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COMMERCIAL OPTIONS FOR WHOLE PLANT UTILISATION
INDUSTRIAL HEMP & MEDICINAL CANNABIS

JUNE - 2022

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New Zealand Medicinal Cannabis Council
Te Kaunihera o Te Rongoā Taru o Aotearoa

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This project has been funded by the Bioresource Processing Alliance

(project no. BPA2138)

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It is acknowledged that medicinal cannabis and industrial hemp are subject to different regulations and the impact of this for whole plant utilisation will be highlighted where relevant, throughout this white paper. For example industrial hemp is defined under the Misuse of Drugs Industrial Hemp Regulations 2006 as low THC industrial hemp. This is to be considered separately from any other use of cannabis.

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FOREWORD

Our medicinal cannabis and industrial hemp industries are reaching an exciting phase in their development. However, with significant growth there are a range of new challenges that will soon need to be overcome.

One of these challenges will be the rapid increase in plant biomass being generated over the coming years, with utilisation options today limited through lack of commercial pathways and current regulations.

This white paper is seen as an important first step in understanding the enormous potential for better utilising the whole plant through identifying and assessing a range of options. By drawing on the expertise of our industry members, as well as the wider research community in New Zealand, we can better understand the promising areas of research and the technologies and innovation that will be required in order to be successful.

By taking a wide lens on hemp and medicinal cannabis sectors that encourages greater collaboration, as well as between regulators and the wider industry, we believe we will be well positioned to deliver commercial value through whole plant utilisation.

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EXECUTIVE SUMMARY

The volume of biomass from medicinal cannabis and industrial hemp is significant and expected to rise rapidly over the next few years. Given this, the industry needed help to identify and evaluate potential commercial options for bioresources obtained from hemp or cannabis beyond their primary use. And given this biomass represents a significant proportion of the plant, consideration also needs to be given to options that could embed a circular bioeconomy approach.

Whole plant utilisation means considering options beyond primary use, with by-product from flowers and leaves, hemp seed (after processing), fibre and hurd, and the roots. In doing this, an industry-led approach was taken, whereby a number of opportunities were first established according to the part of the plant. These were then used to identify and assess potential options.

FLOWERS & LEAVES

The opportunity focussed on better characterisation of cannabinoids in different conditions

Extraction of parts of the medicinal cannabis plant other than flowers for increased cannabinoid yield and extraction of flowers and leaves for high-value non-cannabinoid chemicals, provides a potential increased value add to the industry. High-value substances could be extracted from industrial hemp to give products that could be used in nutraceuticals or cosmeceuticals. Optimising yields of cannabinoids or non-cannabinoids can be achieved by selecting cultivars and using external growing conditions (e.g., light, UV, temperature) to manipulate the expression of desired compounds. While these can be applied in the controlled environment of the greenhouse, there is also an opportunity to make use of New Zealand's natural regional climates.

SEED

The opportunity focussed on the commercial potential of hulls and seed cake

Conventional uses of seed cake include the manufacture of flours, or used as an ingredient in food formulations to provide nutritional benefits. Development of commercially viable processes for hemp protein concentrates and isolates from cake is a potential area for innovation. Additionally, improving hemp ingredient functionality (e.g. solubility) and verifying health benefits are important areas for research that could broaden market potential. Cosmetic, nutraceutical, fibre ingredient and fungi growth media are examples of conceivable applications identified for hemp hulls. Animal feed and pet food markets, while currently restricted in New Zealand, would likely provide a future growth area for hemp products.

FIBRE & HURD

The opportunity focussed on the quality of fibre from hemp seed production for application in material uses…

Significant amounts of hempseed straw are produced as a by-product of hemp seed production. When decorticated, this fibre can be used in composite materials. If not decorticated, hempseed straw can be processed into whole stalk composites. In addition, approaches like wet preservation allows stock piling of raw material for later conversion into fibre boards or polymer composites while avoiding the uncertainties of retting.

… and the potential for hurd as a primary product

Hemp hurd has been investigated for a raft of different applications and is already used in commercial products, some of which are already or could also be produced in New Zealand. While growing hemp hurd primarily for hurd ("hurd-first") is conceptually as feasible as currently used fibre-first concepts, further insights into how to optimise hurd properties for specific applications may be required.

ROOTS

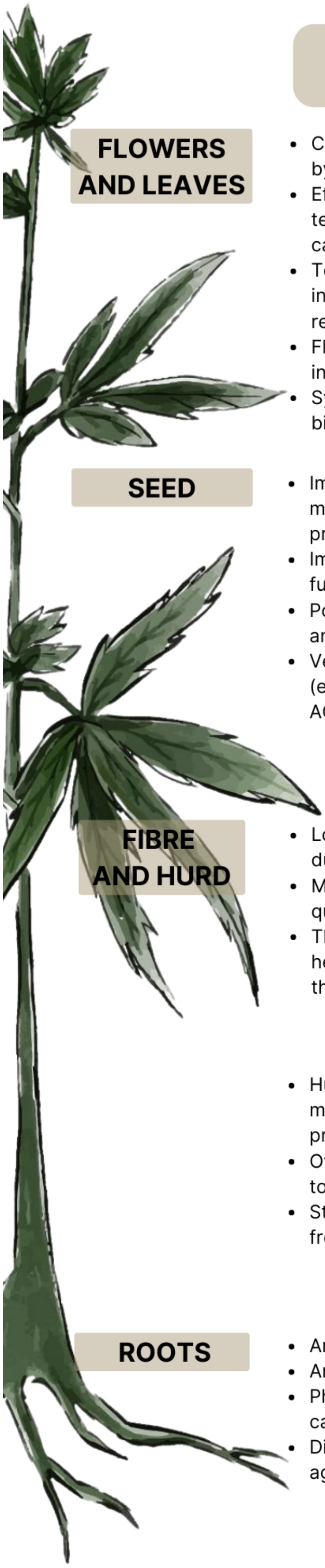
The opportunity focussed on better understanding of volumes, composition and potential

Roots have been used in traditional medicine for thousands of years due to their anti-inflammatory and antioxidant effects. The main phytochemicals present in roots are phytosterols and triterpenoids, plus minor amounts of alkaloids and lignans. The most common commercial use of hemp roots is to add them (either ground up or as an extract) into salves or balms to be applied on the skin, but they can also be consumed in the form of teas or butters.

An overall summary of options has been presented in Table 1, covering the areas of research, required technology and innovation, as well as potential products and markets.

It is acknowledged that these potential commercial options have not been limited only to those allowable through current regulations for medicinal cannabis or industrial hemp in New Zealand. In some cases, the proposed commercial options are not currently possible given the restrictions in place. We therefore recommend that any future regulatory changes consider the plant as a whole and allow for better overall utilisation. This would put New Zealand in a strong position to maximise the profitability of medicinal cannabis and industrial hemp in global niche markets.

Table 1. Summary of commercial options for whole plant utilisation of cannabis/hemp



	RESEARCH AREAS	REQUIRED TECHNOLOGY AND INNOVATION	POTENTIAL PRODUCTS AND MARKETS
FLOWERS AND LEAVES	• Cannabinoid composition by cultivar • Effects of UV and temperature on cannabinoid profile • Terpenes: anti-inflammatory, muscle relaxant, neuropathic pain • Flavonoids: anti-inflammatory • Synergetic effect of bioactives	• Recovery from hemp threshing residues • Systems using natural light and filters to maximise cannabinoid and other bioactives • Bioactive co-extractions (during cannabinoid extraction)	New product formulations containing: • Cannabinoids • Terpenes • Flavonoids
SEED	• Impact of manufacturing methods on by-product properties • Improving hemp ingredient functionality (e.g. solubility) • Polyphenols: anti-oxidant, anti-inflammatory • Verifying health effects (e.g. hemp peptides and ACE inhibition)	• Development of new products utilising hemp flours and ingredients • Recovery of peptide bioactives from residual protein • Methods to facilitate high yield extraction of polyphenols • Commercially viable processes for hemp protein concentrates and isolates	Fibre from seed production: • Geotextiles • Bio-composites • Insulation Un-decorticated: • Composites • Wood substitutes • Biochar
FIBRE AND HURD	• Locally developed tailored dual-purpose varieties • Methods to assess fibre quality in the stalk • The value in returning hempseed straw back to the soil	• New harvesting systems to preserve fibre quality • New retting and decortication technologies	• Flours • Nutritional supplements in food formulations • Cosmetics • Nutraceutical • Animal feed • Pet food • Fungi growth media
	• Hurd specific agronomy to maximise yield and processability • Overcome poor adhesion to bio-composite matrix • Standards & specifications from end users	• Modular and scalable hemp processing systems. • Integration into existing hemp product value-chains • Development of hemp hurd-first high-value products	• Animal bedding • Construction materials • Landscaping materials • Pulp and paper • Carbon fibre production • Biofuel and biochemicals
ROOTS	• Anti-oxidant activity • Anti-microbial activity • Phytosterols for cardiovascular health • Diseases associated with aging	• Harvesting and cleaning roots	• Salves or balms • Teas • Butters

THE OPPORTUNITY

Background

Estimates predict that there is between 4,645 to 5,997 tonnes per year of dry biomass generated from industrial hemp production* and 2.58 tonnes per year from medicinal cannabis production† that end up as waste. This is expected to rise rapidly over the next few years as the industry takes off in New Zealand.

This biomass represents a significant proportion of the plant and is hardly surprising given that for medicinal cannabis only the flower is utilised, and for industrial hemp the stalk and/or seeds. The remainder of the plant is currently composted or otherwise disposed of, with options and requirements being limited by existing regulations.

An illustration of the percentage (%) by dry biomass for each plant section is given in Figure 1, noting this will vary by cultivar and primary use.

