two different surveys in Survey Monkey, and distributing them, predominantly via email, to businesses within the European industrial hemp industry and UK agricultural industry respectively. The first of the two surveys aimed to gather data from a range of business throughout the industrial hemp supply chain, in order to assess, and geographically map, value chains, analyse sector growth, subjectively analyse perceived business threats and opportunities, and finally analyse predictions for market change over the next 10 years. Similarly, the second survey aimed to gather data from a range of arable and mixed farm businesses, from around the UK, based on management structures, cropping choices, break-crop practises and subjective perceptions and thoughts on industrial hemp as a cultivar, as well as how the farm businesses are likely to change in the near future.

Once surveys were closed, raw data from both surveys was transferred to Microsoft Excel and question responses for all verified responses to each survey, were coded into single spreadsheets. This allowed basic frequency analysis to be conducted for each question, as well as more in-depth descriptive statistical analysis, and analysis of qualitative data, in order to identify significant findings and trends within each market. A grounded theory approach was then taken to discuss the results in relation to the findings of the literature review, in order to assess potential pathways for growing industrial hemp in the UK, and subsequently make conclusions on the overall feasibility of the project proposal.

## 3.1 European Industrial Hemp Market Survey (Survey 1)

### 3.1.1 European Market Survey Methods and Resources

The European Industrial Hemp Market survey was distributed using an email link generated by Survey Monkey (surveymonkey.com). Business contacts were identified using a range of resources including; EIHA (eiha.org), Google search (google.com), BHA (britishhempassociation.co.uk), social media (facebook.com), Euro Pages (europages.com), Market Watch (marketwatch.com), JEC Group (jeccomposites.com) and Grow2Buld (grow2build.eu). Out of an approximate distribution of 120 contacts, a total of 28 responses were received, giving an approximate response rate of 23%. Although a few of the responses were received after networking at the Hemp and CBD Expo event at the NEC Birmingham, which was held on 3rd March 2019. Although the number of responses received was disappointing, being lower than anticipated, responses were deemed valuable and suitable for analysis. The information was analysed directly, without prior hypothesis, but in conjunction with existing market data, when forming theories and drawing conclusions.

It should be noted that there were no bias or influential factors affecting whether or not a business was sent the survey, except that they had to be an active business operating within the European industrial hemp industry, and that the business contact details were freely available on their own website or from a credible source. Even the businesses approached at the NEC Hemp and CBD exhibition were randomly selected and completed the survey based on the practicality of the situation. The survey was introduced to all respondents equally and without bias or prior information which could have be influential on results.

### 3.1.2 European Market Survey Results

Business Size and Age

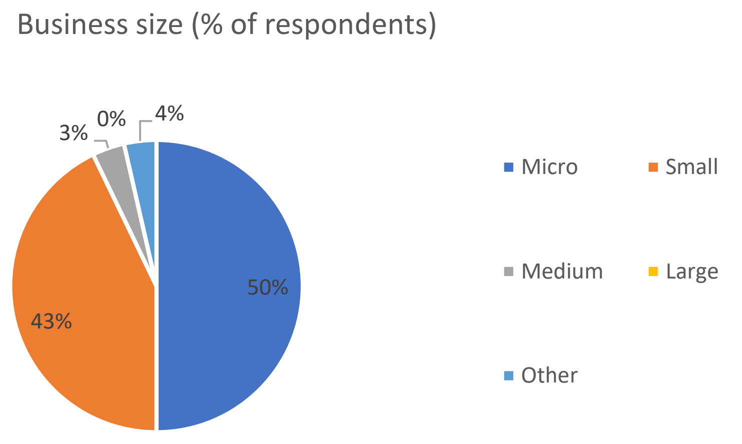


Figure 9: Survey 1 – Q1 Business size distribution

Most businesses that responded to the survey were classed in this research as 'small' or 'micro' in size, with 50% having less than 10 employees. Only one respondent reported more than 50 employees, apart from a trade association of over 700 members and 2500 resellers, who selected 'other' in this question. Categories were; Micro (<10 employees), Small (10 to 49 employees), Medium (50 to 250 employees), Large (over 250 employees).

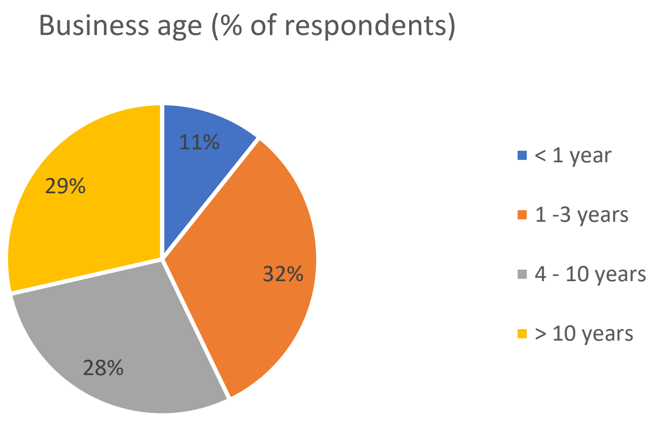


Figure 10: Survey 1 – Q2 Business age distribution

The businesses represented a relatively wide age range, with three respondents less than 1 year old, whilst approximately 30% (eight businesses) were over 10 years old.

## Business Operations

Respondents were asked to select their main business operations from a list of 19 choices including 'other'. Notably, a quarter of respondents listed farming as an operation, with similar numbers reporting research and development, logistics and packaging. Approximately one third of businesses were involved in food processing and consultation, whilst between 35 and 40% of respondents listed processing of health products and cosmetics and/or pharmaceuticals and import/export activities. Most significantly, more than 50% of respondents listed business-to-business sales and end-consumer retail amongst their main business operations.

The Mode average of operations selected, per respondent was 5, indicating a relatively vertically integrated and multifunctional, yet predominantly sales focussed supply chain amongst the business responses.

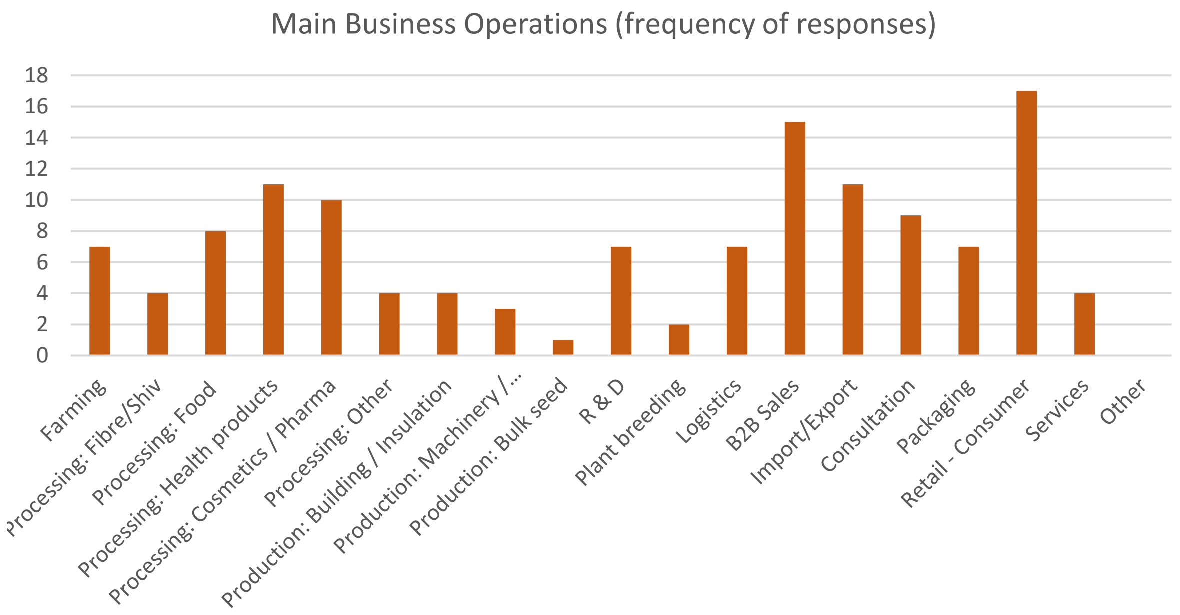


Figure 11: Survey 1 - Q3 Business Operations

The least common business operations were; bulk seed production (1 business), plant breeding (2), machinery and equipment production (3), services (4), production of building and insulation materials (4) and processing of fibre and other raw materials (4). Interestingly, only 14% of respondents, listed the processing of hemp fibre and shives, whilst twice that number listed processing of hemp food products and almost 40% listed the processing of hemp-derived health products.

The lack of respondents reporting industrial hemp seed production, plant breeding, and machinery and equipment manufacture, suggests that the survey population missed such businesses, and/or that these are niche markets, supplied by a minority of businesses within the industrial hemp market. Analysed in conjunction with figure 4, the EIHA supplier list also suggests there are few suppliers of industrial hemp machinery/equipment and such businesses are particularly likely to be in Germany. Similarly, there were only 3 suppliers listed for bulk seed (for sowing), of which one was in Germany, one in France and one in Slovakia.

## Business Products and Services

Respondents were also given the choice of 19 product and services options, as well as 'other', to describe in more detail the types of industrial hemp related products and services offered by the company.

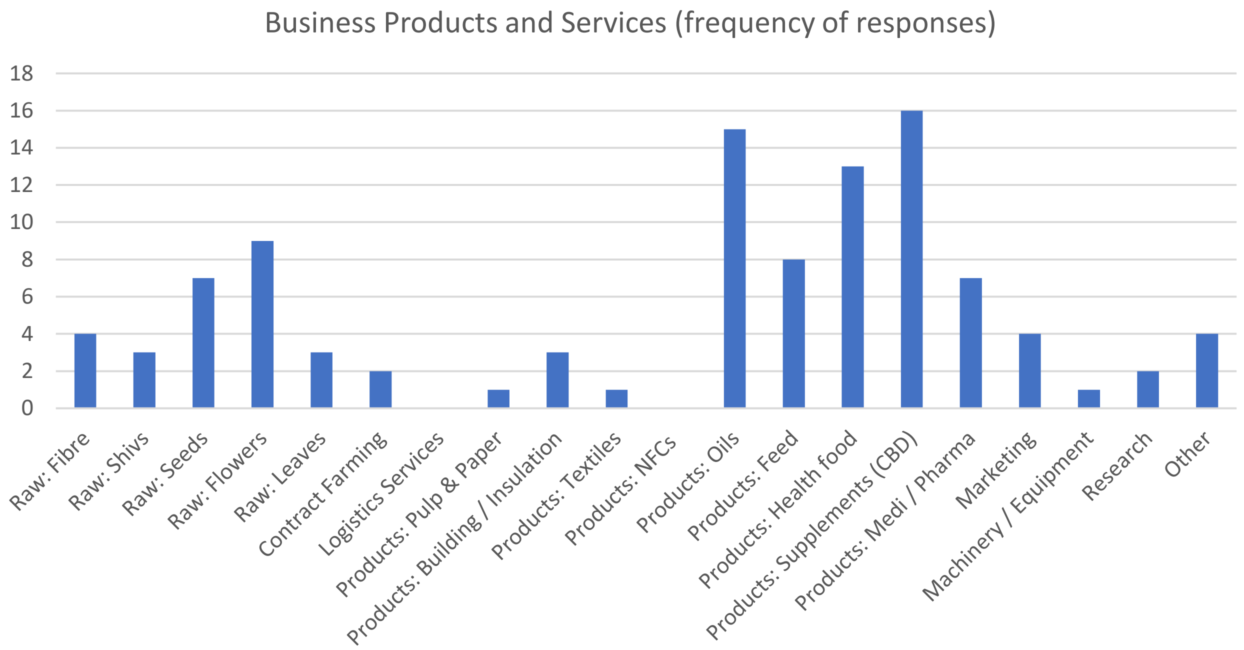


Figure 12: Survey 1 - Q4 Business Products and Services

As shown in Figure 12, most businesses that listed raw materials were respondents who have internal farming operations. Furthermore, from the previous question, most processing operations were for health products, food, cosmetics/pharmaceuticals. The most common products selected were supplements (CBD), oils and health foods at 57%, 54% and 46% respectively. On the other hand, only 25% of respondents reported pharmaceutical products, and given that 36% reported processing of cosmetics and/or pharmaceuticals as operations, this suggests cosmetics are more common. Animal feed was reported by a surprising 29% of respondents.

The 'other' category included one report of yarn products, two of packaging and one of business development services.

Business Compound Annual Growth Rate (CAGR)

Figure 13 shows the number of responses received for each CAGR category. CAGR was intended to provide a snapshot comparison of the businesses smoothed rate of growth over the previous 3 years. Whilst it only provides an indication, this information provides insight into the health and growth of the industry.

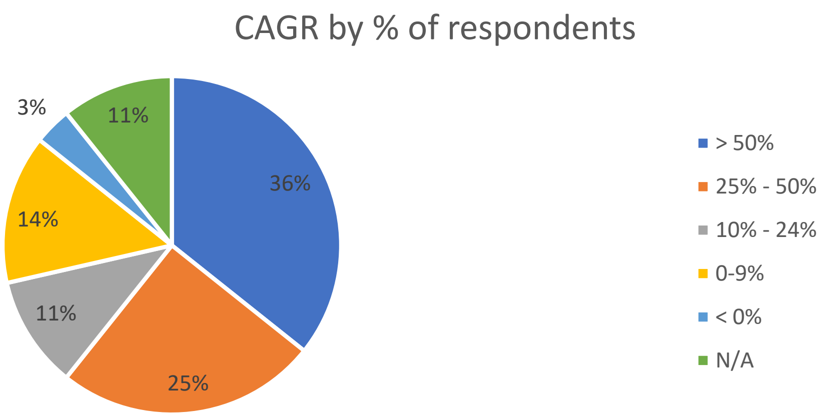


Figure 13: Survey 1 - Q 5 Business Compound Annual Growth Rate (CAGR)

It should be noted that it was subsequently realised that the CAGR data obtained could not be considered as accurately representative, due to the inability to verify the figures obtained and relatively broad CAGR categories. Additionally, it was not specified in the survey whether the question referred to compound revenue growth over the last 3 financial years, as opposed to sales growth, or some other metric, therefore there was additional lack of uncertainty in the respondent's answers. However, only 3 respondents answered 'N/A', two of which were businesses less than a year old. Also, with 36% of business respondents reporting CAGRs over 50% in the last 3 years and 25% reporting CAGRs over 25%, there is a strong indication that most businesses in the sample are achieving substantial rates of growth.

## Geographical distribution of suppliers

Question six was the first of a series of questions to analyse the geographical distribution of the European industrial hemp supply chain, based on the survey sample.

Out of 30 European countries, the respondents were asked to select the locations of their suppliers. This could include suppliers of raw and processed industrial hemp products and materials, as well as items such as print and packaging, other equipment and machinery or digital goods and services. For clarity in the visual information, Russia was omitted and instead included in the analysis of 'other' countries (those outside Europe).

Figure 14 shows the geographical distribution of suppliers using a Map Chart generated in Microsoft Excel. The darker the map colour, the higher the density of suppliers, as reported by the survey respondents.