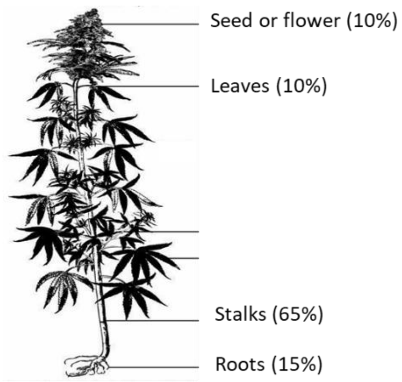


Figure 1. Cannabis/hemp plant sections as percentage of dry biomass

Given this, there is an opportunity to consider how we can better utilise the whole plant to generate additional value streams and shape future regulations to support commercial activity.

Project goals

This project aims to provide the industry with guidance to help identify and evaluate potential commercial options for bioresources obtained from hemp or cannabis beyond their primary use.

These should deliver the following outcomes:

- New business opportunities for NZ companies
- Increased employment opportunities
- New products for export from current resources leading to an increase in export revenue to NZ
- New technologies
- Environmental benefits, including reduced waste going to landfill
- More sustainable profitable businesses

* Annual industrial hemp production is estimated to be 5,880 - 7,225 tonnes of dry biomass of which 79-83% is predicted to end up as waste. This is based on 1,345 hectares grown in the 2019-20 growing period, with 4-5 tonnes of dry biomass produced per hectare, of which 1000 tonnes are used for seed and 200 tonnes for fibre.

† For medicinal cannabis, current annual production is estimated at 3 tonnes of dry biomass, of which approximately 86% is predicted to be waste

BPA overview

The project titled ***Hemp/Cannabis Whole Plant Utilisation*** has been funded by the Bioresource Processing Alliance (BPA). The BPA provides access to the combined world-class science capabilities and technical facilities of four of New Zealand's national research providers – AgResearch, Callaghan Innovation, Plant & Food Research, Scion – alongside New Zealand's Universities. The BPA also provides funding support for appropriate projects that utilise the expertise of these research partners.

The BPA's goal is to generate additional revenue for New Zealand by working with the primary sector to get better value out of biological by-products. In this project, the goal is to maximise the commercial potential for hemp/cannabis beyond its existing primary use.

Project team and approach

The project team comprises the BPA partner organisations: AgResearch, Callaghan Innovation, Plant & Food Research and Scion. It also includes two industry partners: New Zealand Hemp Industry Association (NZHIA) and the New Zealand Medicinal Cannabis Council (NZMCC), representing commercial industrial hemp and medicinal cannabis interests, respectively.

The team has taken the following approach, which are key inputs to inform this white paper:

i) Generating insights from a series of conversations with businesses on the current hemp/cannabis situation and opportunities for biomass to deliver commercial value

ii) Holding a stakeholder workshop to confirm industry-led priorities for commercial evaluation of hemp/cannabis biomass opportunities

i) <u>Key Insights from industry conversations</u>

Representatives from a range of medicinal cannabis and hemp businesses were interviewed to identify a number of key insights. For **Medicinal cannabis** these businesses included Cannasouth, Eqalis, Greenfern, Greenlab, Helius, Puro, Rua Bioscience, Kariki Pharma. For **Industrial hemp** these businesses included Hemp New Zealand, Hemp Connect, Carrfield, Kanapu, Hempseed Holdings.

The key insights were presented during the stakeholder workshop as themes and then further developed based on attendee feedback. They are relevant here as key considerations for evaluating potential commercial options.

Table 2. Key insights from industry conversations

Significant business impact	Biomass today represents a significant cost for many businesses given the disposal requirements to comply with regulations. These activities include shredding, composting or being treated as medical waste. It was recognised that all options need to be compared to the economic impact of current methods of disposal.
Existing regulations limit options	The current regulations limit the ability to use significant biomass from cannabis or hemp plants commercially, so it is hoped this project will inform regulatory changes in the future. Furthermore, while there is interest in research projects for biomass, current regulations create barriers to accessing or using the material for R&D activity, particularly for medicinal cannabis.
Cannabinoid potential	Both cannabis and hemp businesses wanted to understand better the role of cannabinoids (especially CBD) as potential commercial options for biomass. Differences in regulation were highlighted for CBD products in New Zealand compared with other countries that would need to be addressed. This is because flowers are not the only part of the plant containing cannabinoids. e.g., they are also found in leaves.
Opportunity to build industry reputation	Taking a whole plant approach was seen by many as an opportunity to build the industry's reputation as a whole. This was especially recognised in light of the growing focus on sustainability, which could allow an agreed New Zealand approach to differentiate in the global market. Potential options mentioned were carbon sequestration, compostable materials and packaging.
Learn from other industry experiences	Many pointed to successful industries in New Zealand, such as wine and kiwifruit, where participants took a more collaborative approach, evidenced by export growth and global reputation. There was an opportunity to apply learnings from successful industries to cannabis and hemp. This collaborative approach may be even more beneficial when considering industry-wide options for utilising the whole plant beyond primary use.

Overall, there was a recognition that New Zealand's share of the global market would continue to be small, even with best case growth estimates. Given this, it was important to set priorities and focus on the industry in market niches where we can collectively compete on a global stage. We took this same approach to identify options for better utilising the whole plant.

ii) Prioritisation workshop with industry stakeholders

A workshop with key industry stakeholders was used to guide prioritisation for evaluating potential commercial options.

The virtual workshop was held on 2nd December 2021 for three hours and included key stakeholders representing industry, BPA partner organisations, industry partners, MPI, universities and iwi. There were 75 registrations and 34 attendees to the workshop. A survey was provided to workshop attendees, that 31 people completed.

Following the workshop, we set the focus areas per by-product, taking into account industry direction. In addition to an overview for each area, this white paper addresses the specific points highlighted in the table below.

Table 3. Key areas of focus to address by source of by-product

BY-PRODUCT: FLOWERS & LEAVES ○ Overview of the volume, composition, restrictions and potential ○ Cannabinoid characterisation by cultivar ○ Effect of UV on cannabinoid profile and content
BY-PRODUCT: SEED ○ Overview of the volume, composition, restrictions and potential ○ Commercial potential of husks and seed cake
BY-PRODUCT: FIBRE & HURD ○ Overview of the volume, composition, restrictions and potential ○ Quality of fibre from hemp seed production for application in material uses ○ Hurd as a primary product
BY-PRODUCT: ROOTS ○ Overview of the volume, composition, restrictions and potential

Circular bioeconomy

The concept of a circular bioeconomy joins the ideas of a circular economy [1], one where the materials flow back into products rather than to waste, and the development of sustainable biobased feedstocks. Combining the two concepts is greater than the individual ideas and has been suggested to play a vital role in meeting global climate change targets [2]. This approach is driven by the fact that the earth is a closed system with finite resources and that continual growth under a linear model (i.e. product to waste) is impossible in the long term if the human population continues to increase.

A circular bioeconomy has been seen to be as needed to achieve many of the 17 UN Sustainability Goals [3] and global recovery from the COVID-19 pandemic [4]. However, its implementation must be carefully considered for the maximum beneficial outcomes, considering economic, social, and environmental aspects of the transition from a predominantly fossil-based linear economy to a circular bioeconomy [5].

A core principle of a circular bioeconomy is that biobased resources are utilised fully at every step and that materials flowing to actual waste, e.g., landfill, are reduced ideally to zero. In this context, the biobased feedstock's entirety should be considered input into other processes.

Specifically for the cannabis/hemp industries, all parts of the plant should be covered for use and not just the very narrow parts of the plant for a single application, e.g., thought should be given to roots, stem, and leaves in the case of the medical cannabis industry. This approach diversifies products for the company growing the cannabis or becomes a feedstock for another company.

There is a natural and pressing opportunity to embrace and embed the practices of a circular bioeconomy early in the establishment of New Zealand's medicinal cannabis and industrial and hemp industries, so they become best practice from the outset.

BY-PRODUCT: FLOWERS & LEAVES

Overview

Flowers

The cannabis flowers are the primary biomass type sought after by cannabis growers for medicinal purposes. Specifically, the flowers of the female plants have the highest extractable concentration of cannabinoids [6]. The flowering structures are known as calyxes (home for the seeds) and bracts (Figure 2). In non-pollinated plants, the trichome rich calyxes are responsible for releasing cannabinoids and other terpenes. The bracts are also rich in trichomes and secrete cannabinoids and terpenes [7].

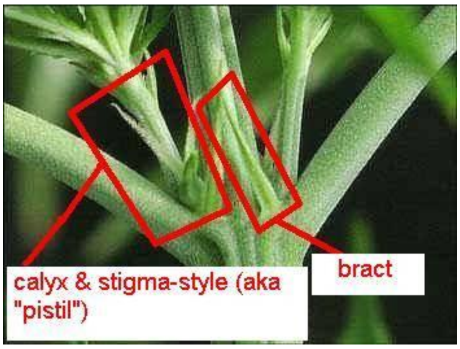


Figure 2. Calyx and bract, the flowers of cannabis‡

Leaves

The leaves of cannabis plants are separated into two classes. The fan leaf is the leaf structure most commonly associated with the cannabis plant. The other leaf structure is the sugar leaf found in conjunction with the buds during flowering (Figure 3).

Figure 3. Fan leaves (left) and sugar leaves (right)

Sugar leaves are named not because of their actual sugar content but rather due to a large number of trichomes (hair like projections that express many plant bioactives).

‡ https://www.icmag.com/threads/inflorescence-anatomy-bract-vs-calyx.214969/

These leaves have reported uses in making edibles and infusions, and also for composting [8]. There are reports of smoking the leaves. However, this is generally not seen as an appropriate use [9].

Volume

Flowers make up 16.3% and leaves 15.1% of the mass of cannabis plant, meaning that the leaves provide approximately an equal resource to utilise for high-value chemical compounds compared with cannabis flowers.

Composition

Depending on the application of the cannabis plant (medicinal or industrial), the THC and CBD concentrations have significant variation between the flowers and the leaves.

THC and CBD represent only two of over 90 discrete cannabinoids identified in the cannabis plant [10]. However, differences in cannabinoid concentration depend on tissue type, age, variety, growth conditions (nutrition, humidity, light level), harvest time and storage conditions [6, 11, 12]. For instance, cannabis grown outdoors generally has lower levels of cannabinoids when compared to indoor grown plants [11], female plants tend to have higher cannabinoid concentrations [13], and a link between cannabinoid concentration and plant height has been established [13] . One of the more important parameters to determine cannabinoid profile is the cultivar, and this will be explored in more detail in the following section.

Other than cannabinoids, there is an extensive array of chemicals found in these plants. Terpenes and flavonoids [14] are of particular interest due to their bioactivities [6, 10]. Specifically, of the terpenes found in cannabis, Russo and Marcu [15] highlighted 17 monoterpenes and 10 sesquiterpenes that have been shown to have medical applications ranging from antimicrobial to anticancer activity. The primary terpenes are identified as β-myrcene (monoterpene) and β-caryophyllene (sesquiterpene) [16]. β-myrcene has been shown to act as an anti-inflammatory and a muscle relaxant, and β-caryophyllene is an anti-inflammatory agent and shows some activity in relieving neuropathic pain and some degenerative diseases [15].

All industrial and medicinal cannabis plants have a unique flavonoid in the form of cannflavin A and cannflavin B. Cannabis leaves contain about 1% total flavonoids, especially apigenin and quercetin. Cannflavin may make up 0.15% which makes it very difficult to isolate using standard methods [15]. This has been shown to have therapeutic activity reducing inflammation without significant side effects [10, 11, 15].

It has been suggested that the positive benefits of cannabinoids are a synergistic effect of all of the bioactives present in cannabis, not just the cannabinoids themselves, in what is commonly described as the *entourage effect* [14].

Restrictions

Opportunities with developing product markets outside of the cannabinoids are hampered by the Ministry of Health taking a narrow view of the cannabis plant. For example, there is potential for cannflavins to be the main product and cannabinoids to either be a side-stream or not isolated. For these opportunities outside of cannabinoids to be developed, cannabis needs to be less viewed at the plant level and more considered in the targeted extracts.

Potential

Given the significant amounts of other bioactive compounds found in cannabis, there is the potential to increase the value per plant with either co-extractions (during cannabinoid extraction) or after extractions, which could be by a third party, before the remaining biomass goes to applications such as composting. Several scientific studies have highlighted the opportunity to recover non-psychoactive secondary metabolites such as minor cannabinoids, terpenes and flavonoids from industrial hemp threshing residues [17-19] and dust produced during processing for fibre production [20] and the threshing residues from the seed crops.

Flavonoids are of interest as they cover a range of compounds with known bioactivities and have a high value. Examples of the prices of isolated flavonoids are: cannflavins (185,000 USD / g), catechin (3,000 USD / g), epicatechin (3,450 USD / g), quercetin (3,500 USD / g), kaempferol (3,500 USD / g), apigenin (3,350 USD / g), and ferulic acid (3,350 USD / g)[§].

Thought needs to be given to the end-of-life applications of the remaining biomass. This is the vast proportion of the biomass available for use after bioactive and other chemicals have been extracted. This cannabinoid-depleted residual biomass can be used to obtain phenolic-rich extracts with an antioxidant capacity [21].

Cannabinoid characterisation by cultivar

The concentration of cannabinoids is influenced by the specific cultivar being used. Multiple studies have been published focusing on the different cannabinoid profile between cultivars of a specific geographical region such as England [22], South Africa [13], Turkey [23], Albania [24], Italy [25] and US [26]. A 2019 study of extracts from female buds belonging to cultivars ground in the US showed that across nine different medicinal cannabis cultivars, there was a range of THC concentrations from 3.2% to 26.3, CBD from 0.1% to 1.6%, and overall cannabinoid totals ranging from 6.4% to 28.4% [27]. It should be noted that while there was a general trend that higher total THC correlates with higher total CBD (removing outliers), several cultivars where the total CBD was far higher were found (Figure 4).

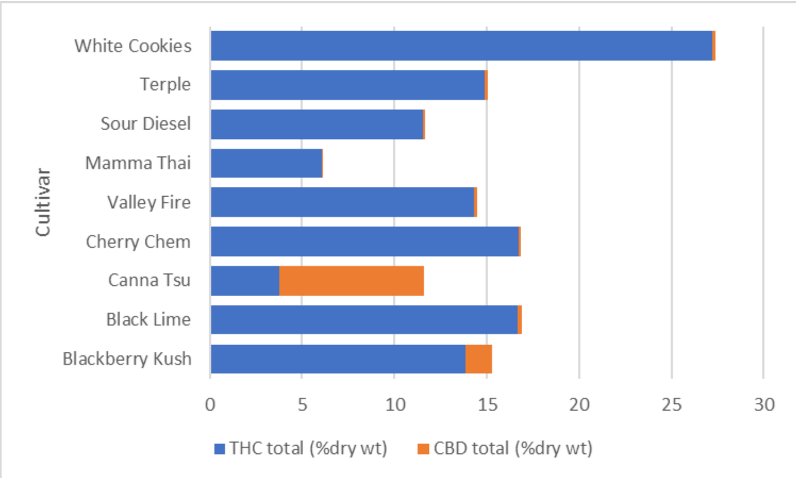


Figure 4. Concentrations of %dry wt. of THC (total) and CBD (total) across nine cannabis cultivars. Data taken from Zager et al. [27]

Although it is accepted that there is a single species of *Cannabis sativa*, a wide range of cultivated varieties ("cultivars") has been created as a result of centuries of breeding and selection [12]. The most common way to categorise such strains is based on plant morphology ("phenotype"), which considers features such as leaf shape, plant height, colour, smell, and speed of growth, and generally distinguishes between *indica* and *sativa* [28].

A more consistent classification based on the relative content of three major cannabinoids (CBDA, THCA and CBGA) has also been proposed, distinguishing between three main chemical phenotypes ("chemotypes"): chemotype I (CBDA:THCA ratio <1, i.e. THC dominant), chemotype II (CBDA:THCA ratio close to 1:1), and chemotype III (CBDA:THCA ratio >1, i.e. CBD dominant with low concentrations of THC and/or CBG). Additional chemotypes IV (CBGA:CBDA/THCA >1, i.e. CBG dominant) and V (total cannabinoid content <0.02 %) also occur but are far less common [29].

However, the chemotype approach only considers ratios of major cannabinoids rather than actual concentrations. A more comprehensive classification into "chemovars" was first proposed by Hazekamp [12] to

[§] All prices taken from https://www.biocrick.com/

group cannabis plants by their chemical profile, most often by looking at the main cannabinoids along with the two-to-four most dominant terpenes, using a multi-variant data analysis tool to classify cultivars in a small number of chemically distinct groups; however, this type of classification is still in its infancy. Several studies examine the detailed cannabinoid composition across multiple cultivars [25, 26, 30].

Effect of UV on cannabinoid profile and content

A study looking into cannabis plants grown in Albania showed that increased temperatures caused higher concentrations in both flowers and leaves [24]. Temperature treatment with UV-light and lightning profiles has been shown to influence cannabinoid and other metabolite concentrations [31-35].

Specifically, studies have shown an increase of Δ^9-THC of 22% and 48% in the leaves and 15% and 32% in the flowers using UV-B radiation at 6.7 and 13.4 kJ/m^2 respectively [34]. Islam *et al.* [33] found increases in CBD concentration ranging from 10.44 µg/g (dry wt.) to 48.01 µg/g (dry wt.) using the application of LED sourced light, as compared to a control of natural light.

The profile of the light used influences this effect, with high-pressure sodium (HPS) lamps causing a decrease in THC concentrations in the flowers compared with light emitting diodes (LED) as a light source, with the main difference being the higher proportion of lower wavelengths (<500 nm) emitted by the LED source. This study also showed that wavelength profiles could be used to target individual cannabinoids, such as enhancing CBG (cannabigerol) concentrations [36].

BioLumic (Palmerston North, New Zealand) produces lighting systems that radiate the young plants in a one-off event and then select for the plants with desired traits. Specifically for cannabis, they report 27% and 25% increases in THC and CBD, respectively, along with an increased mass of flowers per plant of 32% to 59% depending on cultivar [37]. This approach speaks to cannabis chemovars being a more important metric than cultivars [12, 38, 39].

Making use of New Zealand's climate

Besides warmer temperatures [24], UV light can be used to manipulate cannabinoid profiles [31-35].

Of the light that reaches the earth from the sun, approximately half is as viable light (400 – 700 nm), and the rest is UV (10 – 400 nm) and IR (700 nm – 1 mm) [32]. The UV wavelengths are further divided into UV-A (320 – 400 nm), UV-B (280 – 320 nm), and UV-C (100 – 280 nm). The Earth's surface receives around 95% of its UV as UV-A, 5% as UV-B, and no UV-C [40]. UV-A has been shown to increase the concentrations of THC, CBG, THC, and THCV, and UV-B to increase THC production, with UV-A interacting with cryptochrome (photoreceptor) and UV-B with UVR8 (UV-B receptor and protection from damage) eliciting the response [31, 32].

Considering these factors, then to maximise the production of most cannabinoids and other bioactives, plants should be grown in regions with high durations of sunlight, and warmer temperatures would be preferred (Figure 5). These sunlight and temperature location benefits could then be overlapped with areas that have higher UV-A and UV-B flux (Figure 6). This would suggest that the upper South Island and the East Coast of the North Island are prime growing regions to have improved cannabinoid yields. If considering UV flux, then areas such as Kaitaia have the potential to produce higher yields of cannabinoids and bioactives.