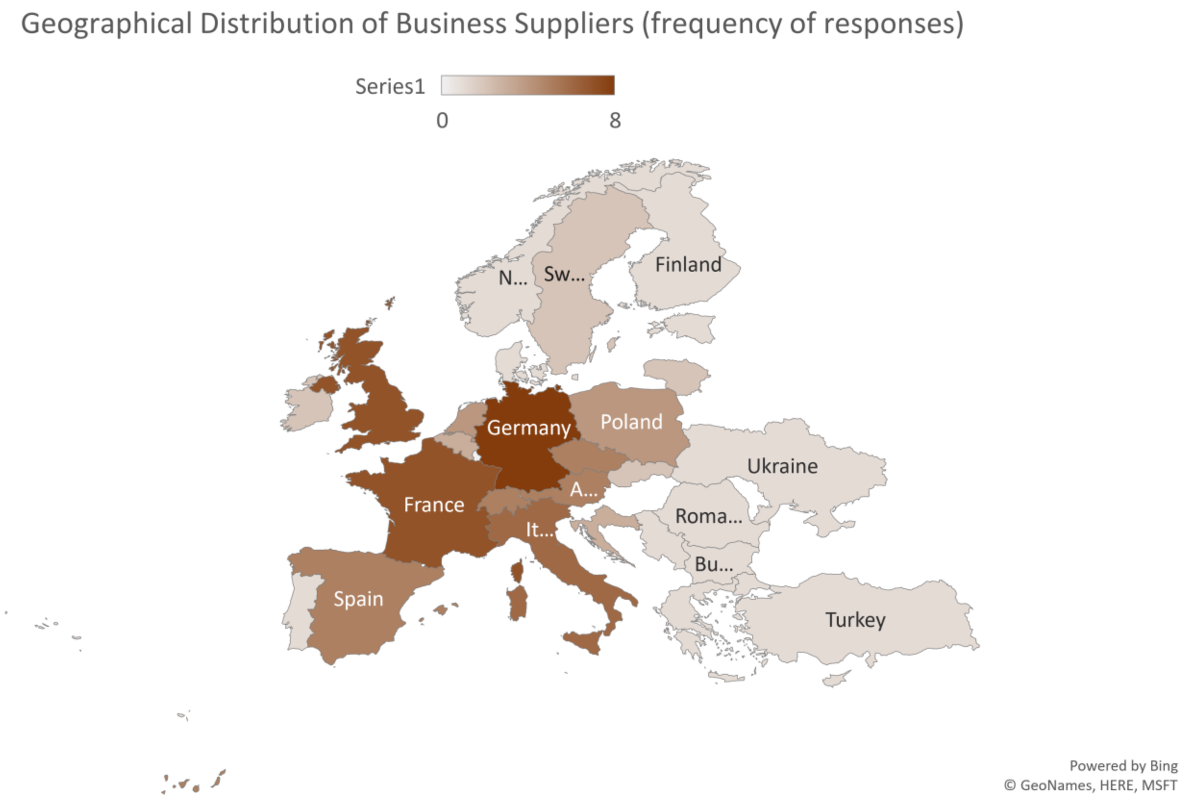


Figure 14: Survey 1 – Q6 Geographical distribution of business suppliers

Germany was listed by 8 respondents (29%) as a location of their suppliers. Similarly, both France and the UK were reported 7 times (25%) and Italy, 6 (21%). Austria, Czech Republic, Spain and Switzerland were also relatively popular, being listed 5 times each (18%). Furthermore, 25% of respondents listed 'other' which consisted of China (14%), USA (7%) and Canada (4%).

In total, suppliers were listed in 31 different countries, with only Russia and Luxembourg not being selected by the sample of 28 businesses.

## Geographical distribution of customers

The survey respondents were subsequently asked to select the countries in which their customers are based, again for insight on the geographical distribution of the industrial hemp supply chain. Results are shown in figure 15.

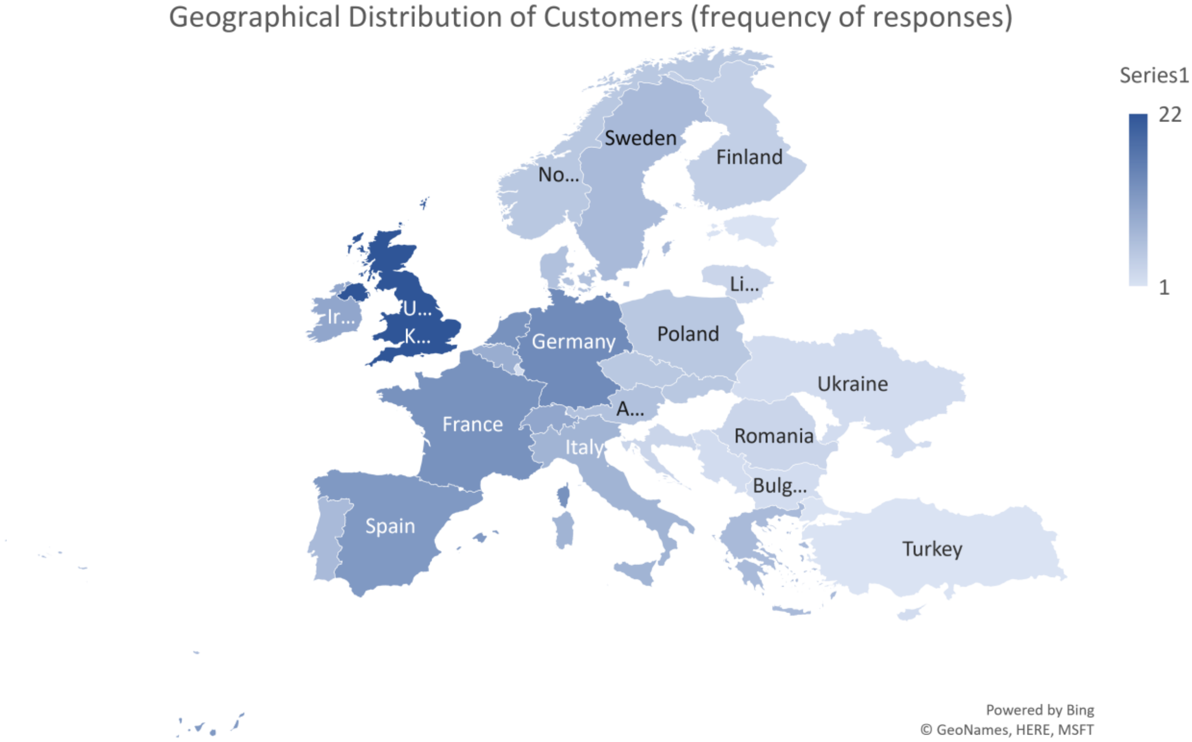


Figure 15: Survey 1 - Q7 Geographical distribution of business customers

All European countries that were given as options were selected by the business sample, including Luxembourg and Russia, which were both selected by two respondents (7%). Also, in the category 'other', Australia (11%), Japan (7%), China (4%), USA (11%), South Africa (4%) and Canada (4%) were reported. Additionally, two respondents commented 'Many' and 'Global' respectively for this question, indicating the diversity of the customer base for this industry. This data shows that even within a small sample of European businesses, distribution of industrial hemp products is on a global scale and the industrial hemp market spans most European countries.

Most significantly, the UK was listed by 22 respondents (79%). This indicates that the UK is a very important consumer market for industrial hemp businesses throughout Europe. The data implies that the UK is one of the most important markets for such products by a significant margin, with the second most important being Germany with 14 responses (50%) and thirdly France and the Netherlands (46%). Other important consumer markets reported were Spain (43%), Switzerland (36%), Ireland (36%), Belgium (32%) and Italy (29%).

## Geographical distribution of cultivation

The third question designed to gain insight on the geographical distribution of the supply chain asked respondents to list the countries in which their industrial hemp is cultivated. Broadly speaking this may include the location of the farms of the businesses reporting farming operations (i.e those vertically integrated), as well as the tier 1 suppliers of raw or processed materials to businesses further down the supply chain.

Inevitably, the average frequency of responses was lower than for the previous two questions. However, 26 European countries were listed, as well as USA (4%), Latvia (4%), Canada (11%), China (7%) and India (4%) listed under 'other'. The countries with the highest frequency of responses were Spain (21%), Czech Republic (18%), UK (18%), and Slovakia (18%). Therefore, whilst it appears that the majority of respondent's industrial hemp cultivation takes place in Spain, the results are not conclusive, as the sample size was small, and responses were relatively evenly divided across the range of countries. Further analysis is required to identify any trends in cultivation regions based on the various product types. The data does indicate that industrial hemp cultivation is very geographically diverse and takes place in most European countries, and secondly that the UK is relatively important in terms of industrial hemp cultivation for the sample of respondents.

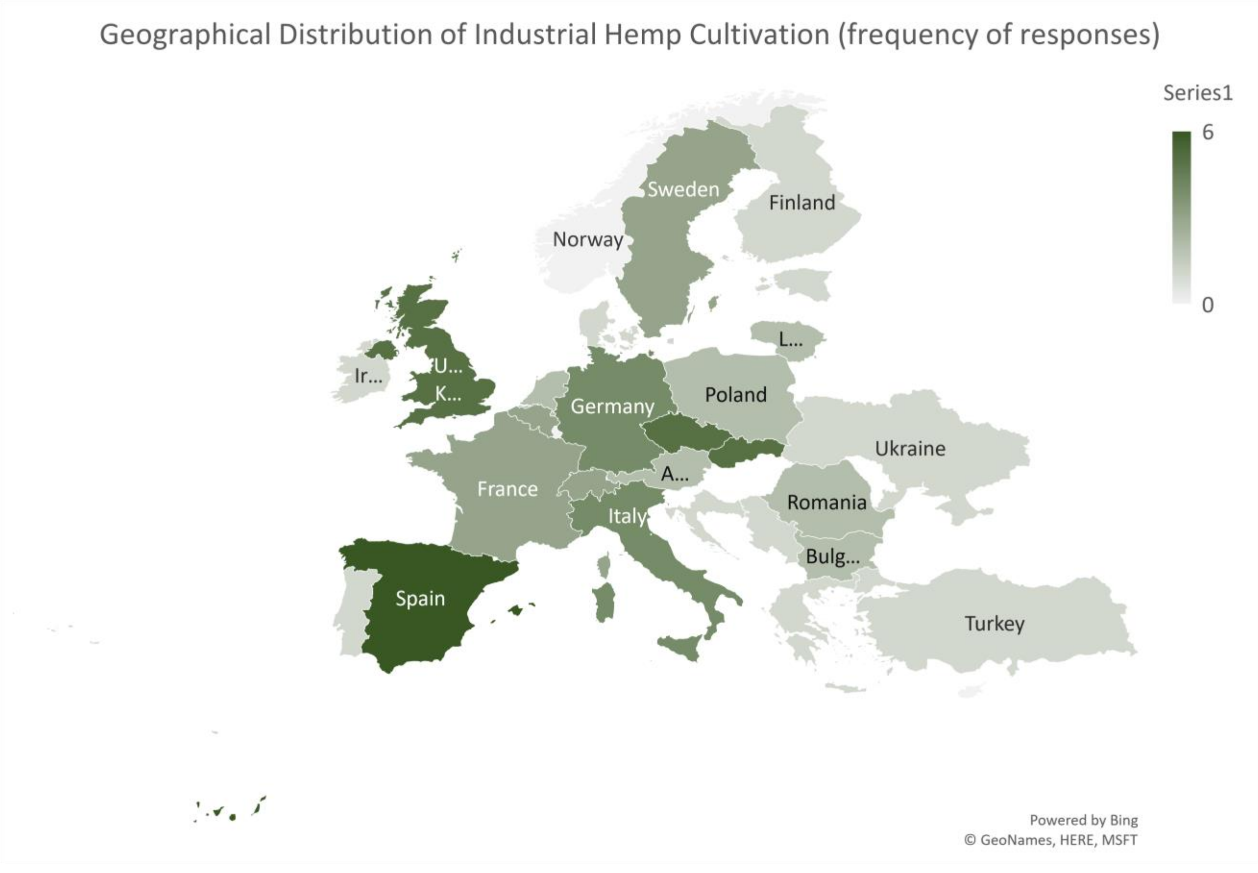


Figure 16: Survey 1 - Q8 Geographical distribution of cultivation

## Perceived Business Threats

Question 9 of the survey asked respondents to list the main threats to the business from a list of 12 options including 'other'. Figure 17 shows a pie chart of the full sample response.

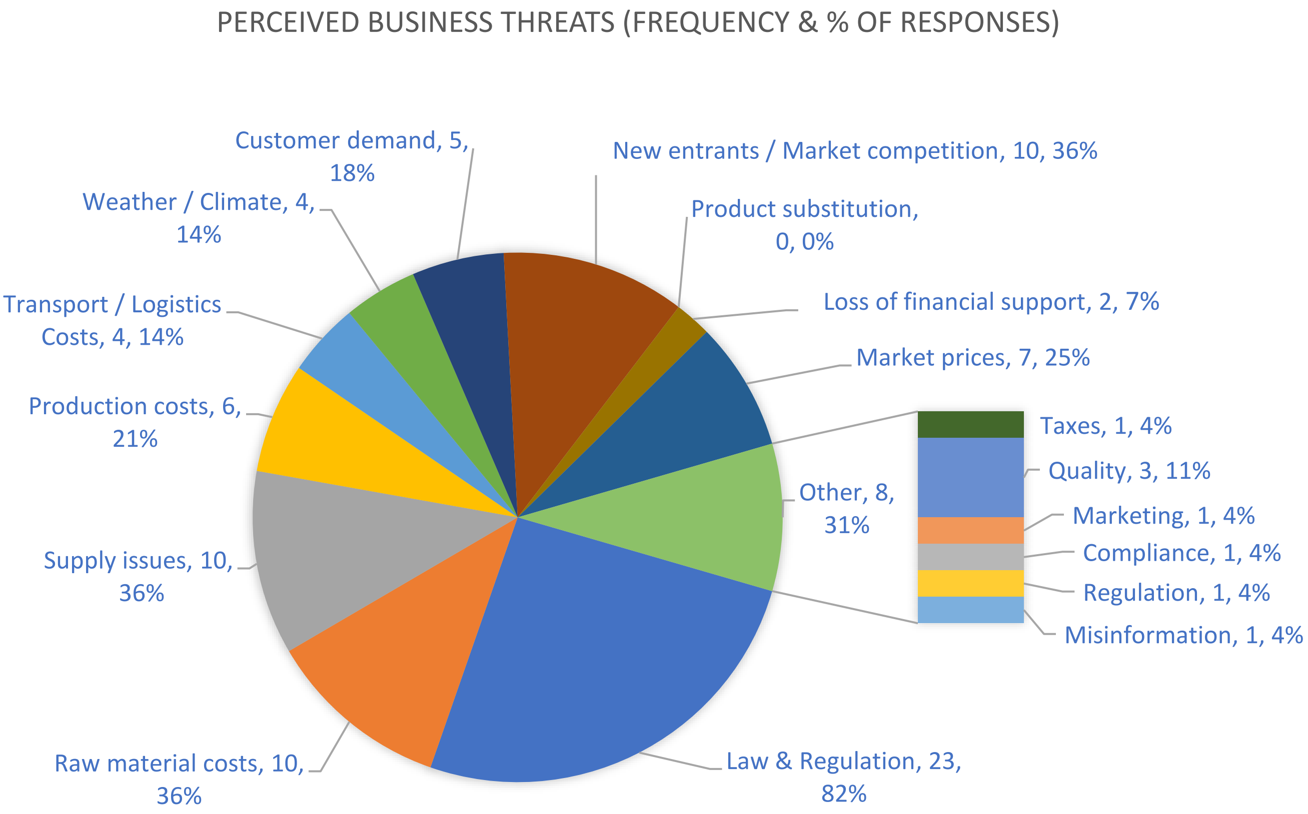


Figure 17: Survey 1 - Q9 Business Threats

The data shows that law and regulation changes pose a threat to 82% of survey respondents. Whilst the data cannot signify if this is the greatest threat to respondent businesses, it is clearly the most common issue these businesses are facing. Other common business threats reported were raw material costs, supply issues and new entrants/market competition, which were each reported by 10 different businesses (36% of the sample).

## Perceived Business Opportunities

Similarly, question 10 requested respondents to list the main opportunities for the business based on 12 options including 'other'. Figure 18 shows the frequency and percentage of responses of business opportunity categories.