While there is far better control of environmental conditions when cannabis is grown indoors (Figure 7), it is estimated that lighting consumes around 79 – 86% of the total power consumption of the operation. In the USA, this translates to approximately 1% of the total energy consumption for the entire country, and in states with a significant cannabis industry, e.g. California, it can represent up to 3% [36].

Therefore, there is potential to develop a unique New Zealand system (either fully indoor or a hybrid) that makes the most use of natural light and, with the judicious use of light filters, maximises cannabinoid and other bioactives production.

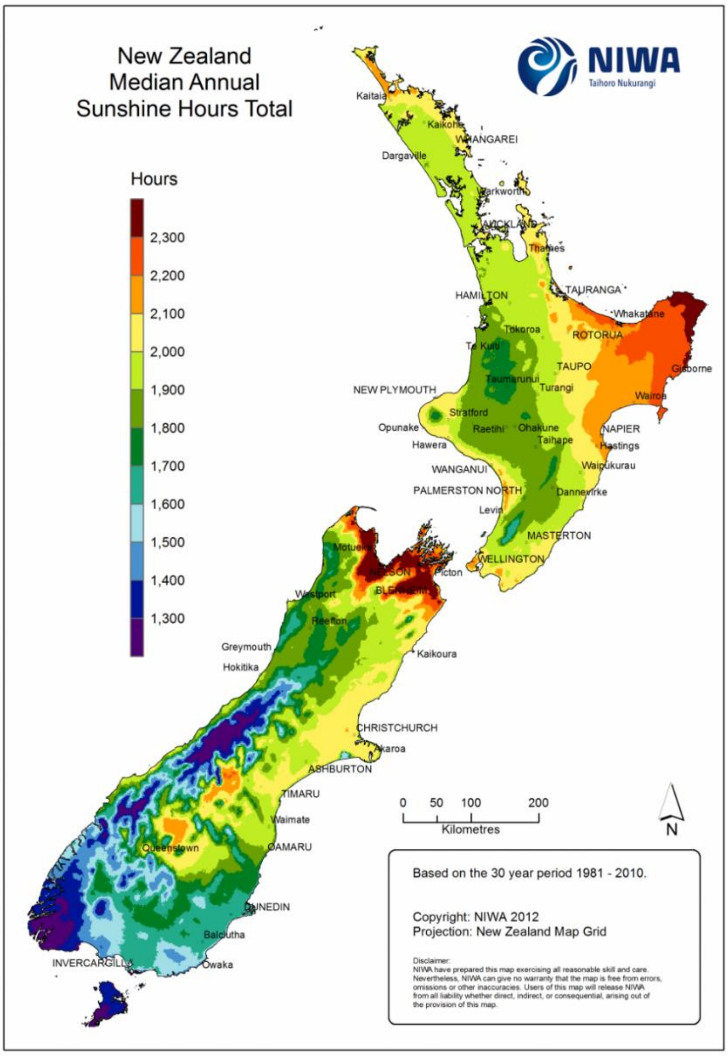


Figure 5. Average hours of sunlight across NZ over a 30-year period

NIWA Instruments

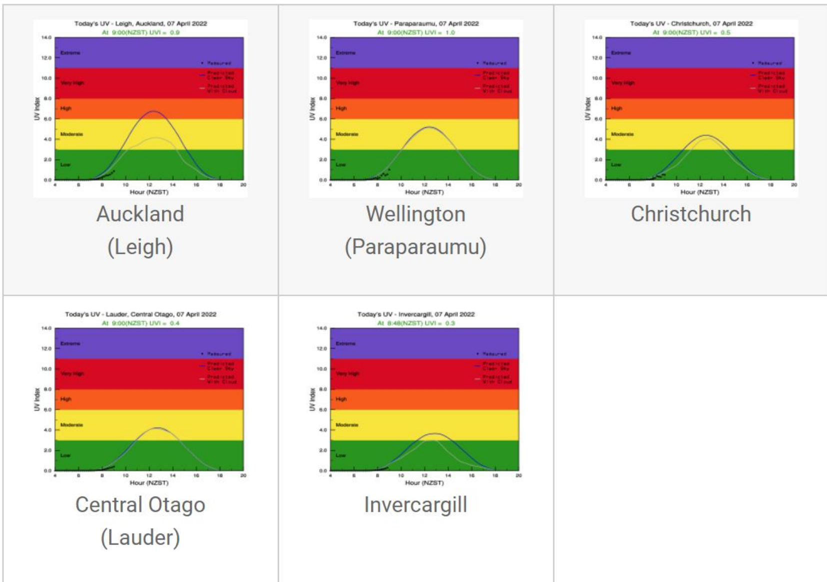


Figure 6. UV profiles at five locations around New Zealand (on 7 April 2022)

Figure 7. Cannabis grown indoors showing the significant amount of artificial lighting required

Summary

- Extraction of other parts of the cannabis plant for increased cannabinoid yield and extraction of flowers and other components for high-value non-cannabinoid chemicals provides a potential increased value add to the industry. While this perhaps fits better for those growing for medicinal purposes, the non-regulated high-value substances could be extracted from industrial hemp with low THC and low cannabinoids to create products that could be used in nutraceutical or cosmeceuticals.
- Optimising yields of cannabinoids or non-cannabinoids can be achieved by selecting cultivars and using external growing conditions (e.g., light, UV, temperature) to manipulate the expression of desired compounds. These can be applied in the controlled environment of the greenhouse, but there is also an opportunity to make use of New Zealand's natural regional climates.
- Cultivars are best considered as chemovars. This reflects the base genetics and the expression of those genetics under specific growing conditions.
- Regulations around the use of cannabis for medical or industrial use need to consider the plant as a whole and all the value-add secondary metabolites. This would put New Zealand in a strong position to maximise the profitability of growing medicinal cannabis and industrial hemp for global niche markets.

BY-PRODUCT: SEEDS

Overview

Legislative changes in 2018 unlocked the use of hemp seed from industrial hemp plants containing low levels of THC as a food product or ingredient in New Zealand [41]. Many New Zealand companies have since invested in hemp seed cultivation, processing and product development leading to a wide range of hemp seed products on the New Zealand market. A recent report for the Ministry of Primary Industries [42] predicted that New Zealand has the potential for $30m in annual revenue for hemp food products by 2030.

Whole hemp seeds (Figure 8) are typically used in edible oil manufacturing, leaving behind a press cake (meal). Alternatively, the seeds can be de-hulled (shelled), and the interior seed 'heart' utilised, leaving behind hulls (shells) [43]. Hemp cake and hulls are the two primary by-products of hemp seed processing and will be the focus of this section of the paper.

Figure 8. Whole hemp seeds, ©AdobeStock

Volume: Hemp cake and hulls

When whole hemp seeds are processed into hearts, the hulls are separated by milling (such as impact milling), followed by screening and air aspirator technologies, similar to methodologies used to process other seed products [44]. The hulls contain residual amounts of protein, depending on the efficiency of the separation process and fibre and polyphenols. A typical de-hulling process results in 60% of the seed mass being recovered as hulls (as well as some dust and fines), leading to approximately 300 tonnes of hull mass per year based on current production rates [45]. Pictures of hemp hulls and hemp cake are shown in Figure 9.

Commercially, hemp oil is produced using pressing (screw or hydraulic, and hot or cold), solvent extraction methods (such as using hexane), or sometimes a combination of methods, similar to the processes used in other high-oil seed crops such as soy and olive [46]. Based on a New Zealand commercial operation, a cold press process might produce 60–70% press cake, equivalent to approximately 300–350 tonnes annually [45]. The different oil recovery methods can impact the condition and content of oil, processing-sensitive bioactives and nutrients, and the overall sensory quality of the residual cake in different ways.

The predominant use for hemp seed oil is in food, and nutraceutical, and cosmetic products, although industrial uses such as lubricants, biodiesel, and inks are possible [47].

*Figure 9. Hemp hulls (left), ©AdobeStock and cake (right), © 2022 Midlands Holdings***

Composition

Unlike the inflorescence and leafy matter of low THC hemp plants, the seeds contain negligible levels of cannabinoid compounds [48, 49]. Hemp seeds are well known for their nutritional value, and many components of the seed composition have been well studied. Examples of whole seed, cake, and hull composition from several authors are provided in Table 4.

Table 4. Examples of hemp whole seed, cake and hull composition, a[50], b[51], c[52]. ND = not determined. Note, carbohydrates were determined by difference and include fibre content. Neutral and acid detergent fibre methods are commonly used by animal feed industry to evaluate feed composition.

Component (% as is)	Whole seed[a]	Whole seed[b]	Seed cake[a]	Seed cake[c]	Hulls[a]	Hulls[b]
Moisture	5.9	6.7	4.9	5.6	5.1	8.0
Crude fat	30.4	32.3	10.2	11.1	10.3	11.5
Crude protein	24.0	23.9	40.7	33.5	12.7	13.1
Ash	4.8	5.0	6.7	7.2	3.9	3.2
Carbohydrates (by difference)	34.9	32.1	37.5	42.6	68.0	64.1
Total dietary fibre	ND	31.5	ND	42.6	ND	ND
Soluble fibre	ND	2.7	ND	16.4	ND	ND
Non-soluble fibre	ND	28.8	ND	26.2	ND	ND
Neutral detergent fibre	32.1	ND	30.5	ND	64.9	ND
Acid detergent fibre	23.5	ND	21.5	ND	50.2	ND

The oil (crude fat) fraction is notable for being rich in polyunsaturated lipids, essential fatty acid content (linoleic, α-linoleic and γ-linoleic) and fat-based vitamin content (including tocopherols). These lend themselves to health-targeted applications [52-54].