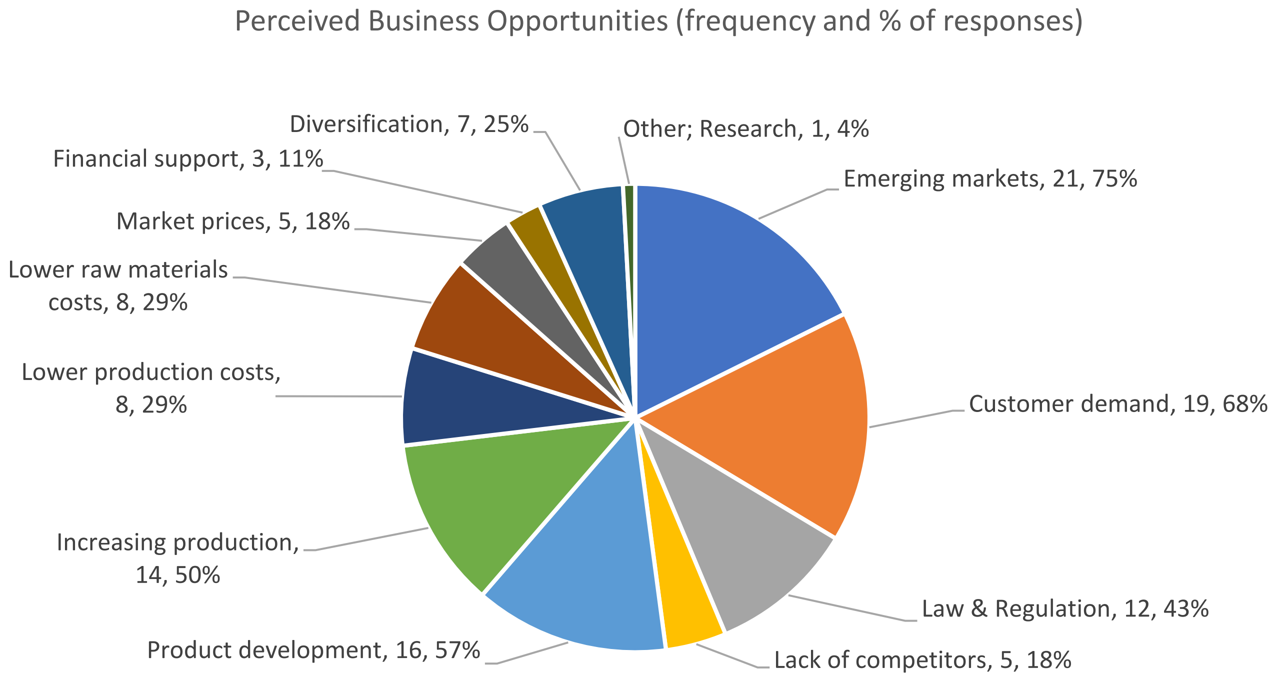


Figure 18: Survey 1 - Q10 Business Opportunities

The overall frequency of responses for business opportunities was around 30% higher than that of business threats, indicating that respondents feel positive about the market in general and the future of their business.

The most frequently reported business opportunities were emerging markets with 21 responses (75% of respondents), closely followed by increasing customer demand (68%), product development (57%), increasing production (50%) and law and regulation changes (43%). The least frequently reported, other than research, were financial support (3 respondents, 11%), market prices (18%), and lack of competitors (18%). The results indicate that the market is highly competitive and changeable, although most respondents report that there are opportunities within emerging markets and strong customer demand. Additionally, half of respondents see opportunity in increasing their production output and developing new products, whilst almost half predict changes in law and regulation may present further business opportunities. Again, these results depict a changing and growing marketplace, with strong growth opportunities, albeit from a small survey sample.

## Business investment and expansion

To establish the proportion of businesses in the sample undergoing expansion or actively investing, question 11 asked if the businesses were currently investing and/or expanding. Fixed answers of 'yes' and 'no' were offered. Question 12 subsequently offered respondents a free-text answer box to report how such expansion or investment was being implemented. Analysis of answer texts was then conducted in excel by organising answers, extracting key words, and combining similar phrases, to generate a list of answer phrases. These phrases were then used to generate a Word Cloud in order to graphically depict the key areas of expansion and growth.

Figure 19 shows that 25 (89%) respondents reported that they were actively investing and/or expanding as a business. Two respondents (7%) reported that they were not, and one respondent did not answer the question. Figure 20 shows a Word Cloud generated for the responses submitted to question 12, referring to how the 89% of respondents who reported active expansion or investment were doing so. It shows that investing in infrastructure/machinery/equipment are the most common areas of growth.

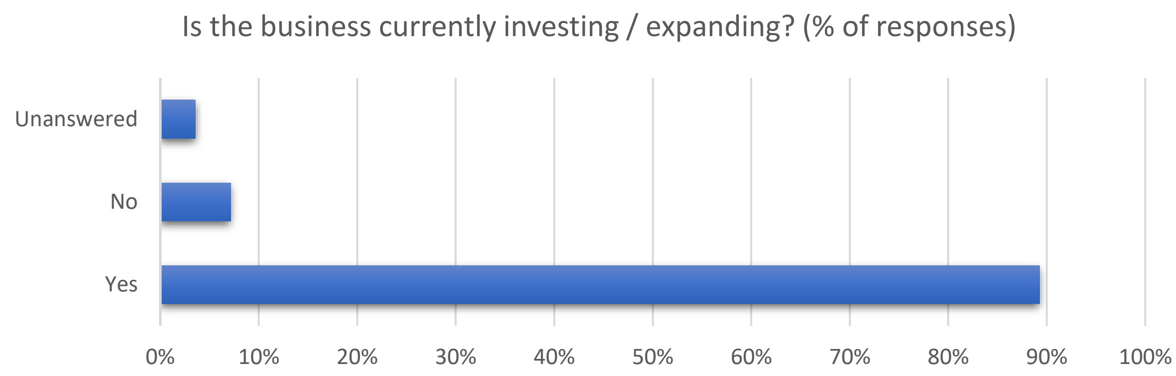


Figure 19: Survey 1 - Q11 Business expansion and investment


Figure 20: Survey 1 - Q12 Key areas of business expansion and investment

## Business costs

The final business insight requested in the survey was to identify the main business costs for each business. Again, a free-text answer box was provided, and the key words and phrases were formatted, extracted and processed as a Word Cloud for visualisation.

Figure 21 shows the Word Cloud for reported business costs.


Figure 21: Survey 1 - Q13 Business costs

'Labour' was the most frequent response by a significant margin, reported by 39% of business sample. Additionally, raw materials were reported as a main business cost by 21% of respondents and 'extraction' costs were listed by 3 respondents (11%).

## Respondent's prediction on whether the industrial hemp market will increase over the next 10 years

The final survey question was designed to gain qualitative insight on how the respondents perceive the market will change in the long-term. It was hoped that, despite potential bias, respondents would provide insight into their feelings on whether current industrial hemp market growth is sustainable in the long-term, or whether certain market factors and conditions may be driving a rapid, but short-lived and unsustainable rate of growth.

The question therefore had two parts; a simple yes/no answer as to whether they think the market will continue to grow over the next 10 years, and secondly a free-text answer box to explain why they have such opinions.

Figure 22 shows the frequency response for the first part of the question, which unsurprisingly shows that 93% of respondents believed the market would increase. Although one respondent selected 'no' and another selected 'not sure'. The respondent who answered 'no' entered 'strict laws' as their answer to the second part of the question. The respondent who answered 'not sure' entered 'public perception' as their answer to why. Subsequently, Figure 23 provides a Word

Cloud for visualisation of the explanations provided by some respondents as to why they predict the market to increase. Figure 23 shows that 'legislation' and 'public perception' are perceived as positive drivers behind potential market growth, but sceptics also believe the same drivers could result in market decline.

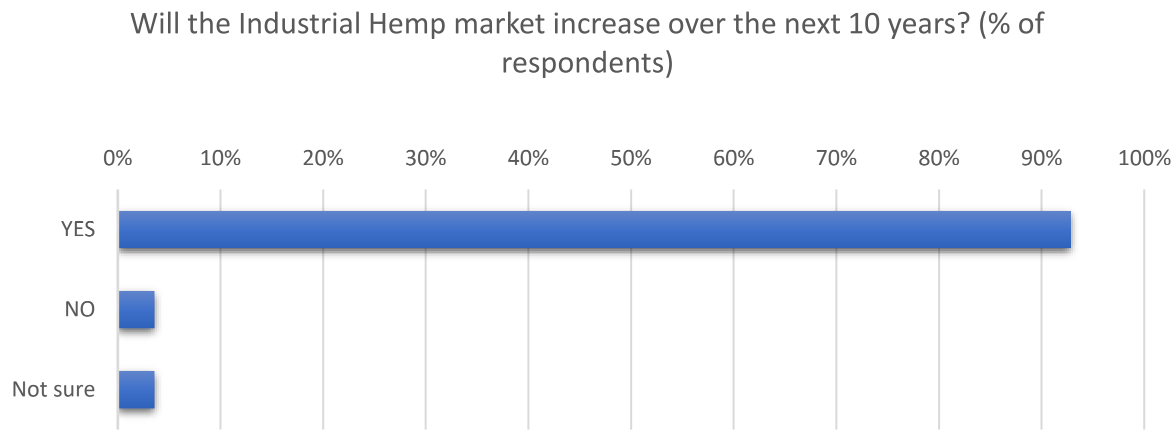


Figure 22: Survey 1 - Q14 Prediction on market growth over 10 years


Figure 23: Survey 1 - Q14 Reasons for predicted market growth/decline over 10 years

## 3.2 UK Farm Businesses Survey (Survey 2)

### 3.2.1 UK Farm Business Survey Methods and Resources

The UK farm business survey (Survey 2) was also designed on Survey Monkey, and distributed, via email link, to arable and mixed farm businesses throughout the UK. Email links were distributed via SAC Consulting to 146 farm businesses from their subscribers lists, as well as by Crop Management Information (CMI) Ltd to their client base, which led to a significant number of responses from England, which broadened the reach of the survey considerably. In total 94 responses were counted, with 68 respondents (72%) based in Scotland, 25 respondents (27%) based in England, and one respondent (1%) based in Wales.

Once again survey responses were grouped and coded in Microsoft Excel, which subsequently meant that a combination of frequency analysis and descriptive statistics could be used to show the distribution of responses to each question graphically, as well as describe the key trends identified from the business sample, in terms of quantitative data such as; business type, structure, operations, soil types, and cropping practises. Followed by qualitative information including; the main factors affecting cropping and break-crop practises, business concerns, perceptions and knowledge on industrial hemp, and perceptions of future business change and growth. A grounded theory approach was adopted throughout, in order to extract uncomplicated, insightful business trends, without bias or preconception. Results could then be applied in comparison with industrial hemp market data and information obtained in the literature review to deduce valuable conclusions.

### 3.2.2 UK Farm Business Survey Results

<u>Business Sizes and Management Durations</u>

Figure 24 shows the distribution of responses related to business size. There were no businesses within the ‘very large’ category, therefore it was omitted. All farm businesses surveyed were less than 5000 hectares in size. The significant majority (69%) of farms were classed as ‘small’ (between 26 and 500 hectares), whilst 29% of farms were classed as ‘medium’ (between 501 and 2500 hectares). Only two businesses were outside this range, with one respondent classed as ‘micro’ and one ‘large’.

Figure 25 shows the response distribution related to management period. There were no businesses that reported a change in management within the last year, therefore this category was omitted from the data. For the significant majority (81%) it was at least 10 years since a change in management, and for 16% it was between 4 and 10 years.

These data sets indicate that a broader range of categories in both questions may have provided greater insight into the size and management structure of the respondent businesses. However, to derive greater insight from the data set obtained, Figure 26 shows the management period distribution of the ‘small’ and ‘large’ businesses independently. It should be noted that the ‘micro’ sized business reported current management since between 1 and 3 years, and the ‘large’ business reported over 10 years since a change in management.

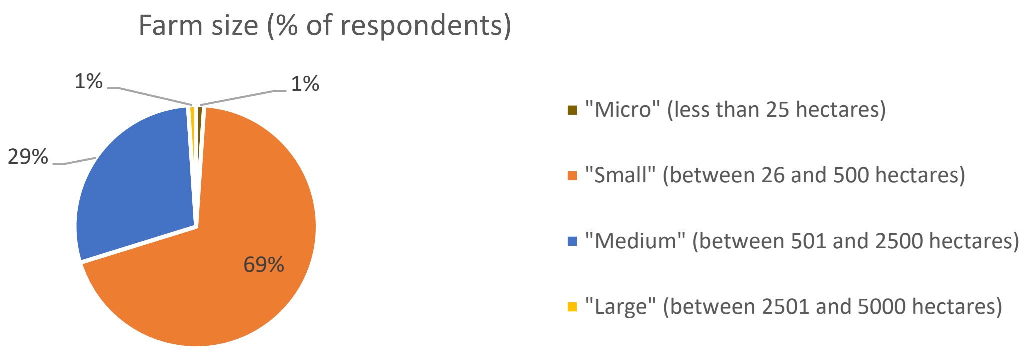


Figure 24: Survey 2 - Q1 – Farm business size

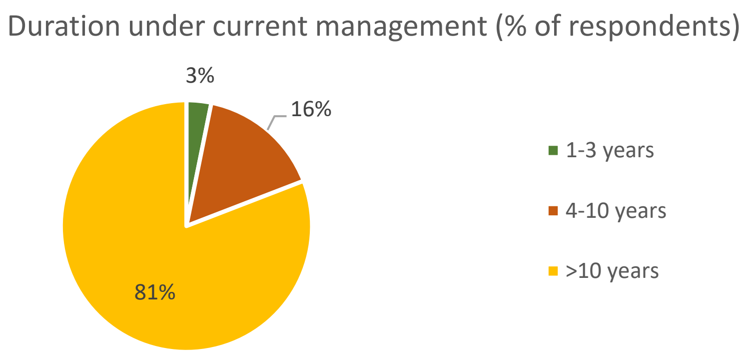


Figure 25: Survey 2 Question 2 – Management duration

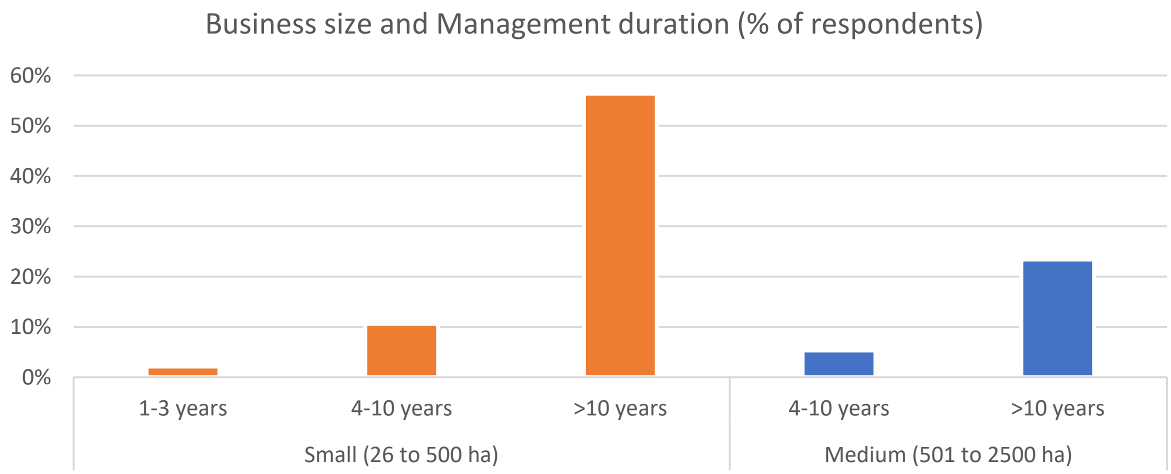


Figure 26: Survey 2 Farm Size and Management Duration

It was found that 56% of the businesses surveyed were between 26 and 500 hectares (small) in size with at least 10 years since a management change. 11% of businesses were small with between 4 and 10 years since a management change. Just 3% reported it was between 1 and 3 years since a management change, all of which were small. 23% of businesses were between 501 and 2500 hectares in size (medium) with at least 10 years since a management change, whilst 5% where of medium size and between 4 and 10 years since a change in management. Notably, the ratio between management periods are similar for both size categories, at around 80:20 when comparing the longer management periods to the shorter periods. This indicates that businesses in the sample were just as likely to have been under the same management for more than 10 years, regardless of business size.