The seed heart has a high protein content that is readily digestible and is a valuable source of methionine, cysteine and arginine. Like many grains, the essential amino acid composition is primarily limited by low lysine content compared with protein reference requirements set by the FAO/WHO [50, 55, 56].

Insoluble fibres (lignin and cellulose) make up the majority of the fibre content and are concentrated in the hulls. Also present are xylan and pectin fibres, which have potential nutritional value as prebiotics [57]. The hull is also rich in polyphenol content, and hemp-unique phenolic compounds, including N-trans-caffeoyltyramine and cannabisin B, with antioxidant properties, have been discovered [58].

Unlike many seeds, hemp has low starch and sugar content, lending to low glycaemic index applications. Overall, hemp seed foods are reported to have low allergenicity [59, 60], although potential allergens have been identified [61, 62]. Hemp has the potential for use in products where soy, wheat or other allergens cannot be used.

Phytic acid is the primary anti-nutrient of concern in hemp seed and can lead to poor absorption of minerals during digestion, so it needs to be managed when considering its use in diets [54, 63].

Available insights and research

Food: Flour

Various grades of hemp flours can be produced from the press cake or hearts by milling and sieving, with the more refined flours containing less fibre [64, 65]. It is also worth considering the hull as a potential source for specialty high fibre flour production [57]. High fibre hull flours, with bioactivity from polyphenol compounds or prebiotic fibres, could be an interesting opportunity for innovation.

Hemp flours have been used in direct-to-consumer foods and product formulations. Hemp flours are typically included in formulations because of their nutritional benefits and are used to supplement fibre, protein, essential fatty acids and other nutrients.

With the majority of fibre and oil separated, refined flours can contain protein concentrations of up to approximately 50–70% and are often marketed as ‘hemp protein powders’ commercially. There are now a wide range of products made using hemp seed flour on the New Zealand market. These include baked goods, meat alternatives and smoothie beverages (Figure 10). In addition, Good Hemp’s ‘Seed Milk’ is a UK example of a dairy alternative containing hemp seed (4%).

Hemp seed flours are an active area of research. Iorgacheva and Sokolova [66] showed that including 15% hemp meal flour in bread sticks was possible without significant changes in dough rheological characteristics. Apostol *et al.* [67] found that sensory and physicochemical values at addition rates of 5% and 10% were ideal for white wheat bread and 15% and 20% for whole wheat bread. Locally, the Riddet Institute has been supporting industry innovation by developing meat alternatives using hemp ingredients in collaboration with Sustainable Foods Ltd and Greenfern Industries [68].

Although having well-recognised nutritional value, the functional properties (solubility, foaming, emulsification etc.) of hemp seed flours are not currently considered to be advantageous over competing seed sources. To illustrate, the functional properties of various flour grades of hemp cake were reviewed by Barta *et al.* [69]. The finest grade flour (highest protein and lowest fibre content) had superior water solubility and water and fat holding capacities than the coarsest grade.

However, compared with rape seed and sunflower seed cake flours, hemp seed flours were lower in overall functional performance. Development of processing methods to improve functionality and further research into the best ways to incorporate hemp seed ingredients into food products will benefit maximising market potential.

Hemp Flour, Hemp Connect

Pure Hemp Protein, Hemp New Zealand

Golden Hemp Protein Powder, Mainland Hemp

Hemp Seed Flour, Midlands††

Hemp Hearts Protein Powder, Pure Heart Aotearoa

New Zealand Hemp Protein Powder, The Brothers Green

Superfood Smoothie, Cacao, Banana & Hemp, Chia Sisters

Our Southern Plains, Sprouted Grain and Hemp Bread, Coupland's

Keto Hemp Bread, Dovedale

Hemp Protein Smoothie raspberry, Hemp Up

Hemp, White Bean & Black Pepper Crispbread, Huntley & Palmers

Hemp Dark Chocolate bar, Matakana Superfoods

Classic Hemp Burger Patties, Sustainable Foods

Figure 10. Examples of New Zealand hemp flour products and formulated products.

Food: Concentrated protein ingredients

As with soy, wheat and pea, processes for the manufacturing of concentrated protein ingredients have been developed for hemp, although the range of hemp protein isolates and concentrates on the market currently appears limited.

Removing residual oil from hemp seed is an important step before protein recovery and often cold pressing and solvent methods are combined [70]. This is to minimise the potential for oxidised lipid compounds in the residual protein. Removing the hull is also beneficial for improving the sensory characteristics, including reducing the bitterness of concentrated proteins [71].

Hemp concentrate (protein >70%) is made by washing and removing water soluble components from defatted and de-hulled hemp seed material. Hemp protein concentrate and isolate can be recovered from hemp seed or hemp seed cake, and potentially from the residual protein attached to hulls when separated during de-hulling. Hemp protein isolate (>90% protein) is typically made by alkaline (generally pH 9–10) solubilisation of the protein, separation from insoluble non-protein components, and then acid-based isoelectric precipitation of the protein using acid [59]. These techniques are similar to those employed by the soy industry [72].

Alternative protein recovery processes and methods have been explored. Malomo and Aluko [73] used enzymes to digest fibre and phytates in hemp seed meal, followed by ultrafiltration to remove the digested compounds from the remaining protein fraction. The use of salt solutions to form protein micelles followed by centrifugation and ultrafiltration has also been studied [74]. The salt extraction approach is also a key part of patent WO2014019074A1 [75] (Burcon Nutrascience (MB) Corp) that includes the acidification of the protein to improve solubility for use in beverages.

Patent WO2021253136A1 [76] (Botaneco Inc.) takes a different approach with whole hemp seeds milled and then separated into solid, light liquid (oil) and heavy liquid phases (protein) using decanter centrifuge and disc stack separator technologies. To improve ingredient purity, WO2021217265A1 [77] used resin treatment during an alkaline recovery process to remove off flavours from hemp protein. As with all new processing methods, challenges with scalability, yield and economic performance must be resolved before achieving commercial feasibility.

Like hemp flours, concentrated hemp protein ingredients have been used as nutritional supplements in food formulations. For example, patent WO2013138906A1 [78] covers an infant hemp protein formula. Developing processes that target and preserve bioactive activity from other components, such as prebiotic fibres, alongside concentrated hemp protein could be an interesting proposition for the nutritional ingredient market.

Dairy-hemp interactions have been explored in a thesis study by Chuang [79] to support the future development of hybrid products. It was found that challenges with protein aggregation and poor hemp protein solubility still need to be solved, and technologies such as high-pressure processing and extrusion technologies might be useful for this aim. Improvement of hemp protein functionality has been focused on several studies [80]. Gentler, non-isoelectric precipitation methods, like the salt micelle process explained above, were found to be better for preserving native protein structure and led to improved functionality, including gelation [73, 74, 81]. Controlled enzymatic hydrolysis of concentrated hemp protein was shown to improve solubility. However, other functional parameters worsened, likely due to the disruption of protein structure [82].

Nutraceuticals

The list of potential bioactive compounds found in hemp seed is large, and both hemp cake and hulls are possible targets for the extraction of nutraceutical products [83].

Many studies have focused on bioactive peptides from hemp protein, and Wang and Xiong [59] provide a comprehensive summary of these. Multiple in vitro and in vivo (animal) studies of hemp peptides were produced using various enzymes and chemical methods to measure health effects. The specific health-promoting activities identified include angiotensin-converting-enzyme (ACE) inhibition (relates to high blood pressure treatment), metal binding, antioxidant activity, and cholesterol and glucose regulation.

Setti *et al.* [84] employed fermentation and enzyme treatments to recover bioactive peptides from the residual protein in the high fibre bran leftover after sifting hemp cake flour. There is no reason why this approach could not also apply to the hull fraction from de-hulling. The extracts showed antioxidant and anti-hypertensive activity. The methods used could provide an avenue for developing value-added nutraceutical and cosmetic products, subject to techno-economic analysis indicating that the extracts can be isolated with consistent activity and economically.

Production of polypeptides from cake using enzyme treatments has also been the focus of recent Chinese patents CN105925651B [85] and CN112913970A [86]. For peptide products to be successful commercially, challenges around the consistency of production methods need to be resolved and further knowledge about gastrointestinal stability, mechanisms for bioactivity and evidence for benefits through clinical trials is needed [87]. Acceptable sensory properties will also be an important factor to manage as hydrolysis of proteins can lead to bitter tasting peptides [88].

Another class of hemp seed compounds with potential health benefits are the polyphenols, which are generally concentrated in the hull of the hemp seed [89]. Of particular interest are the compounds unique to hemp, notably cannabisin (A, B, C, etc.) and N-trans-caffeoyltyramine, which show potential to have antioxidant, anti-mutagenic and anti-neuroinflammatory activity [90-92]. These compounds may be recovered from hemp seed products through liquid-solid extraction processes using solvents such as methanol or ethanol, with the potential for using other technologies including ultrasound, microwave and high-pressure treatment to facilitate high extraction yields [91]. High heat and pressure extrusion technology has been shown to increase the polyphenol activity of both hulls and cake materials and could be a means for enhancing these prior to use in food or nutraceutical products [93, 94].

As previously mentioned, hulls also contain xylan (estimated to be in the order of 10% w/w) and could be a source for producing xylan oligosaccharides that have prebiotic fibre activity. This concept is similar to that of Arumugam *et al.* [95] to produce xylan oligosaccharides from peanut shells using alkaline extraction and enzymatic treatment with xylanase.

Greenfern Industries, Hemp Connect and Callaghan Innovation are currently working together on a project funded through the BPA to investigate potential uses for hemp seed hulls [96]. The project aims to reduce processing waste, develop methods for manufacturing new products such as antioxidants, protein peptides and soluble protein, and explore market channels and opportunities.