## Farm Business Types (main functions and structural organisation)

Respondents were asked if the farm was conventional, organic or both/neither (with comments requested). The results were as follows;

93% (87 respondents) - Conventional

2% (2 respondents) - Organic

5% (5 respondents) - Neither/Both

The 5 respondents who reported neither/both reported a mixture of conventional and organic cultivation on their farms. Two of the businesses reported a smaller proportion was organic, whilst one reported a smaller proportion was conventional. The remaining two respondents simply commented 'both'.

The two respondents who reported the farm was organic were 'small' and 'micro' in size, both in Scotland. The 'micro' sized business was a biomass producer and bark tannery, growing Oak, Willow, Hazel and Flax. The 'small' organic business was an arable farm, growing a simple rotation of grass, spring barley and vegetables, with intercrop mixtures and grass as break-crops.

Subsequently, respondents were asked to select their main business functions from a list of 14 options, including 'other' which was used to describe any diversification activities. Figure 27 shows the distribution of businesses in terms of their farm business structure (core farm activities). The data shows that 92% of respondent businesses were within the main target audience of the survey, consisting of arable (43%), mainly arable with some livestock (30%) or mixed (19%) farming businesses. The remainder were either mainly livestock (4%), livestock only (3%) or not applicable (1%).

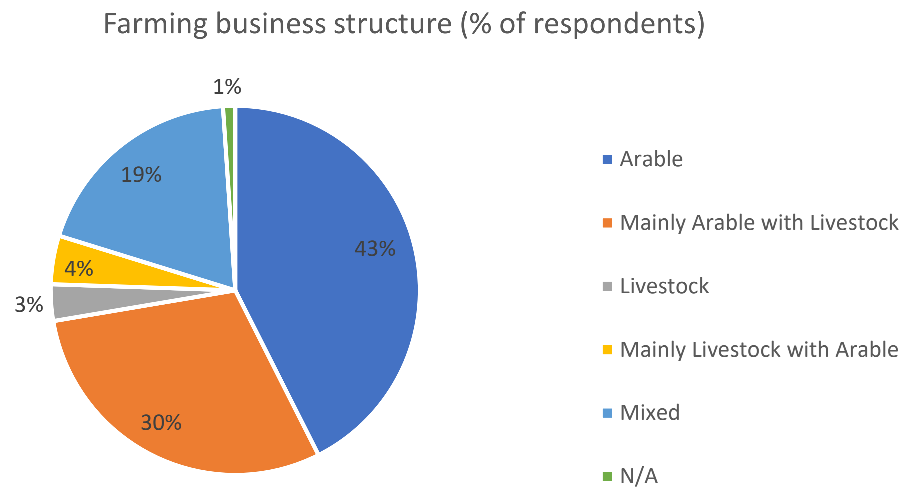


Figure 27: Survey 2 - Q3 Farm business structure

Additionally, figure 28 shows the distribution of farming related business functions reported. It shows that, as well as the core farming operations, 46% of the businesses were undertaking additional farming activities. This included 18 businesses (19%) who reported contract farming services. Furthermore, 12 businesses (13%) reported environmental/ permaculture/ conservational farming practises. Other than that, 6% of businesses listed on-farm seed production, 4% had equine facilities and 3% reported on-farm processing activities.

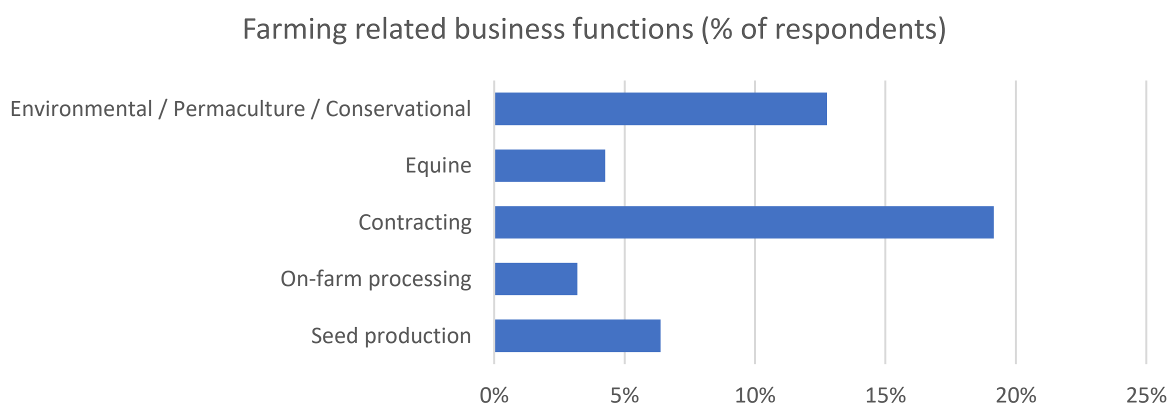


Figure 28: Survey 2 - Q3 Farming related business functions

In terms of farm diversification activities, 21% of respondents reported some form of diversification. The most significant were; renewable energy systems and activities (7%) and property related activities (5%), consisting of holiday accommodation (2%), property rentals (1%), bed & breakfast (1%) and property development (1%). Other mentions included quarries (2%), plant machinery hire (1%), haulage (1%), distilling (1%), farm shop (1%), material production (1%) and the bark tannery (1%).

Soil Types

Survey respondents were asked to list their main soil types in question 7. This was an important insight in order to assess the proportion of farms with soils potentially suited to industrial hemp cultivation. As identified during the literature review, industrial hemp tolerates a range of soil types and conditions but is particularly prone to water logging and poor soil structure, such as heavy and compacted soils. The cultivar therefore requires well-structured and free-draining soils. Additionally, whilst hemp can tolerate dry conditions, for high yields, soils with relatively good moisture levels are necessary. Therefore, soil types such as well-structured loams, silty, sandy, or well-drained silty clay loams, or sandy loams with good moisture and nutrition levels are best suited.

Soil type options given in question 7 of the survey were based on the soil texture triangle (see figure 29) which calculates soil texture based on the proportions of the 3 soil minerals clay, sand and silt. Soil type is calculated from the diagram by taking the line horizontally based on Clay (%), or diagonally from Silt or Sand (%) to find the intersection point with the other components.

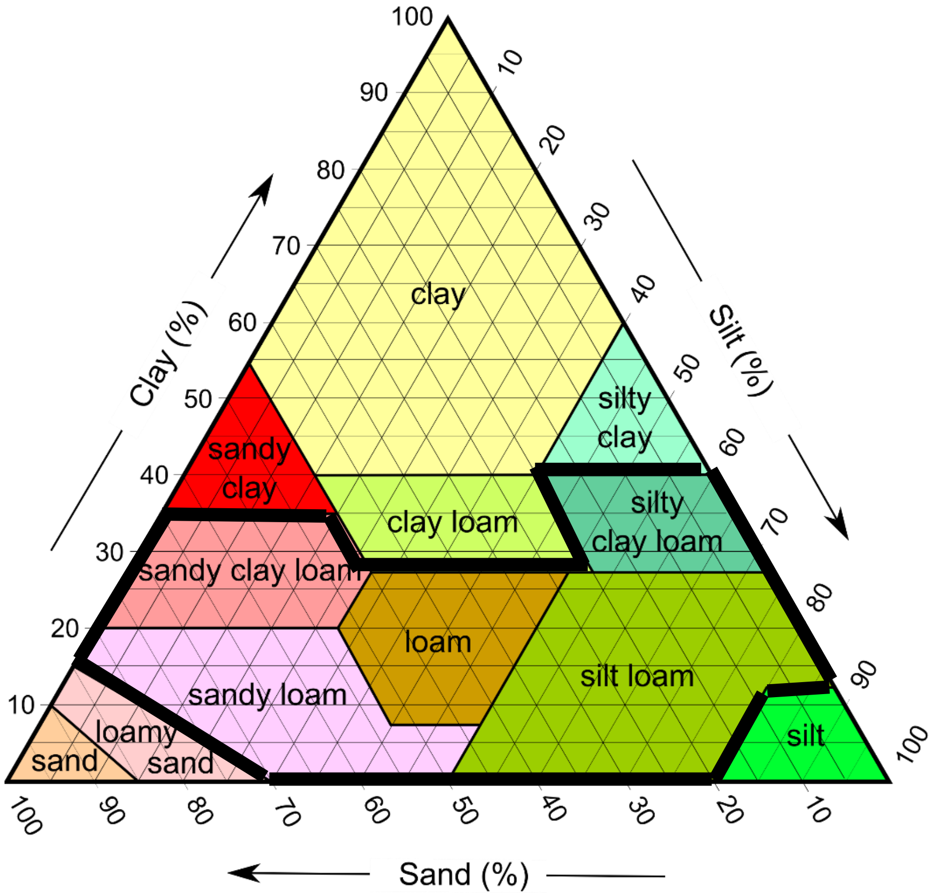


Figure 29: Soil types (textures). Source: *http://msnickellecearthsci.blogspot.com/2013/09/soil-soil-everywhere-and-please-dont.html*

Subsequently, figure 30 provides the distribution of soil types from the survey responses. The data shows that the most common soil type, listed by 34 respondents, was sandy loam (36%), followed by clay loam (26%), sandy clay loam (20%), loam (19%) and clay (17%). The average (mean) number of soil types listed per respondent was 1.7, although 56% of respondents listed only one soil type, so the modal average was one. The distribution in the number of soil types listed per respondent is given in figure 31 which shows that only 4% of respondents listed more than 3 different soil types. Therefore, it is likely that frequency data of soil types reported gives a good indication of soil type distribution. Finally, the percentage of respondents that reported at least one soil type deemed suitable for industrial hemp cultivation (within the bold lines in figure 29) was calculated to be 77% of the sample.

## 77% of Farms have soil types suited to industrial hemp cultivation

(based on 72 of 94 survey respondents reporting at least one suitable soil type).

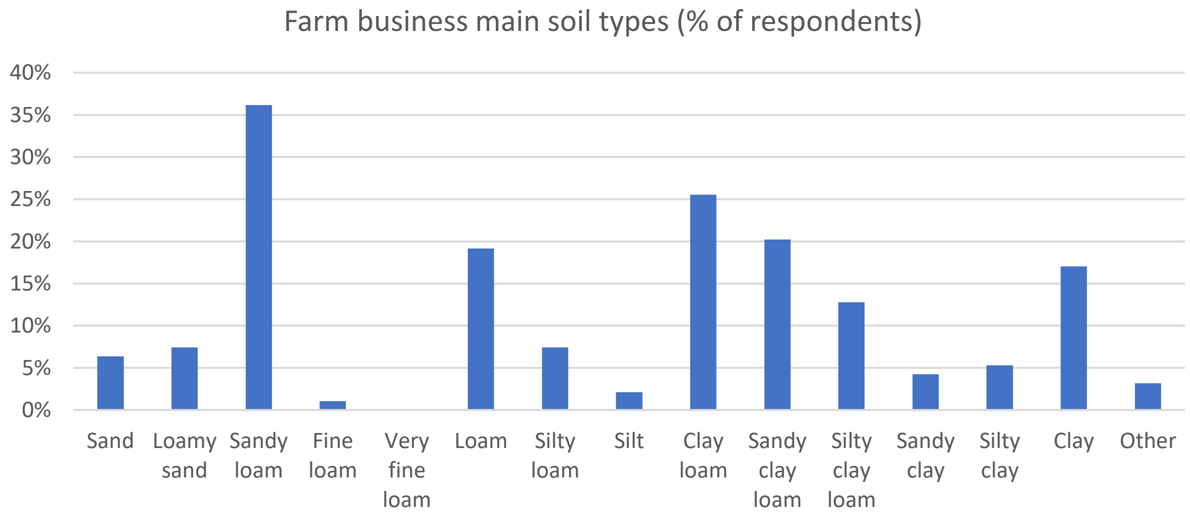


Figure 30: Survey 2 - Q7 Farm soil types

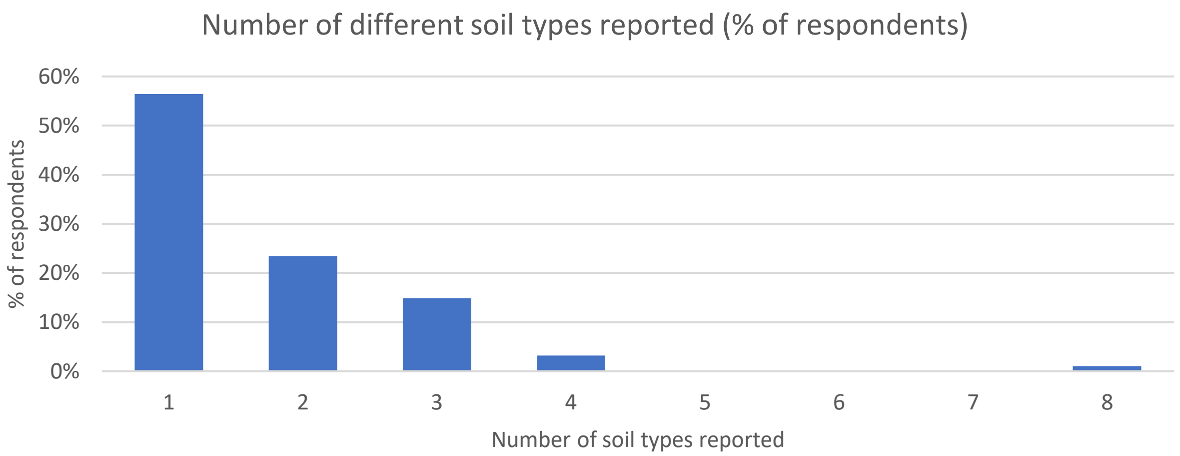


Figure 31: Survey 2 - Q7 Number of different soil types reported

## Crop Rotation Practises

In question 8 of the survey, respondents were asked to list their most common crop rotation practise using up to nine free-text boxes. This data was 'cleaned' to group similar answers for data analysis. For example, answers including; 'Wheat', 'W Wheat' and 'Winter Wheat', were treated as a single cultivar 'Wheat' for the analysis, as Spring Wheat was not specifically reported. Similarly, 'Winter Barley', 'W Barley' and 'S Barley' were treated as a single cultivar 'Barley' for the main analysis, but 'S Barley' was specifically reported and was therefore represented as a derivative in the analysis.

There were 524 individual responses to this question and approximately 40 different cultivars listed by the survey sample of 94 farm businesses. The calculated average (mean) of years in the crop rotation, per respondent, was 5.5 and the mode average was 6 years. Figure 32 shows the distribution of crop rotation lengths (in years) based on the data obtained. The data shows that despite a range of rotation lengths reported between 1 and 9 years, 80% of respondents had a rotation length between 3 and 7 years. Furthermore, 55% of respondents had a rotation length between 5 and 7 years.

Despite the large number of cultivars listed, most were niche choices accounting for less than 1% of responses. In fact, 88% of responses corresponded to just 15 different cultivars, of which 8 were derivatives based on sowing timing (winter/spring). Therefore, there were a group of 7 main cultivars; wheat, barley, oilseed rape, potatoes, grass, oats and beans making up most cropping choices for the sample group. A range of vegetables other than potatoes and beans, were also reported, consisting of 10 different cultivars. As such, the cultivar groups labelled 'other vegetables' and 'niche crops' were included in the analysis. Table 1 shows the resulting statistical analysis for the cultivars reported, based on their frequencies in the rotations.

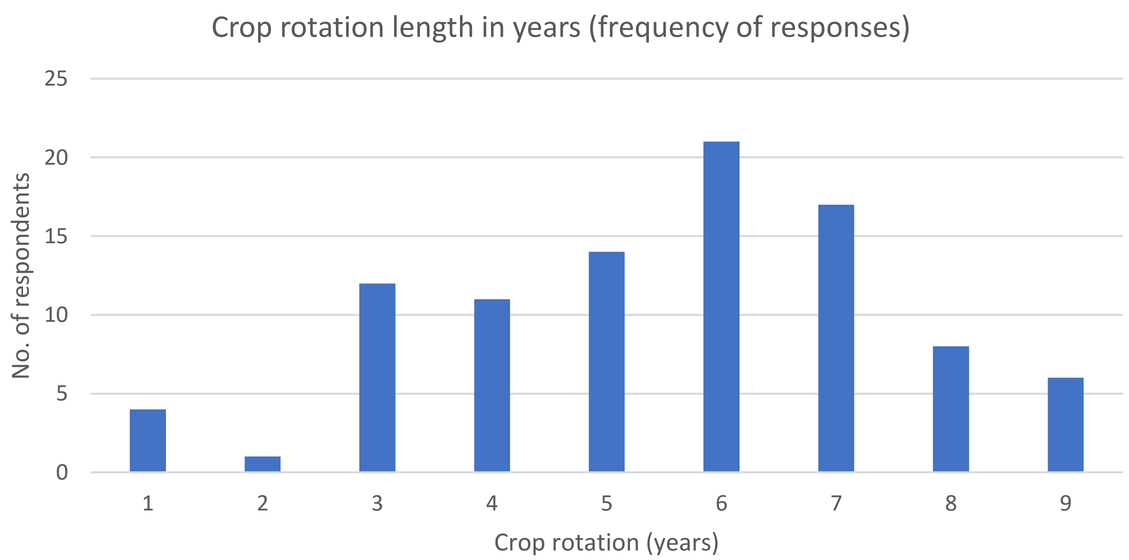


Figure 32: Survey 2 - Q8 Crop rotation length

| Cultivar | Years in rotation 0 | 1 | 2 | 3 | 4 | 5 | 6 | Total sample (no.of growers) | % of survey population | Statistical Analysis (Population) Mean (yrs) | Mode (yrs) | St Dev | CV | Statistical Analysis (Sample) Mean (yrs) | Mode (yrs) | St Dev | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Barley** | 18 | 32 | 24 | 11 | 8 | 1 | 0 | **76** | **81%** | 1.60 | 1 | 1.22 | 76% | **1.97** | **1** | **1.05** | **53%** |
| ***(Spring Barley)*** | *44* | *27* | *11* | *6* | *5* | *1* | *0* | ***50*** | **53%** | | | | | | | | |
| **Wheat** | 26 | 24 | 25 | 11 | 7 | 0 | 1 | **68** | **72%** | 1.50 | 0 | 1.30 | 87% | **2.07** | **2** | **1.08** | **52%** |
| **Oilseed rape** | 48 | 44 | 2 | 0 | 0 | 0 | 0 | **46** | **49%** | 0.51 | 0 | 0.54 | 106% | **1.04** | **1** | **0.20** | **19%** |
| **Potatoes** | 66 | 27 | 1 | 0 | 0 | 0 | 0 | **28** | **30%** | 0.31 | 0 | 0.48 | 155% | **1.04** | **1** | **0.19** | **18%** |
| **Oats** | 67 | 24 | 3 | 0 | 0 | 0 | 0 | **27** | **29%** | 0.32 | 0 | 0.53 | 166% | **1.11** | **1** | **0.31** | **28%** |
| ***(Spring Oats)*** | *83* | *10* | *1* | *0* | *0* | *0* | *0* | **11** | **12%** | | | | | | | | |
| **Grass** | 71 | 13 | 2 | 3 | 4 | 1 | 0 | **23** | **24%** | 0.50 | 0 | 1.10 | 220% | **2.04** | **1** | **1.33** | **65%** |
| **Beans** | 78 | 15 | 1 | 0 | 0 | 0 | 0 | **16** | **17%** | 0.18 | 0 | 0.41 | 228% | **1.06** | **1** | **0.24** | **23%** |
| ***(Spring Beans)*** | *86* | *7* | *1* | *0* | *0* | *0* | *0* | **8** | **9%** | | | | | | | | |
| **Other Vegetables** | 68 | 22 | 4 | 0 | 0 | 0 | 0 | **26** | **28%** | 0.32 | 0 | 0.55 | 172% | **1.15** | **1** | **0.36** | **31%** |
| **Niche' crops** | 77 | 11 | 5 | 0 | 1 | 0 | 0 | **17** | **18%** | 0.27 | 0 | 0.66 | 244% | **1.47** | **1** | **0.77** | **52%** |

Table 1: Survey 2 – Q8 Statistical analysis of the main cultivars in the crop rotation

Table 1 was produced by extracting the number of times each cultivar group was reported in the rotation, for each respondent, and counting the results. Subsequently, the frequency of occurrence of each of the main cultivars in the rotation could be plotted. Figure 33 shows the distribution of main cultivar choices, based on survey responses, as well as their effective dominance in the rotation. Descriptive statistics including, mean, mode, standard deviation and coefficient of variation were subsequently calculated for the survey population (including non-responses), and for the survey sample of growers, for each cultivar's occurrence within the crop rotation.

Notably, Barley (in general) was the most common cultivar amongst survey respondents, listed by 76 respondents (81% of survey population), of which 61% of responses were specifically for Spring Barley. Furthermore, over half (58%) of the barley growers listed the cultivar more than once in the rotation; 32% listed it twice, 14% listed it 3 times, 11% listed it 4 times in the rotation and one grower (1%) listed it 5 times. The mean average amongst growers was 1.97 years, although the mode average was 1 year. The corresponding Coefficient of Variation (CV) was 53%.

Wheat was similarly common, although given that Spring Wheat was not specifically mentioned by any respondent, it seems reasonable that most, if not all, responses were referring to Winter Wheat. Therefore, (winter) Wheat, with 68 respondents (72%) listing the cultivar, was more common than Winter Barley and Spring Barley cultivars, with Spring Barley the second most important cultivar (53%). Wheat was also more likely to be repeated in the rotation as 64% of growers listed it more than once; 37% listed it twice, 16% listed it 3 times, 10% listed it 4 times and one respondent (1%) listed it 6 times in the rotation. The mean average for Wheat was 2.07 years, the mode average was 2 years, by a slim margin, and the CV was similar to Barley at 52%.

Oilseed rape was the most common non-cereal crop grown, reported by 49% of respondents. Significantly, only 2 respondents, of 46 Oilseed rape growers grow the crop more than once in the rotation. Therefore, the cultivar is clearly grown as a single-year break-crop by almost half of the farms in the survey. Potatoes and Oats were reported by around 30% of the survey population, and, similar to Oilseed rape, were most likely to only be grown once in the rotation. Grass was another popular break-crop choice, but unsurprisingly was more likely to be grown for multiple years in the rotation. Lastly, the likelihood of a respondent selecting at least one different (niche) cultivar within their main crop rotation was 18% (reported by 17 respondents).

## 49% of Farms grow Oilseed rape within their main crop rotation

(based on 46 of 94 survey respondents reporting oilseed rape at least once in their rotation)

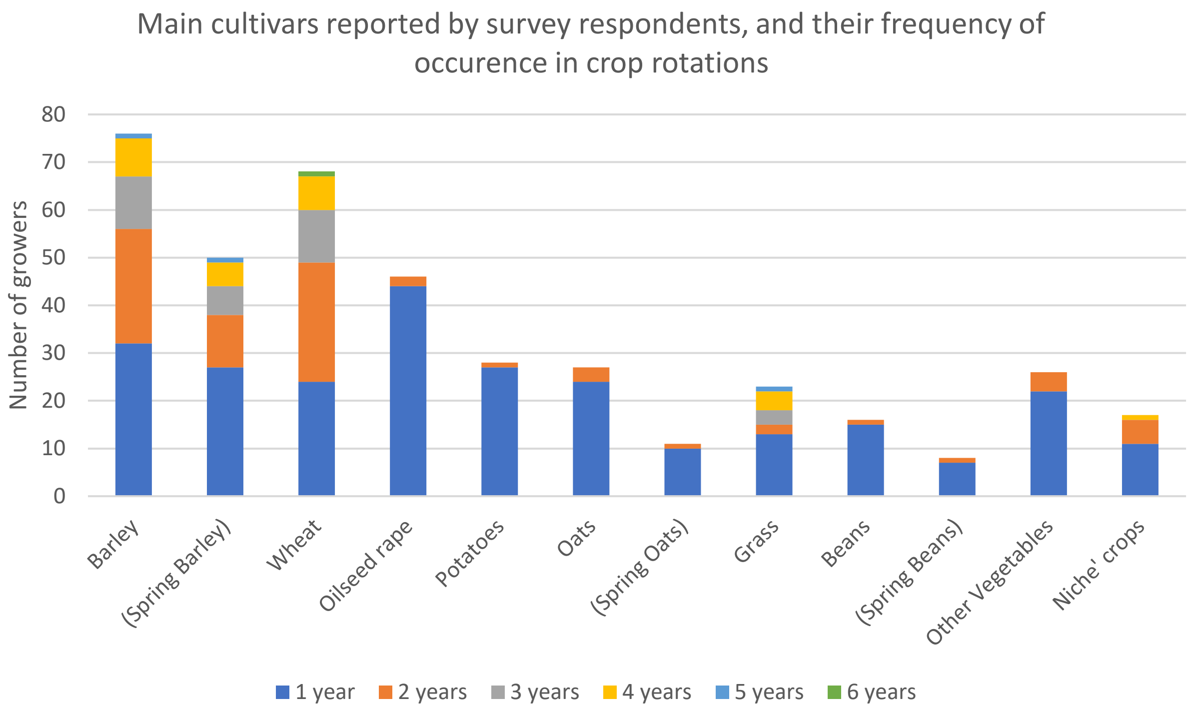


Figure 33: Survey 2 - Q8 Main cultivars in reported crop rotations

## Typical crop rotation example based on survey data

Overall, whilst the data depicts a diverse range of cropping choices and rotation lengths in the UK, there is a relatively clear trend in the data showing farmers operating rotations of between 3 and 7 years (most likely 5 to 7 years), consisting of Winter Wheat (likely 2+ years), Barley (2+ years), likely to be Spring Barley, or both Winter and Spring Barley, Oilseed rape (1 year), and a choice of either potatoes (1 year), Oats (1 year), grass (between 1 and 4 years), beans (1 year), an alternative vegetable crop (1 year), or a 'niche' crop (1 or 2 years). Using this information, a typical crop rotation example is outlined below.

| | |
|---|---|
| Year 1: | Winter Wheat |
| Year 2: | Winter or Spring Barley |
| Year 3: | Oilseed rape |
| Year 4: | Winter Wheat |
| Year 5: | Spring Barley |
| Year 6 (+): | Potatoes/Oats/Grass/Beans/Other Veg/Niche crop |

Break-crop options and choice factors

Question 9 and question 10 of the survey asked respondents to list their current choice of break-crops and subsequently to select the most important factors or considerations when selecting a break-crop. This meant that cultivars could be listed that either were or were not included in their main crop rotation. The data was used to establish the most important break-crops amongst survey respondents, the relative selection of niche crop choices and the most important factors in selection.

Answers to question 9 were provided using up to 5 free-text boxes and of the 94 verified survey respondents, 90 responded to this question. From the 90 respondents, there were a total of 224 individual responses and 29 different break-crop options reported. Eighteen of the cultivar options were reported by only one or two respondents, and a further 5 cultivars were reported by less than 8% of respondents. It follows that there was a group of 6 main break-crop options reported by the survey group; Oilseed rape (53%), Grass (37%), Potatoes (33%), Oats (27%), Peas (19%), Beans (19%), which, unsurprisingly corresponds closely with the main cultivars listed in the respondents' main crop rotations. Although grass and peas were reported more frequently as break-crop options than they were in the main crop rotation. Furthermore, vegetables other than potatoes, peas and beans, were also frequently reported as break-crop options, albeit with only 6 varieties specifically reported. Overall, either 'vegetables', or a certain variety of vegetable, was reported by 19% of respondents. Figure 34 shows the distribution in break-crop choices. Once more, the categories 'other vegetables' and 'niche crops' were included for simplicity.

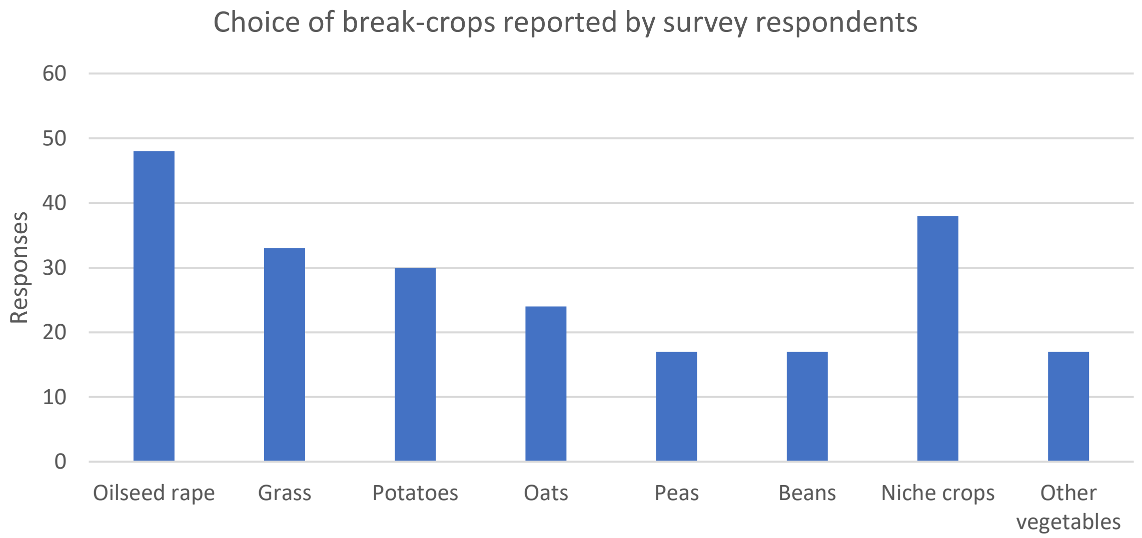


Figure 34: Survey 2 – Q9 Distribution of break-crop choices

Of the 'niche crops' category, just over half (20 responses) were for green manure (6), Sugar beet (5), Maize (5) and Fallow (4). However, the other 18 responses (20% of respondents) corresponded to 13 different cultivar options, with each receiving 2 or less responses. Therefore, more respondents reported a niche crop as a break-crop choice than there were for either peas, beans or 'other vegetables'. This demonstrates that niche crop options are relatively common as break-crop choices with 1 in 5 respondents listing a niche crop (excluding green manure, Sugar beet, Maize and Fallow).

## 1 in 5 Farms choose 'niche crops' as break-crops

(18 of 90 survey respondents reported at least one niche crop as a break-crop option).

Table 2 and Figure 35 show the number of break-crop options reported (per respondent) and the corresponding frequency of responses. Subsequently, descriptive statistics were calculated. The mean average number of break-crop choices per respondent was 2.61, whilst the mode average was 2 break-crop options. The Standard Deviation was 1.11 with a Coefficient of Variation of 43%.

| Number of break-crop options | Frequency of responses | % of Respondents | Mode | Mean | St Dev | CV |
|---|---|---|---|---|---|---|
| 1 | 12 | 13% | 2 | 2.61 | 1.11 | 43% |
| 2 | 35 | 39% | | | | |
| 3 | 27 | 30% | | | | |
| 4 | 9 | 10% | | | | |
| 5 | 6 | 7% | | | | |
| 6 | 1 | 1% | | | | |

Table 2: Survey 2 – Q9 Number of break-crop options per farm business

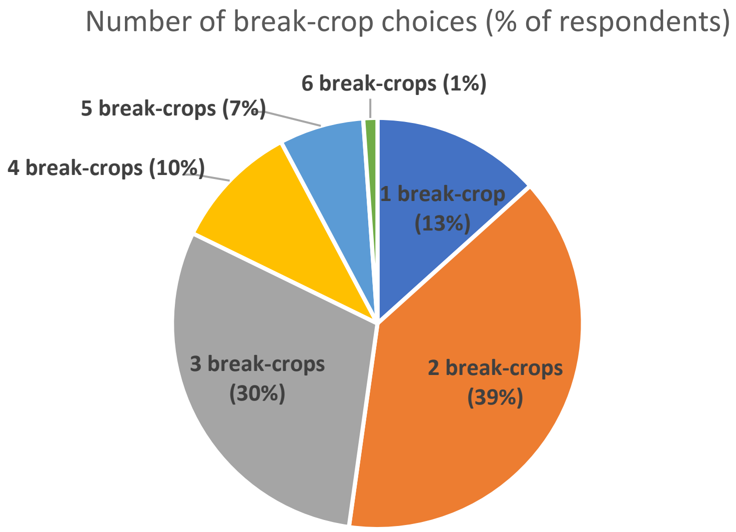


Figure 35: Survey 2 – Q9 Number of break-crop options per farm business

The data shows that 82% of farms reported 3 or less break-crop options with more than two thirds of farms currently have a choice of between 2 and 3 different break-crops. Whilst 13% of farms listed only one break-crop option, farms were more likely to have more than 3 options than only one.