Animal nutrition

Internationally, hemp seeds and cake are utilised as animal feed [97]. This is not currently permitted in New Zealand. However, it is foreseeable that this may change in due course, given the approval for hemp in food use in 2018. Studies for the inclusion of hemp seed meal in animal feed have been carried out across a range of animals, including sheep [98], goats [99], carp [100], ruminants in vitro [101], dairy cattle [102, 103] and poultry [104-106], showing the wide potential for application.

Hemp seed products can be a valuable source of protein and essential fats without major changes to animal production traits [107]. The high arginine amino acid content (higher than soy and rapeseed alternatives) of hemp seeds is a useful attribute for feed formulation due to its role in supporting growth. However, the phytic acid content needs to be managed as this can inhibit nutrient uptake [63].

In general, animal feed uses tend to be less lucrative than other food products, supplements, nutraceuticals, and cosmetics [43, 108]. However, use in pet foods may be a means to derive higher value. An example of an Australian product for pets, Hemp Eco Edible Pellets for Pets from Hemp Shack, is provided in Figure 11. Formulating hemp-based pet foods and specialty animal or aqua feeds may be an attractive future option for New Zealand businesses and a productive way to utilise press cake.

Figure 11. Hemp Eco Edible Pellets for Pets (Hemp Shack, Australia)

Other uses

An interesting use for hemp seed hulls was identified in two patents that cover processes for forming a cosmetic base by degumming the hulls to purify the fibre content and milling to a fine particle size [109, 110]. The patents describe benefits of low toxicity and unique electrical charge properties.

Further, multiple Chinese patents have been filed covering the inclusion of hemp hulls (and hemp seeds and bran in some cases) in the preparation of growth media for the cultivation of edible fungi including CN105036895A [111] and CN104956915B [112]. This type of application may be worth investigating in a collaboration between New Zealand-based hemp seed and mushroom producers.

Other potential uses for both hemp meal and hulls exist in producing biodiesel and bioethanol through enzymatic treatment and anaerobic fermentation of the oil and fibre components [113, 114]. Other biorefinery applications might include producing materials such as bioplastics and packaging from the hull xylan and cellulose content.

A process of making a traditional Korean hanji paper product using hemp hulls is described in patent KR1016270B1 [115] and suggests that the hull may have specialised material applications. Evidence of activated carbon products made from hulls was not identified during this review and may be an application for further evaluation similar to that being researched for peanuts [116, 117].

Required innovation and paths to market

The progress of New Zealand hemp companies' towards establishing a thriving hemp seed industry is readily seen in the wide range of hemp-based products on the local market and the growing export opportunity for hemp hearts and oil.

Further development of profitable products from hemp cake and hulls will be invaluable for complementing the growth of hearts and oil production. Careful selection of end product applications that provide an advantage over the global competition will be critical from a marketing perspective. Moreover, research into and verification of the health benefits of hemp seed products will be important for supporting the differentiation and value of New Zealand-made hemp products.

Many of the novel processing methods described in the previous sections require further research and development and clarity around freedom-to-operate to translate lab-based concepts into commercial reality. These types of processing innovations, along with knowledge of specialised formulated applications, could be an avenue for New Zealand-owned intellectual property.

In the meantime, many production methods from industries related to hemp seed provide a starting point for manufacturing. Coupled with the wealth of processing and distribution experience and infrastructure within New Zealand, particularly for food products, there is plenty of capability that can be leveraged towards hemp seed. The Ministry for Primary Industries has backed Hemp Connect through the Sustainable Food and Fibre Futures (SFFF) fund to help establish a hemp seed processing plant [118].

From a regulatory perspective, a review of legislation to allow hemp seed products in New Zealand for use for animal nutrition would be a positive step for extending hemp seed product uses and could unlock high-value animal feed and pet food applications.

Hemp cultivar development targeting improved seed sensory characteristics, lower shattering rates, higher yield, lower anti-nutrients, and higher phytonutrients will benefit hemp seed products [119]. Currently, hemp cultivar development is dominated by international organisations. New Zealand-focused variety development may provide a means to create nutritional benefits unique to New Zealand-made hemp seed products for both humans and animals.

The use of hemp cake and hulls for value-added products presents an exciting pathway for enhancing the sustainability of the hemp seed industry and is a strong motivator for continued development in this field.

Summary

- The primary by-product streams from the processing of hemp seed are press cake (at approximately 300–350 tonnes per year) and hulls (at approximately 300 tonnes per year).
- Conventional uses of hemp cake include the manufacturing of flours which can be sold directly to consumers or used as an ingredient in food formulations to provide nutritional benefits.
- Development of commercially viable processes for hemp protein concentrates and isolates from hemp cake is a potential area for innovation.
- Additionally, improving hemp ingredient functionality (e.g. solubility) and verifying health benefits are important areas for research that could broaden market potential.
- Cosmetic, nutraceutical, fibre ingredient and fungi growth media are examples of potential applications identified for hemp hulls.
- Legislative changes to allow the use of low THC hemp seed by-products for animal nutrition would unlock animal feed and pet food markets.

BY-PRODUCT: FIBRE AND HURD

Overview

Fibre and hurd make up the hemp stalk and are produced in all situations where hemp is grown regardless of the final product. This section looks at fibre and hurd as a by-product, in instances when they are not the primary reason for growing hemp. It also looks at the by-product produced by fibre and hurd processing when they are the primary product.

Volume

The total plantings of industrial hemp by region from 2015-2021 are shown in Table 5. While there was a downturn in 2021, the reason is not known. This is expected to increase again in 2022, with one business planting around 1000 Ha.

As New Zealand had no fibre decortication facilities for most of this time, it is assumed that most of this hemp was grown for seed. The resulting hemp-seed straw was a by-product and was either burnt, composted, or used as garden mulch.

New Zealand's medicinal cannabis industry is in its infancy, and it is difficult to judge volumes. It is expected, though, that volume of indoor grown hemp will be relatively small and that tight restrictions on its use are likely to continue.

Medicinal cannabis grown outdoors is also a new sector for the industry. Currently, the largest grower, Puro, grew 10 ha in the 2020-21 season. Baldini *et al.* [120] reported inflorescence yields for eight varieties over two years, averaging 1.74 ton/Ha with the highest yield of close to 4 ton/Ha and an average stem biomass of 6.1 ton/Ha. This suggests a potentially significant stem yield could be generated from outdoor floral production.

Table 5. Area of hemp planting s in NZ by region from 2015 to 2021

Area Grown in NZ - Hectares	2015	2016	2017	2018	2019	2020	2021
Auckland	11.0	11.2	14.2	0.0	-	-	-
Bay of Plenty	-	-	19.4	0.6	12.5	0.0	0.1
Canterbury	7.2	0.2	-	130.0	168.4	813.9	446.6
Capital and Coast	-	-	-	5.0	12.0	-	-
Counties Manukau	-	-	0.2	-	0.5	0.4	-
Hawkes Bay	-	-	-	0.0	60.2	9.0	89.0
Lakes	-	-	-	-	10.0	0.0	0.6
MidCentral	-	-	-	11.0	202.8	40.4	14.9
Nelson - Marlborough	0.0	1.4	1.0	2.4	9.4	53.8	61.0
Northland	-	-	1.0	0.5	2.1	0.6	0.4
Palmerston North - Mid central	-	-	-	-	-	-	-
Rotorua - Lakes	-	-	-	-	-	-	-
South Canterbury	-	10.6	12.6	12.0	112.7	197.7	143.0
Southern	1.0	-	32.0	3.3	19.0	72.0	75.8
Tairawhiti	1.7	2.5	0.1	10.3	26.2	0.2	7.2
Taranaki	-	-	3.7	0.5	0.5	1.1	8.3
Waikato	0.4	-	-	38.0	1.0	58.6	8.0
Wairarapa	50.2	12.1	17.9	30.0	64.3	31.5	-
Waitemata	0.0	4.1	4.0	0.0	0.5	-	0.0
West Coast	-	-	-	2.0	4.3	4.7	6.0
Whanganui	-	-	-	5.2	40.0	51.0	-
Total Area Grown	71.6	42.1	106.2	250.8	746.4	1,334.9	860.7

Composition

The term hemp fibre is predominantly used to describe the outer bast fibres of the stalk. Bast fibres are 10 to 100 times longer than the fibres that can be obtained from hemp hurd, which predominantly are less than 2 mm long but can be up to 8 mm. While the cell walls of bast fibres are thicker than that of wood fibres, hurd fibres are chemically close to wood fibres [121].

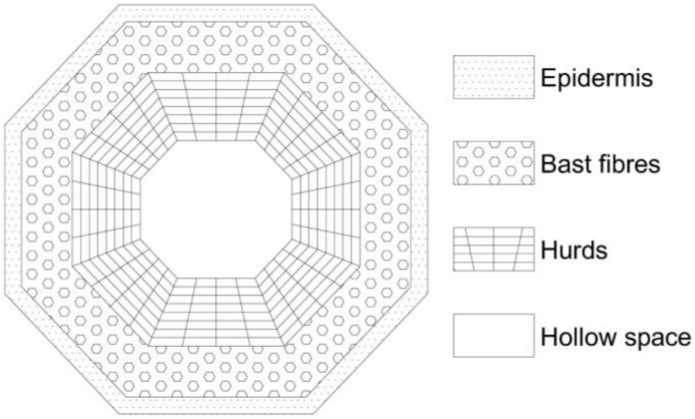


Figure 12. Schematic cross-section of a hemp stem [121]

New Zealand hemp is not grown for hurd production, but hurd is a by-product of hemp fibre processing/extraction or, in some cases, seed processing. It is sometimes also referred to as "wood hemp core" [122] or "shives". Hurd makes up about 60 - 80 % of the hemp stem and contains about 45 % cellulose, 25 % hemicellulose and 21 % lignin [121, 123].