## 82% of Farms have less than 4 break-crop options

(based on 64 of 90 survey respondents reporting 3 or less break-crops)

For question 10 and the consideration factors of break-crop selection, a total of 12 options were listed, including 'other' and respondents were asked to select a maximum of 5 answer choices. There were 94 responses to this question. Figure 36 shows the distribution of factors and Table 3 shows the number of break-crop consideration factors reported, the frequency of responses and subsequently the descriptive statistics calculations.

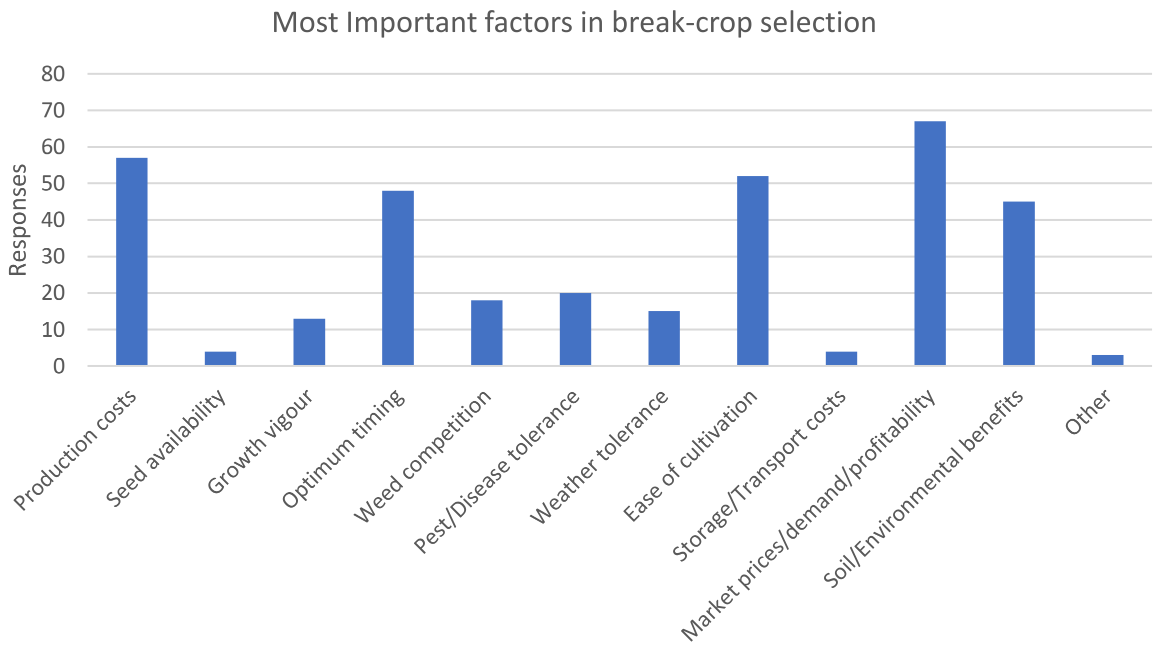


Figure 37: Survey 2 – Q10 Break-crop selection factors

| No. of break-crop choice factors | Frequency of responses | % of Respondents | Mode | Mean | St Dev | CV |
|---|---|---|---|---|---|---|
| 1 factor | 11 | 12% | 5 | 3.69 | 1.31 | 35% |
| 2 factors | 7 | 8% | | | | |
| 3 factors | 17 | 19% | | | | |
| 4 factors | 26 | 29% | | | | |
| 5 factors | 33 | 37% | | | | |

Table 3: Survey 2 – Q10 Number of break-crop selection factors

Table 3 shows that two thirds of respondents listed 4 or 5 factors which they would describe as their most important considerations when selecting a break-crop. The Mode average was 5 factors and the mean average 3.69. This indicates that the question may have been more effective if respondents were not limited to a maximum of 5 answer choices. A ranking system may also have been effective for this question. However, Figure 37 shows clearly that 5 of the factors are considered most important amongst survey respondents, which were; market prices, demand and/or profitability (71% of respondents), production costs (61%), ease of cultivation (55%), optimum timing (51%) and lastly, soil and/or environmental benefits (48%).

<u>Most important factors in break-crop selection</u>

| | | |
|---|---|---|
| Market prices / Demand / Profitability | 71% | (67 of 94 survey respondents) |
| Production Costs | 61% | (57 of 94 survey respondents) |
| Ease of cultivation | 55% | (52 of 94 survey respondents) |
| Optimum timing (sowing/harvest) | 51% | (48 of 94 survey respondents) |
| Soil / Environmental benefits | 48% | (45 of 94 survey respondents) |

It follows that, for industrial hemp to become a viable break-crop option for farm businesses, the cultivar must be competitive in terms of the factors listed above. Additionally, other important factors listed were; pest/disease tolerance (21%), weed competition (19%), weather tolerance (16%) and growth vigour (14%). 'Seed availability' and 'Storage/transport costs' were each only reported by 4% of respondents amongst their 5 most important factors, indicating that they are relatively unimportant for the existing choice of break-crops. Additionally, the answers given by 3 respondents who selected 'other' were too general to provide any valuable insight.

Overall, whilst it is known that industrial hemp provides soil and environmental benefits, as well as relatively low production costs (due to low input requirements) and sowing and harvest timing that is desirable dependent on the rotation, ease of cultivation must be ensured, specifically harvesting methods, and there must be a strong market demand and good prices. Furthermore, whilst industrial hemp is known for high tolerance to pests and disease, strong growth vigour and subsequent competitiveness with weeds, weather tolerance may present a risk requiring careful consideration. Finally, whilst seed availability and storage and transport costs were among the least important in the survey data, they are likely to be important considerations for industrial hemp cultivation.

## Opinions on Industrial Hemp as a potential break-crop option

The first question in the series of qualitative data observations asked respondents if they had considered growing industrial hemp as a break-crop option. There were 3 answer choices; 'yes', 'no' and 'currently considering it'. All 94 survey respondents answered the question. Figure 38 shows the result by % of responses. 70 (74%) respondents had not considered the cultivar previously, 16 (17%) had considered it and 8 (9%) were currently considering the cultivar at the time of taking part in the survey.

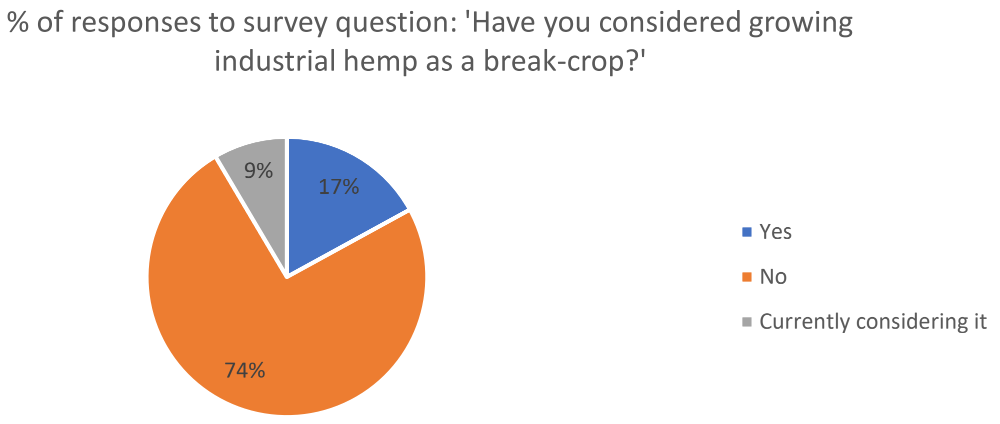


Figure 38: Survey 2 - Q11 Proportion of farm businesses that have considered industrial hemp

Secondly, respondents were asked to rate their knowledge on industrial hemp using a scale, from zero to 10, with zero corresponding to 'none', 5 corresponding to 'fair' and 10 corresponding to 'expert'. There were 91 respondents to the question. Results are shown in Figure 39.

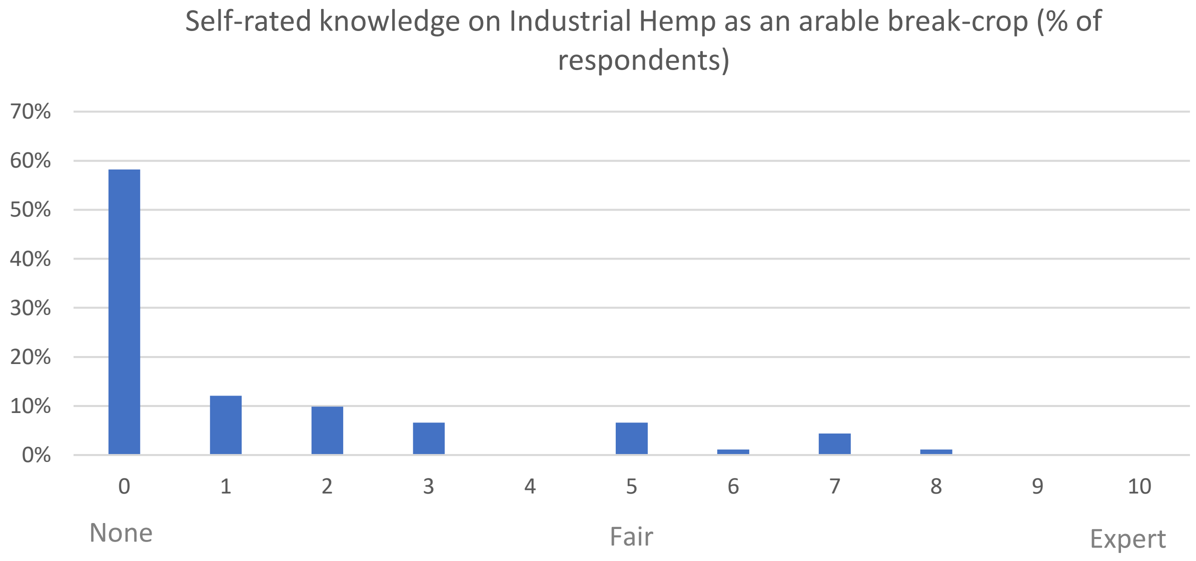


Figure 39: Survey 2 - Q12 Survey respondents' knowledge on industrial hemp

Descriptive statistics were calculated for the data on self-rated knowledge on industrial hemp; the mean average rating was 1.3 out of 10. However, the mode was 0, with 53 (58%) respondents reporting no knowledge on the cultivar as a potential break-crop. However, the data was relatively spread, with a standard deviation of 2.1. Interestingly, more than 1 in 10 (13%) respondents rated their knowledge between 5 and 8, out of 10, suggesting a 'fair' to 'good' level of knowledge amongst those respondents. Although the profound statistic was that 80% of respondents rated their knowledge level below 3 out of 10.

Thirdly, survey respondents were asked to rate how likely they were to grow industrial hemp in the next 5 years. Again, answers were collected using a scale from zero to 10, with zero corresponding to 'not at all likely', 5 corresponding to 'somewhat likely' and 10 corresponding to 'very likely'. There were 91 respondents to the question. Results are shown in Figure 40.

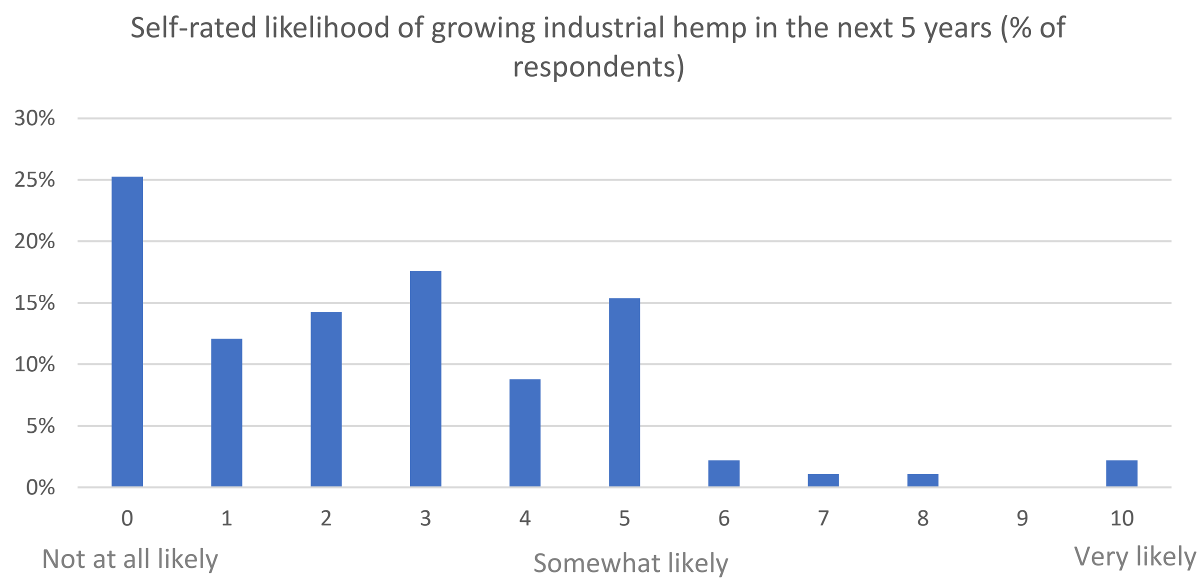


Figure 40: Survey 2 – Q13 Likelihood of farm business growing industrial hemp in the next 5 years

One quarter of respondents rate their farm business as 'not at all likely' to grow industrial hemp within the next 5 years. However, 42% of respondents rated at between 3 and 5, out of 10, hence moving towards 'somewhat likely'. 21% of respondents rated the likelihood of growing the cultivar between 5 and 10, although only 6% rated above 5. Two respondents stated they were 'very likely' to grow the cultivar. Descriptive statistics calculations give the (mean) average as 2.6 out of 10, with a standard deviation of 2.3. The data indicates that, whilst most respondents were relatively doubtful that they would grow the cultivar within 5 years, there was a varying degree optimism for the cultivar, demonstrated by 75% of respondents rating above 0. Furthermore, given that 58% of respondents suggested they had no knowledge at all on industrial hemp as break-crop option and (mean) average for knowledge on the crop was just 1.3, it suggests there is some degree of willingness to consider and learn about industrial hemp as an option.

## Perceived barriers to Industrial Hemp as a potential UK break-crop option

The final qualitative observation looking at the potential for industrial hemp amongst UK farmers, was obtained by asking respondents what they consider to be the main barriers to their business growing the cultivar as a break-crop. There were 20 answer options given, including 'other' and all 94 respondents answered the question. Respondents were asked to give a maximum of 5 answer choices. There was a total of 327 responses, giving an average (mean) of 3.5 responses per farm business. Figure 41 shows the distribution of responses and Table 4 was used to calculate descriptive statistics.

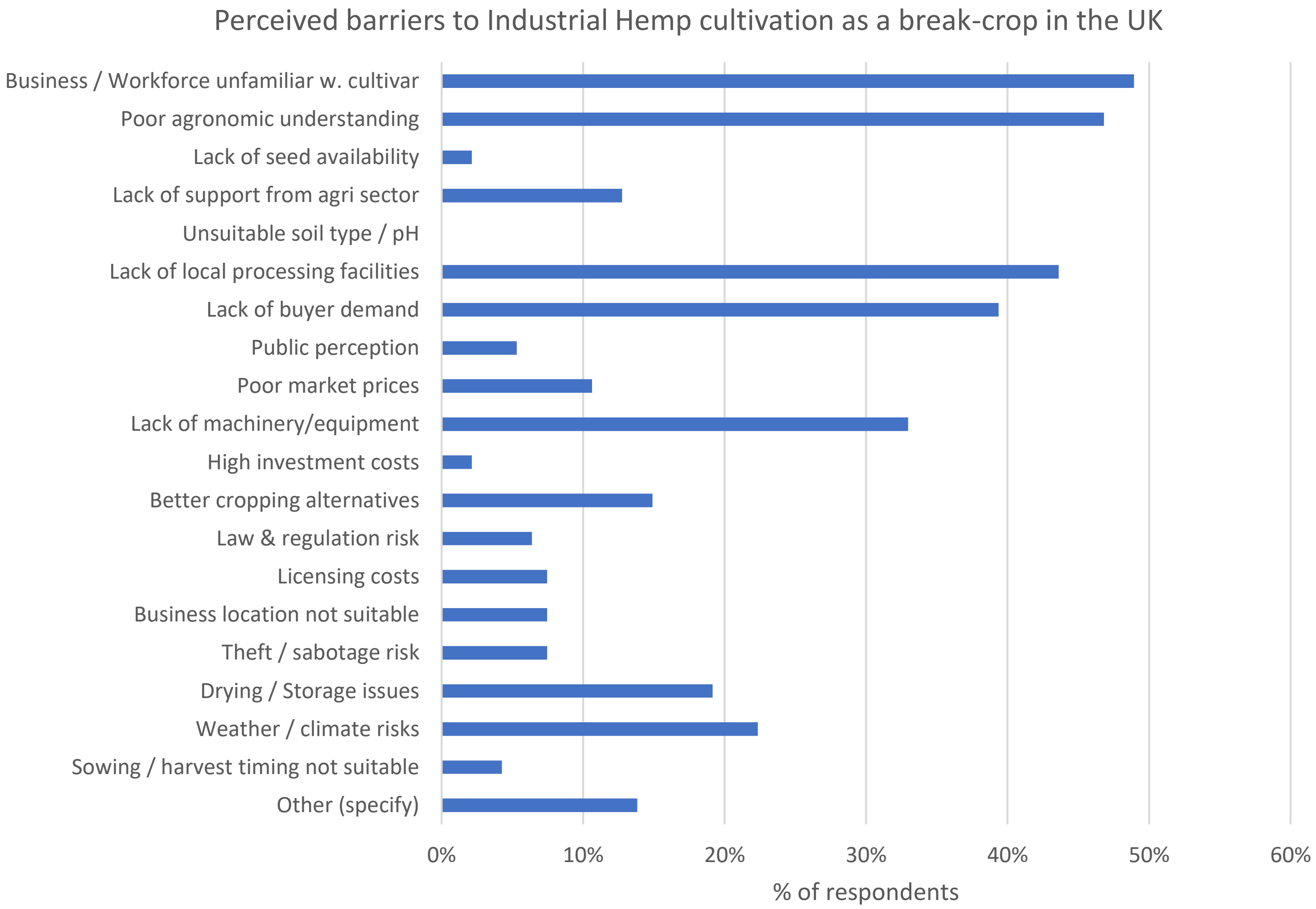


Figure 41: Survey 2 - Q14 Barriers to UK industrial hemp cultivation

| No. of barriers listed | Frequency of responses | % of Respondents | Mode | Mean | St Dev | CV |
|---|---|---|---|---|---|---|
| 1 | 13 | 14% | 5 | 3.48 | 1.51 | 43% |
| 2 | 19 | 20% | | | | |
| 3 | 12 | 13% | | | | |
| 4 | 12 | 13% | | | | |
| 5 | 38 | 40% | | | | |

Table 4: Survey 2 - Q14 Barriers to UK industrial hemp cultivation descriptive statistics

A relatively large proportion (40%) of respondents listed 5 barriers, suggesting that the maximum number of answers requested may have limited the response. However, 60% of respondents gave a relatively evenly spread distribution of answers between 1 and 4 selections and 34% listed 1 or 2 barriers, whereas only 26% listed 3 or 4.

The most important perceived barriers to entry were; that the business and/or workforce were not familiar with the cultivar (49% of respondents) and poor agronomic understanding of the cultivar (47% of respondents). Additionally, 9 (10%) respondents who selected 'other', specified a lack of knowledge on the cultivar as the main barrier. The next most important perceived barriers were; a lack of local processing facilities (44% of respondents) and lack of buyer demand (39% of respondents). The fifth most important barrier, reported by 33% of respondents, was a lack of machinery and/or equipment. These results show that while almost half of respondents' state that a lack of familiarity and understanding of the cultivar are main barriers, a similar percentage are aware there is a lack of processing facilities and one third are aware of potentially lacking machinery and equipment requirements to produce industrial hemp. The perceived lack of buyer demand indicates that many of the farmers were not aware of the rapidly growing industrial hemp markets across Europe and especially in the UK.

Furthermore, around a fifth of respondents reported weather and/or climate risks (22%) and drying and/or storage issues (19%) amongst the main barriers. 15% of respondents supposed that better cropping alternatives were a main barrier for industrial hemp cultivation, 13% selected 'lack of support from the Agri sector' and 11% suggested poor market prices were a main barrier. Significantly, very few respondents (7%) believed licensing costs, business location and risk of crop theft or sabotage were main barriers. Even fewer (6%) selected 'Law and regulation risk', and fewer still (5%) selected 'public perception'. The least responses received were for; unsuitable sowing and/or harvest timing (4%), 'high investment costs' (2%), lack of seed availability (2%) and 'unsuitable soil type / pH' which received no responses. The remainder of those who listed other, specified; 'not interested in changing rotation' (2%), 'niche crops have a poor history' (1%) and one respondent reported they had previously grown the cultivar which 'did not deliver the promised income'.

It is clear from the data that any stigma attached to cannabis, in the form of hemp, is very slight, if present at all amongst the survey group of farmers. The main barriers surround lack of knowledge, understanding and familiarity with the cultivar, as well as a perceived lack of market demand and lack in capability in terms of cultivation, agronomy and processing. Thus, through; information sharing, education, training and crop trials within the sector, as well as investment in processing capabilities, machinery and equipment, it seems that industrial hemp could become a viable break-crop consideration for UK farmers.

## Energy crops or crops for biomass feed-stocks

As industrial hemp has been highlighted as a multi-use cultivar, including as a potentially important renewable energy resource, questions 15 and 16 put the onus back on the respondents' current farm business, to gain insight into the production of energy crops. Firstly, respondents were asked if they currently grow energy crops or crops for biomass systems. Three answer choices were given; 'yes, 'no' and 'currently considering it'. All 94 respondents answered the question. Figure 42 shows the result for question 15.

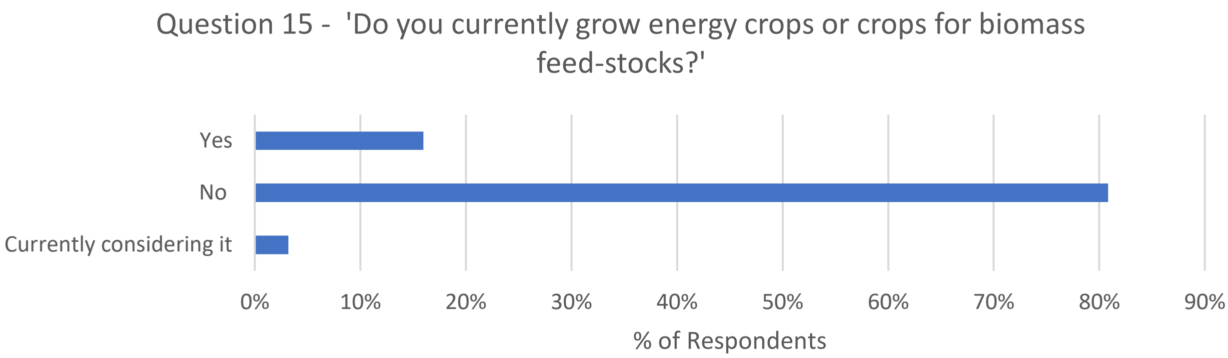


Figure 42: Survey 2 – Q15 Percentage of farm businesses growing energy crops

76 (81%) respondents reported they were not growing energy crops, whilst 15 (16%) were. Three respondents (3%) reported that they were currently considering energy / biomass crops. Subsequently, question 16 requested those who were either already growing, or considering growing energy crops to describe their main considerations for doing so. From the relatively low number of respondents, responses were vague, mixed and variable, making any conclusive analysis difficult. Generally, responses were based around financial considerations, such as profitability and the suggestion that energy crops can improve the viability of land on which cereal crops are unproductive. However, further information would be required to draw any meaningful conclusions on energy crop production in the UK.

## Farm business self-assessments on current break-crop performance

Questions 17 and 18 were designed to gain qualitative insight on how effective farmers consider their current break-crops to be and subsequently the specific concerns they have about their break-crop choices. Combined with the analysis from questions 9 and 10 (break-crop options and selection factors), this data could be used to make informed predictions on how break-crop practises are developing and how industrial hemp might fit into existing crop rotations. For the first part, question 17 requested survey respondents to rate how effective their current break-crops are from zero to 10, with zero corresponding to 'not at all effective', 5 corresponding to 'relatively effective' and 10 corresponding to 'very effective'. There were 92 responses. Figure 43 shows the response distribution.

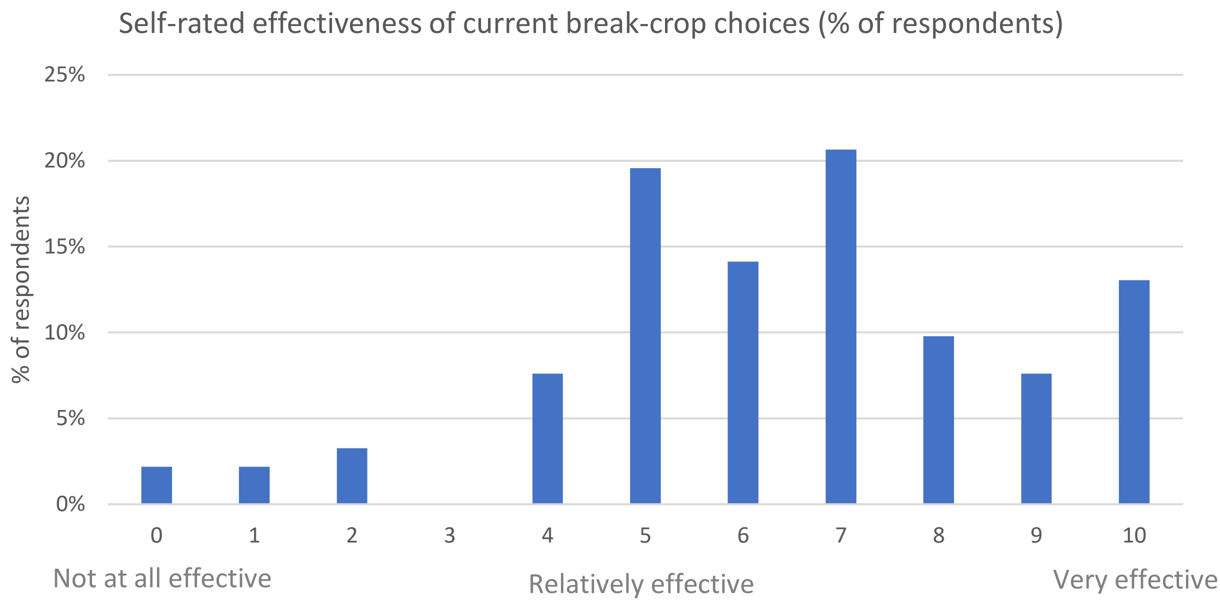


Figure 43: Survey 2 – Q17 Respondents' perception of effectiveness of current break-crops

The average (mean) of the responses was 6.4 out of 10 with a mode of 7 (21% of responses). Significantly, only 15% of respondents rated below 5, more than half (54%) rated from 5 to 7, and around a third (30%) rated at least 8 out of 10. The standard deviation was 2.4, which is high in relation to similar data sets obtained. These responses are likely to be reflective of the wide distribution of crop rotation lengths reported, as well as the significant number of break-crop options listed. However, as around 80% of farms have very similar break-crop practises, the data may point to the fact that certain cultivars have greater beneficial effects for some farm businesses, than for others. Clearly, there are many factors and variables involved, which may affect both the actual performance, and perceived performance, of various break-crops. However, the confidence a farmer has in their current break-crop options is very likely to affect their cropping practises in the future.

To gain further insight, respondents were asked in question 18 to report their main concerns with their current break-crop choices. 12 answer options were given including 'other' and 91 respondents answered the question, giving a total of 223 responses. The average (mean) number of responses per respondent was 2.5. Figure 44 and Table 5 show the distribution of responses and descriptive statistics respectively.

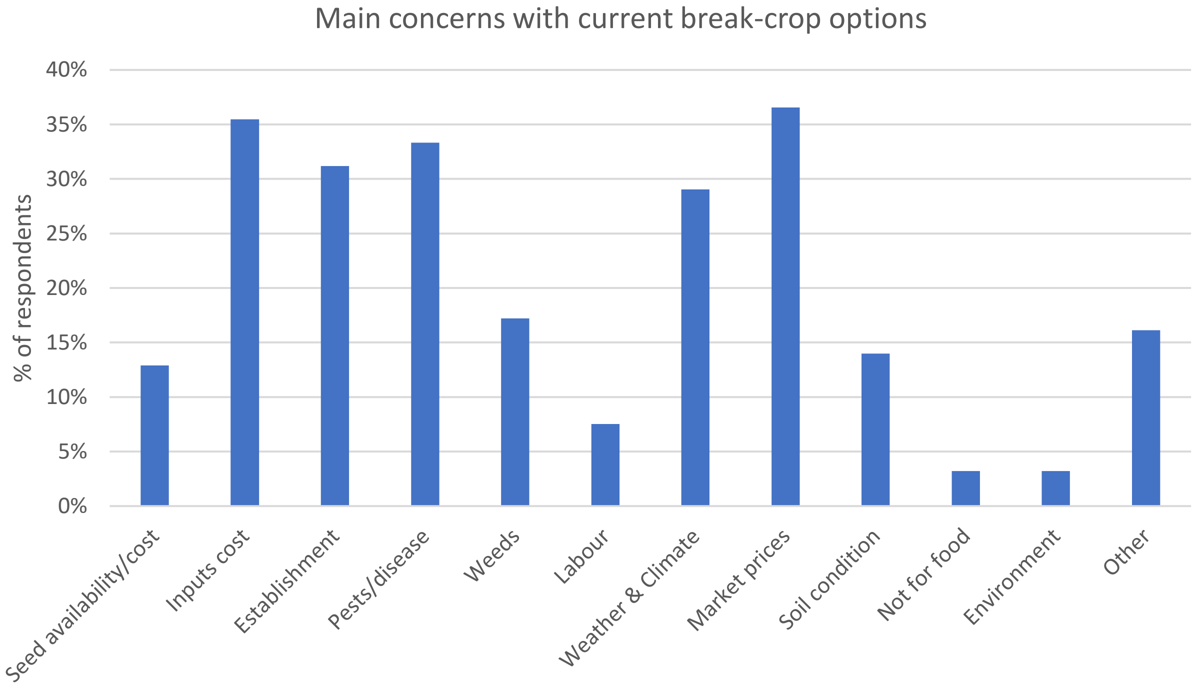


Figure 44: Survey 2 – Q18 Main concerns with current break-crop options

| No. of concerns listed | Frequency of responses | % of Respondents | Mode | Mean | St Dev | CV |
|---|---|---|---|---|---|---|
| 1 | 21 | 23% | 2 | 2.52 | 1.25 | 50% |
| 2 | 31 | 34% | | | | |
| 3 | 20 | 22% | | | | |
| 4 | 10 | 11% | | | | |
| 5 | 9 | 10% | | | | |

Table 5: Survey 2 - Q18 Main concerns with current break-crops descriptive statistics

79% of respondents listed between 1 and 3 main break-crop concerns. Standard deviation was 1.25, and the data was relatively evenly spread in terms of the number of concerns reported by each respondent, reflecting the wide distribution of perceived break-crop performance amongst the survey sample. Figure 44 shows that the most common break-crop concerns were market prices (37%), input costs (35%), pests and/or disease pressure (33%), establishment issues (31%) and issues due to weather and climate (29%). It follows that having alternatives available, such as industrial hemp, which can perform well in certain areas where current break-crops are causing concern, may ease the pressure on farmers. Additionally, 16% of respondents listed ‘other’ and specified 12 different reasons for concern including; specific concerns of pest and disease pressure in Oilseed rape, poor profitability, rotation length and particularly grass breaks ‘slowing’ the rotation, lack of cropping alternatives and pesticide withdrawals.