Restrictions

Growing hemp in New Zealand requires a license [124]. However, harvested hemp stalks free from leaves, flower-heads, and roots are not considered restricted products if they are grown under the industrial hemp Regulations 2006 [125]. Therefore, all hemp stalk is considered a “hemp product”.

The use of hemp straw generated as a by-product from medicinal cannabis plants is at present not possible because residues from all high THC medical cannabis production are required to be disposed of as “medical waste”. Under these restrictions, medicinal cannabis hurd cannot be used as a product or raw material in New Zealand at present.

Potential

The volume of hemp grown in New Zealand is increasing. Given all growing activities produce fibre and hurd, the potential to create commercial opportunities from hemp fibre and hurd is high.

New Zealand’s first fibre decortication facility was commissioned in 2021, to be built in the Canterbury region where most of New Zealand’s hemp growing activity already occurs. This facility will undoubtably increase the growing of hemp in the area.

Hemp hurd for use in hempcrete housing is in high demand both domestically and overseas [42].

Fibre from hemp seed production for application in material use

The bulk of hemp grown in New Zealand is currently for seed, either for production of seed oil or to produce human food products, it's logical that the hemp industry wants a better use for the fibre from the stalk as a by-product in the production of the seed.

Insights and existing research

Traditionally, hemp farmers had to decide whether they wanted to grow varieties specifically for seed or high-quality fibre. The planting density and the planting date are generally different for each [126].

When grown for fibre, the quality of fibre decreases as the plant reaches maturity. This is particularly true in female plants and it is the reason that fibre crops are harvested at male flowering rather than at seed maturity [127]. As the plant matures, a secondary fibre develops in the stalk. Secondary fibre is short and lower quality, and also hinders the extraction of the primary fibre. Van der Werf *et al.* [128] found that secondary fibre content started at 10% and increased as the plant matured to 45% of the available fibre content at seed maturity.

Westerhuis *et al.* [129] studied the rise of secondary fibre in the stem as the plant grew and concluded that plant weight is the primary driver for the height to which secondary fibre develops. As the secondary fibre develops from the base of the plant up, the proportion of quality fibre in the top half of the stalk will be higher than that in the lower half.

Carrfields in NZ is currently researching the height to which the secondary fibre rises at various stages of plant growth to optimise when to harvest for fibre. Although this is primarily for fibre production, some of this knowledge could apply to the stems of shorter seed crops.

Farmers growing exclusively for grain will likely have around 3 tonne of stalks/Ha [45]. In this scenario, the fibre by-product, once decorticated and separated from the hurd, is of lower quality because the variety is heavily branched to encourage multiple flower heads, and it is mostly female pollinated plants harvested at around 70% seed maturity for maximum seed yield.

Generally, it is accepted that this produces short fibres usable only in non-woven applications as reinforcement in bio-composites (mainly automotive), insulation materials, papers and technical uses [130]. However, there could be scope for newer decortication systems to extract more fibre from these types of stalk preserving more fibre length and separating out a larger range of components [131].

Despite the drop in fibre quality, an increasing number of plants have been bred as a dual-purpose varieties where both seed and stalk can be harvested and utilised. In Europe, it has been common to grow dual-purpose varieties since 2016 [132]. The list of approved hemp varieties in NZ [133] contains seven varieties classified as dual-purpose.

Care must be taken with these dual-purpose varieties, as almost all of these have been developed in European conditions and need to be trialled in New Zealand. A dual-purpose crop in one location might not necessarily work in another. This is due to seasonal impacts and the effect of the day length, which affects when the plant goes into the flowering stage.

One of the key investments undertaken by most jurisdictions is the funding and establishment of trials to breed local seed varieties that are best suited for local climatic conditions. David Moore *et al.*, in their report Facilitating the New Zealand Hemp Industry [42], emphasised the development of local approved varieties of seed.

As well as increased use of dual-purpose fibre seed crops, there is also increased activity in the literature about multipurpose crops with split usage such as seed/biomass or extractives (CBD)/biomass, and even triple use such as stalk/extractives/seed, which relies on plants quickly reflowering and setting seed after the harvest of flower material [120, 134].

It may be the case that the decortication of this hemp stalk is not a viable path, depending on the location of the decortication facility and its capacity with respect to the other local sources of hemp stalk with better fibre quality. In this case, an application for the whole biomass (hurd and fibre together) could be an advantage and could be whole stalk bio-composites or other biomass applications such as energy or biorefining.

Another approach may be in a different stalk harvest and storage form, such as wet preservation and storage [135]. Wet preservation is process comprising the direct harvesting of the field-fresh hemp and the subsequent anaerobic storage of the entire plant material [136]. This allows the immediate capture of the biomass with the capability to then store it for up to a year. The final end-use could be a total biomass product or a number of product streams taken from the biomass.

Required technologies and innovation

New or improved technologies that would impact the ability to utilise fibre from hemp seed production are:

- Locally developed varieties (including dual-purpose crops) with performance tailored for New Zealand conditions.
- Methods to assess fibre quality in the stalk to quickly assess variety performance.
- New harvesting systems to preserve fibre quality in the stalk and or selectively separate the higher quality fibre from the bulk material.
- New retting technologies which would improve fibre recovery rates and remove the dependence and uncertainty of the weather (for dew retting).
- New whole-of-stalk application that will allow hemp seed straw to be valorised without going through the expensive (and often unavailable) step of decortication.

Potential products and paths to market

By-product streams from the hemp fibre production are mainly dust and dirt at the decortication stage which can be up to 25% of the input material, although the industrial standard is thought to be about 10%. After decortication, fibre will often be degummed in some way, and this provides a stream of extracted lignin tannins and pectin that could be utilised to produce a resin for application in other hemp products.

Lower grade fibre resulting from seed production can be utilised in nonwoven fabrics for geotextiles and reinforcing networks in bio-composites or as insulation. Un-decorticated hemp straw (whole stem) may be also useful in composites and or wood substitutes (Figure 13) [137].

Wet preservation leads to hemp fibres suitable for fibreboards and the reinforcement of polymer or mineral bonded composites, while removing the uncertainty of retting [136].

Figure 13. Hemp wood [137]

Hurd as primary product

The suggestion of hurd as a primary product challenges the way hurd has traditionally been considered as a by-product from the fibre industry. Some of the drivers for this change in thinking are:

- Hurd is 70% of the biomass of hemp stalks.
- The demand for hurd has increased in recent years.
- The uses for hurd have become more sophisticated, and hurd properties and specification are increasingly important to the industry.
- Dual-purpose crops for hurd and seed, or hurd and flowers may be more easily optimized than fibre and seed.

Insights and existing research

Internationally, e.g., in North America and Europe, hurd as a product is also associated with hemp bast fibre production. Moreover, the hurd market and market prices are linked to demand for hurd and for fibre crop harvesting. For example, in 2022, HempToday® reported an "explosive demand for hurd in Europe" based on the high demand for hurd in the construction sector and limited supply, mainly from France and the Netherlands, which is also tied up in long term supply agreements [138]. The retail cost of European hurd is currently around $0.50-$0.65/per pound, depending on shipment size [139].

However, hemp hurd as a raw material is mainly unregulated, even for building applications. Only France has a certification scheme for hemp hurd. Chanvre Baitement – the French hemp building industry body – has established a certification label that sets standards for hemp hurd used in building products.

The main performance criteria are the absence of other non-hemp organic matter or biomaterials, uniformity of particle or aggregate sizing, moisture content and little dust or fines. Importantly, bast fibres must only be present in a limited amount in the hurd to avoid them damaging mixing equipment or disrupting the mixing process.

Bast fibre has been considered a reinforcing agent in hemp-based building products covered by the certification label. However, it was found that the presence of bast fibres can interfere with how hurd bonds with concrete. This standard is not binding in all of Europe and is not used in the US.

Figure 14. CenC Standards for hemp hurd in building products

The marked-up retail cost of United States hurd is currently around $0.70-$0.85/per pound or $5.25 to $6.75 per cubic foot of installed material [139]. New Frontier Data estimates that the average price for hurd produced in the US between ¼" and ½" currently sells for $0.75 per pound for 1,000 pounds (i.e. one pallet), and for $0.50 per pound for 26,000 pounds (i.e. an entire truckload of 26 pallets) [140].

Trials of hurd, and research and development (R&D) have focused on optimising hurd yields or hurd fibre properties based on growing conditions or cultivar choice [141]. However, some insights can be drawn from bast fibre yield and property studies in New Zealand and overseas.

The University of Vermont conducted a growing trial in 2020 and concluded that plant population density impacts the bast-to-hurd ratio. Lower plant density (<15 plants per square foot), such as often used for hemp seed growth, favoured slower vertical growth, thicker stalks and higher hurd content [142, 143]. A comparison of different cultivars showed that cultivar choice can significantly affect the hurd yields, with *Altair*, *Anka*, *Futura*, *Hlesia* and *Ferimon12* having the highest dry matter content with 9632 lbs/ac to 7300 lbs/ac at about 70% to 73% hurd content [142]. A 2017 New Zealand study showed that increased seed row spacing leads to increased biomass yields even at comparable population seed rates for *Kompolti*, *Fasamo* and *Ferimon12* cultivars [144].

A 2016 study of multiuse cultivars (seed & bast fibre) showed that postponing harvesting from full flowering to seed maturity increased the stem yield of monoecious cultivars but decreased that of the dioecious cultivars. Among the 14 tested cultivars, not one combined the highest stem with the highest seed yield [145].

A recent study on inter-nodal properties of *Fasamo* and *Ferimon12* cultivars in New Zealand also showed that different growing conditions impact the two cultivars differently: "*Depending on the eventual purposes of the crops, a suitable planting strategy could be devised*" [141].