## Predicted changes for farm businesses in the next 5 years

The final question in the survey asked respondents to comment on how their business is likely to change over the next 5 years, using a free-text answer box. 81 respondents answered the question, producing 89 different responses, which were grouped for analysis. For clarity, single responses left over after similar responses were omitted from the analysis. Therefore, only responses submitted by two or more respondents were included. Figure 45 demonstrates that there were many different variations of predicted and planned changes reported by the group. Significantly, out of the sample of 81 respondents, only 6 farm businesses (7% of respondents) reported that no significant changes were likely. The two most common answers were for; increased environmental practises (15%) and uncertainty due to the political environment (12%) in the UK. This likely reflects the great uncertainty surrounding the intended exit of the UK from the European Union, and the corresponding uncertainty surrounding future British agricultural policies. However, most responses for change were centralised around a common theme of improving production efficiencies and reducing environmental impact by improving crop rotations and soils and reducing inputs and costs. Reported methods included; reduced reliance on arable cropping and livestock production, increasing cultivation of break-crops and cover crops, reduced soil tillage and use of cultural controls and technological innovations.

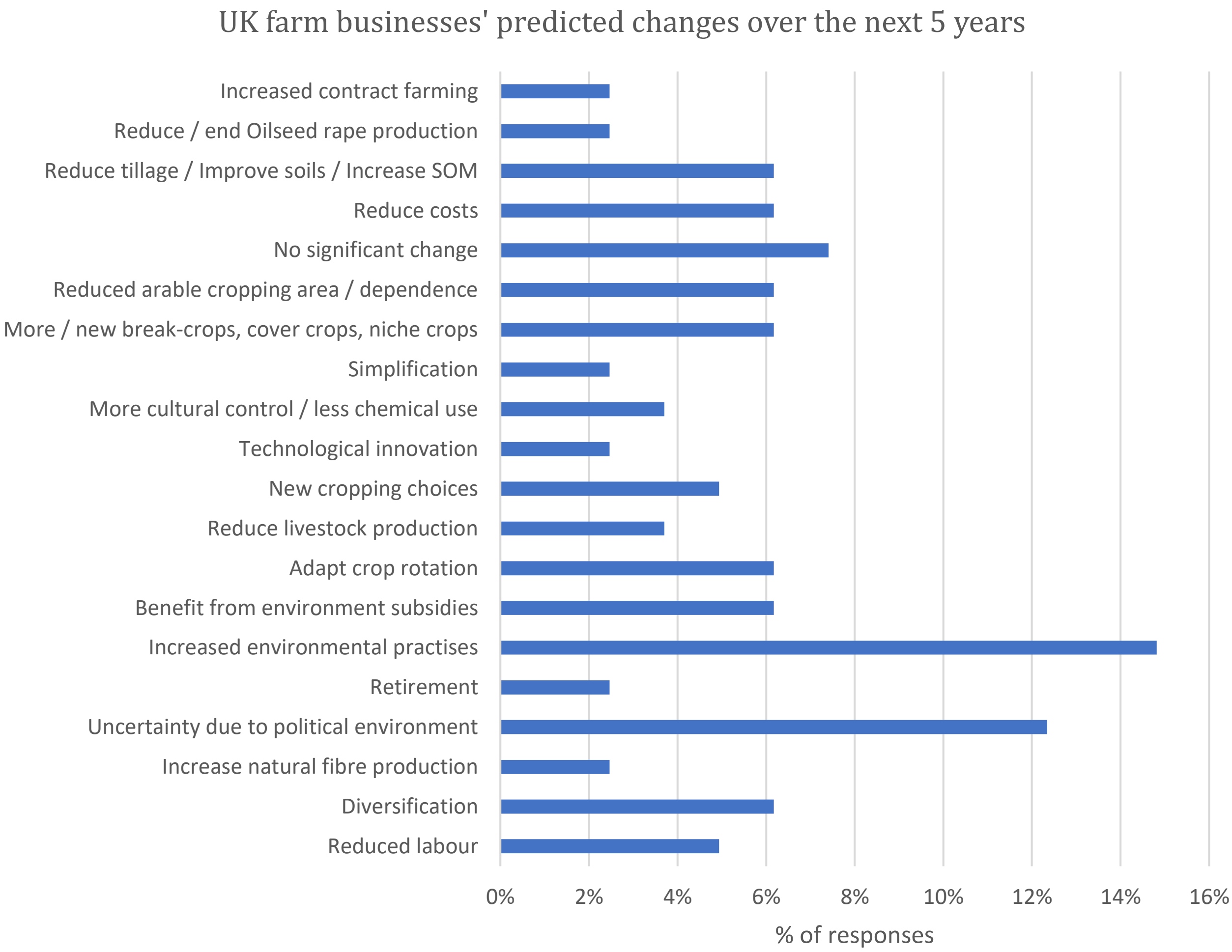


Figure 45: Survey 2 – Q19 Farm business predicted changes over the next 5 years

# Chapter 4: Discussion and Conclusions

Independent market analysis was conducted by distributing two market surveys and analysing the results using a grounded theory approach. The first survey was aimed at a diverse range of businesses within the European industrial hemp industry, and throughout the supply-chain. The survey received 28 responses, for a range of businesses, which were mainly classed as ‘micro’ and ‘small’, having less than 49 employees in this case. The businesses were diverse in age, being just as likely to be between 1 and 3 years old as they were to be over 10 years old. It is important to note that the sample size was small and therefore not likely to be accurately representative of the whole industry. Results could have been improved if a larger sample size had been achieved, perhaps by identifying more resources, engaging with non-English speakers and taking measures to improve the response rate.

Nevertheless, the 28 business respondents had a diverse range of operations, with many reporting raw material processing, business-to-business sales and consumer sales activities, as well as logistics and import/export activities. This indicates a high level of vertical integration, with some businesses reporting cultivation activities all the way to end-consumer sales, along with the required intermediate processes. It was found that seed, flower and leaf production was more common than fibre production, and sales of health food products, oils and CBD products were much more common than products manufactured using hemp fibres. For example, 57% of business respondents sold CBD products, whereas only 11% sold building or insulation products. However, 14% of respondents did report processing of fibre and shives and sales of raw materials, for both construction materials and other materials.

Furthermore, the data indicated that the industry is very geographically diverse. From the total sample, it was reported that suppliers (to the respondent businesses) were located in 31 different countries, with Germany most common, and listed by almost one third of respondents. Similarly, the customer base is equally diverse, if not more so, with customers being reported across all European countries listed, as well as globally. Most significant was that almost 80% of respondents reported that they had customers in the UK, suggesting that the UK already has a well-established customer base for industrial hemp products. It was also found that cultivation of industrial hemp is widespread in Europe, being reported in 26 different countries, with Spain most common by a slim margin.

In terms of the main opportunities and threats reported by the sample of businesses; emerging markets, increasing customer demand, product development, increasing production and changes to law and regulation were most commonly reported as key business opportunities. This shows a clear trend in the data that indicates the market is expanding, both economically and geographically, with significant opportunities for new products in new markets. Customer demand also appears strong and given that the respondents reported such as strong customer base in the UK, UK businesses should be well placed to exploit these demand trends. In terms of the main threats, it is significant that over 80% of respondents reported law and regulation change as a main threat. This demonstrates that depending on how legislation changes, could result in either opportunities or threats, but more commonly businesses view policy change as a threat. Other key threats identified were raw material costs and supply issues, with over one third of businesses reporting them.

Indications of market growth in the European hemp industry were further supported by the fact that 89% of respondents to survey 1 reported actively investing or expanding, with key reasons for investment and expansion being to increase production capability, with new machinery and equipment, and to develop new products. Finally, the most common main costs reported by the businesses were labour and raw materials. Combined with the fact that raw material costs were given as a main business threat by over a third of the sample, shows that this is a key area of concern. Therefore, this indicates that increasing domestic production and developing well-integrated supply chains, could result in significant improvements for UK industrial hemp businesses.

The second survey was distributed within the UK and aimed at both arable and mixed farming businesses, ranging in size, structure and geographical location. The survey generated 94 responses with 72% of businesses being in Scotland, 27% in England and 1% in Wales. In terms of farm size and management, 56% of farms were less than 500 ha in size, and 23% were between 501 and 2500 ha, with at least 10 years under current management. 21% of businesses had less than 10 years under current management, with 14% of them classed as small, and 7% medium in size. 93% of farms were conventional, 2% were organic and 5% reported some of both. In terms of the core farming functions (on-farm production), 73% of businesses were arable or mainly arable with some livestock and 19% were reported as mixed farms. 46% of businesses also reported additional 'farming related' activities, the most common of which was contracting, reported by 19% of respondents. Significantly, 13% of farms reported 'environmental/permaculture/conservational' farming practises.

It was found that 77% of farms in the survey had soil types suited to industrial hemp cultivation, namely; silty clay loam, sandy clay loam, loam, silt loam and sandy loam. With sandy loam the most common, reported by 36% of respondents. It is noted that 56% of respondents listed only one soil type, and only 4% listed more than 3. Therefore, there is some degree of confidence that almost 8 out of 10 farms would have suitable soils to grow the cultivar.

The most common length of crop rotation was 6 years, with 80% of respondents having a rotation length between 3 and 7 years. Whilst 55% had a rotation between 5 and 7 years. Furthermore, 40 different cultivars were listed in total, within standard crop rotations, although most were classed as 'niche' choices, accounting for less than 1% of rotation responses. It follows that 7 main rotational cultivars were identified; wheat, barley, oilseed rape, potatoes, grass, oats and beans. Barley was the most common cultivar, listed by 81% of respondents, and 61% specified spring barley. Winter wheat was similarly common, accounting for most of the crop rotation in most cases. 72% of respondents listed winter wheat, and both wheat and barley were most likely to be listed 2 or 3 times within the same rotation. Oilseed rape was the most common non-cereal cultivar, listed by 49% of respondents, and 96% of them only grow it once in the rotation. Similarly, potatoes, oats, grass and niche crop choices were likely to only feature once in the rotation and were each reported by approximately one fifth to one quarter of respondents.

Farm business respondents also listed 29 different cultivars as break-crop options, but 18 of them were niche choices, with each one only listed by one or two respondents. Six main break-crops were subsequently identified; Oilseed rape, grass, potatoes, oats, peas and beans. Most significantly, it was found that one fifth of farms choose a 'niche crop' as a break-crop, and over 82% of farms listed a maximum of 3 break-crop options. The 5 most important factors affecting break-crop choices, reported by between half and 70% of respondents, were identified to be; profitability, production costs, ease of cultivation, optimum sowing and harvest timing, and soil/environmental benefits. Also high on the list, reported by around a fifth of respondents were; pest and disease tolerance and weed competition. Therefore, industrial hemp should be theoretically considered as an option amongst a significant proportion of farmers.

Farm businesses respondents were then asked if they had considered growing industrial hemp, and how they would rate their knowledge on the cultivar. 74% of respondents said they had not considered it, 17% said they were currently considering it and 9% said they had previously considered it. Furthermore, 80% of respondents reported that they either had very little, or no knowledge at all, on the cultivar's potential as a break-crop. Subsequently, respondents were asked how likely they are to grow industrial hemp in the next 5 years, to which one quarter rated 'not at all likely', whilst 42% rated between 3 and 5 out of 10, of which 5 corresponded to 'somewhat likely'. Therefore, given that 58% reported having no knowledge of the cultivar, there was some degree of optimism on the future of the cultivar as an option.

It follows that the main barriers to growing industrial hemp, as perceived by the sample of farm business respondents, reported by between 33% and 49% of respondents, were identified as; the business/workforce being unfamiliar with the cultivar, poor agronomic understanding, lack of local processing facilities, lack of buyer demand and lack of machinery/equipment. It is noted that farmers perceive a lack of buyer demand, which is possibly currently very true for hemp fibre in the UK. However, it has been shown that there is a significant demand for oils and CBD products, should legislation allow and furthermore, there is high potential for increases in demand for hempseed products and technical fibre-based products. Therefore, the lack of familiarity and understanding, as well as a lack of infrastructure, machinery and equipment, are the main barriers to be addressed.

Additionally, whilst farmers rate their current break-crop performance relatively highly, with approximately half of respondents rating their break-crops as 'relatively effective', and a further 30% rating their performance as effective or 'very effective', it was identified that the main concerns with current break-crop options were; market prices, input costs, pest/disease pressure, establishment, and weather and climate issues. Furthermore, specific concerns included; increasing pest and disease pressure in oilseed rape, grass break-crops 'slowing' the rotation, a lack of alternative break-crops and concerns surrounding pesticide withdrawals. Therefore, again it seems as though industrial hemp could be a viable and effective option to replace various break-crops and address some of the main concerns in farming. Finally, when asked to predict how the farm business may change over the next 5 years, most responses adhered to a trend of; improving efficiency, reducing environmental impact, improving crop rotations and reducing inputs and costs.

Based on the survey results and analysis, the industrial hemp industry in Europe is clearly thriving, and new products and changing legislation can have significant impact on the growth of the industry. Furthermore, markets for hempseed and oils are particularly strong and the UK has a significant customer base for such products. Key concerns and business threats reported were based on law and regulation, and costs of raw materials. Therefore, legislative developments in the UK have potential for significant impact on the industry. UK producers already have a significant opportunity within the market for hempseed, but if legislation permitted the use of the whole plant, UK farmers could produce the crop at high margins and reduce pressures on processors and retailers based on high costs of raw materials and imports. It is therefore plausible that the UK could quickly become a very significant market for industrial hemp cultivation with robust value chains.

Furthermore, the UK farm business survey demonstrated that farmers are ready and willing to adopt new cultivars, such as industrial hemp, and particularly new break-crops for; environmental reasons, to improve their current rotation practises, reduce costs and inputs, increase the efficiency of their operations and improve soil conditions and crop yields. It was found that industrial hemp would be almost ideal to ease most the farmers' concerns, and to replace break-crops, such as oilseed rape, which were reported by many farmers to be suffering issues such as increased pest and disease pressure. The main barriers to farmers adopting industrial hemp, as a break-crop, were identified and can be summarised as; lack of familiarity and agronomic understanding of the cultivar, lack of local processing facilities and lack of on-farm machinery and equipment. Therefore, if farmers and agronomists can be effectively educated on the benefits of the cultivar as a break-crop, and how it can be effectively managed in production, farmers may be willing to invest in the modern equipment necessary to produce the cultivar effectively. Furthermore, cooperative groups, farming unions, or outside investors may be willing to invest in localised processing facilities and value chain mechanisms, to reduce the costs of producing and processing the raw materials.

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