There are limited standards and lack of specifications from end users for sustainably grown natural fibres from industrial hemp. There is limited scientific research on hemp hurd use as raw material, as it is sourced as a by-product from fibre or seed processing. Current research avenues predominantly focus on modifying hemp hurd as filler or extender in existing products.

Hemp hurd, like other bio-based raw materials, varies in properties depending on its source. However, there is evidence that some hurd property variations along the plants are not meaningful if the hurd is used in composite applications [146]. This is potentially beneficial as it ensures ease of hurd supply into such applications. The main commonly reported drawbacks of using hurd and hurd-fibre in biocomposites that need to be overcome are poor adhesion to the matrix, for example, in plastic composites.

Thermal degradation during processing at high temperatures, and humidity absorption in the finished products. Chemical and physical treatments and surface modifications have been reported in the literature [147].

The commonly used physical methods in the context of using hurd in biocomposites are clantering, stretching, thermos-treatment and electric discharge. Hybrid yarns, plasma and corona treatment, treatment or alkalisation have also been successfully investigated to improve composite properties. Chemical methods to alter the hurd surface properties and bond with matrix materials in composites include esterification, liquid ammonia, silane coupling, permanganates, isocyanates, and graft copolymerisation [147].

Furthermore, although integrating biocomposites with synthetic materials reduces the biodegradability of the final product, this hybridisation brought about flexibility in design, better mechanical properties, higher impact strength, better thermal isolation, the capability of sound abatement, and lower density.

Overall, considering the advantages and drawbacks, hemp is a good choice for biofuel production, oil extraction, the fabrication of interiors of automobiles, and biomedical applications, such as paper-based and polymeric microfluidic devices [147].

While many potential hemp hurd applications can leverage the inherent physical benefits of hurd as a material, another driving force in the international interest in hemp hurd is greenhouse gas emission reductions [139, 148]. Internationally, there is growing interest in using agricultural methods to reduce carbon dioxide (CO_2) emissions (carbon farming).

The Centre for Natural Material Innovation at the University of Cambridge (UK) estimates that industrial hemp absorbs between 3 to 6 tons of CO_2 per acre [139]. The Australian GoodEarth Resources PTY, Ltd. claims that one acre of industrial hemp absorbs nearly 40,000 pounds of CO_2 during its growth cycle.

The non-monetary value potential of hemp hurd is the permanent capture of CO_2 in long-life products (e.g., hurd-based concrete and cement). However, any such claims would need to be confirmed by comprehensive life-cycle assessments [139].

Required technologies and innovation

Due to cultivar selection, seeding and growing conditions, current hemp multiuse strategies do not focus on hurd (fibre) property or yield optimisation. If hurd is moving from a by-product to a primary product, this aspect needs further consideration. Any grown-for-hurd or hurd-first strategy will require hurd-specific agronomy. For example, understanding how growing and harvesting conditions, including cultivars and locations, can maximise hurd yield and, more importantly, key properties such as processability and fibre length.

Economically, the widespread use of hemp hurd as biobased raw material is hindered by logistics and supply challenges. According to Steven Allin, director of the International Hemp Building Association (Ireland), "*The main problem […] is the supply. There is not enough hemp grown. The hurds are very lightweight and bulky, so transporting them long distances does not make sense*" [149]. A decentralised or modular and scalable hemp processing system may help overcome such challenges.

Such concepts may also enable by-products from cannabis cultivation, which is often favoured in a decentralised product system [150].

Technology options for on-farm processing of hemp (or cannabis) already exist commercially, including CBD oil extraction systems that produce a fibre/hurd by-product [151] and purpose design, and modular hemp decortication systems, e.g. CannaSystems R-2 [131].

Modular, scalable hemp-to-product processing options could further aid in establishing hemp products on the NZ market by overcoming supply and market-size challenges. This system is said to process up to 50 acres of hemp per day (oil extraction) [151]. The modular decortication plant is priced at about US $325,000 [131].

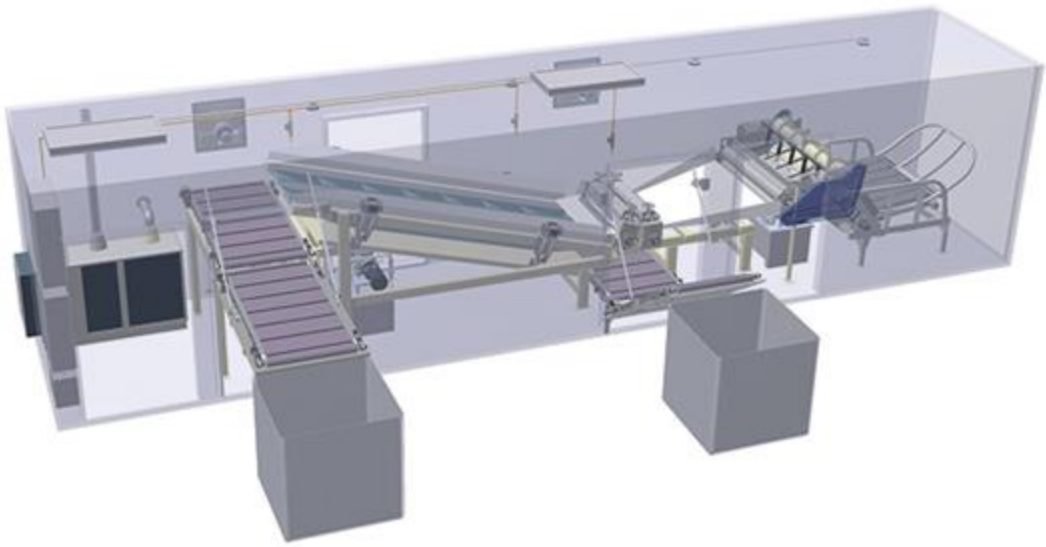


Figure 15. The R-2 system is built into a 40-foot "high cube" shipping container [131].

In the established international cannabis and hemp industry, the control of cultivar, growing, harvesting and retting processes is well understood to control product quality. Leading international industrial hemp product producers have already integrated vertically with farmers to control these processes [139].

One example is Hanffaser, a German insulation manufacturer that has partnered with farmers. To control yield and product quality, Hanffaser tells farmers what cultivar to plant and provides seed, harvesting equipment and operator training [139].

In emerging and fast-growing markets, such as the US, new fibre processors have become operational quickly, leading to the fast growth of the hemp hurd market. However, these markets also identified a need for a robust understanding of the material grades, properties, and specifications. This understanding and development of standards remains critical to adopting hurd as a renewable, alternative biobased raw material in product manufacturing [140].

Potential products and paths to market

Hurd is often mostly still used in animal bedding applications. However, technology, product and market advances have led to hurd and hurd fibre being used as value-add landscaping materials in composites, fibre products, carbon fibre production, absorbent and construction materials, and biofuel production [119, 148, 152, 153]. These potential products from New Zealand hemp hurd can take guidance from international markets.

Animal bedding

The processing of hemp hurd (or "shives") into animal bedding, including sieving and dust reduction, is well established internationally and can be accessed in New Zealand [139]. Internationally, the fact that hemp is grown without pesticides combined with low dust and high absorbency is used as a distinctive marketing advantage over other materials, such as wood shavings [154].

As a natural, plant-based product, hemp hurd can also be used to improve composting operations. Additional inoculation with microbes can benefit composting by improving microbial activity and aeration [155, 156].

Construction materials

Hemp hurd insulation can be marketed as a sustainable alternative for other building insulation while achieving similar R-values per every centimetre of thickness. These products are generally targeted for wall cavity and roof/ceiling insulation, and commercial products in overseas markets achieve required fire ratings (D-s1, d0) by adding soda for fire protection [157-160]. Price remains the main obstacle to product growth. Currently, hemp hurd fibre insulation materials are more expensive than traditional products. Hemp's further market penetration as low-carbon material is expected to reduce product prices [161, 162].

Figure 16. Kobe Hemp Flex wall insulation panels [158]

With or without surface modification, hemp hurd can be used as a filler for plastics and concrete [163]. While the production of hemp plastic composites would be a new, niche operation in NZ, hemp-filled concrete (hempcrete) is more established. Cast into blocks or panels, hempcrete finds its way into walls, floors, ceilings, and roofs internationally and is produced in New Zealand. While various forms of hempcrete have existed for centuries, its standards have not. Developing these standards is currently assessed by ASTM International's subcommittee on industrial hemp (D37.07) [164, 165].

Like wood fibre or wood particles, other agricultural fibres can be processed into rigid boards for building and furniture applications [148, 166]. Hemp fibre (hurd) boards are currently sold by several retailers in North America and Europe [142, 163, 167]. In July 2021, the hemp hurd based CannaBoard was priced between US $45-60 per board, compared to US $33-44 for similar wood fibre (MDF) products in similar markets [168].

Figure 17.Particle boards from hemp as wood alternative in, for example, furniture production [138]

Pulp and paper

In the paper-product sector, hemp is not competitive with wood and other natural fibre, e.g. kenaf, to produce conventional paper products [169]. However, research showed that hemp-fibre based paper could have significant advantages over wood fibre. Examples of these include fibre recyclability, strength, fineness and feedstock yield [167, 170]. Hemp hurd pulping processes and hemp paper products are not well established at the scale required to break into the pulp and paper market. Globally, market examples of specialty hemp paper still do exist. For example, in technical filters, banknotes, medical and cigarette papers, and nanofibers for coatings [152, 167, 170].

Multiple international studies expect these markets, and the markets for specialty fibre products such as filters, to grow in the future [169, 171, 172]. Given New Zealand's existing pulp and paper background, the use of hemp hurd in specialty paper may present a feasible opportunity in the future.

The market price for a roll of hemp (hurd) toilet paper is currently US$0.1 – US$0.5 [173].

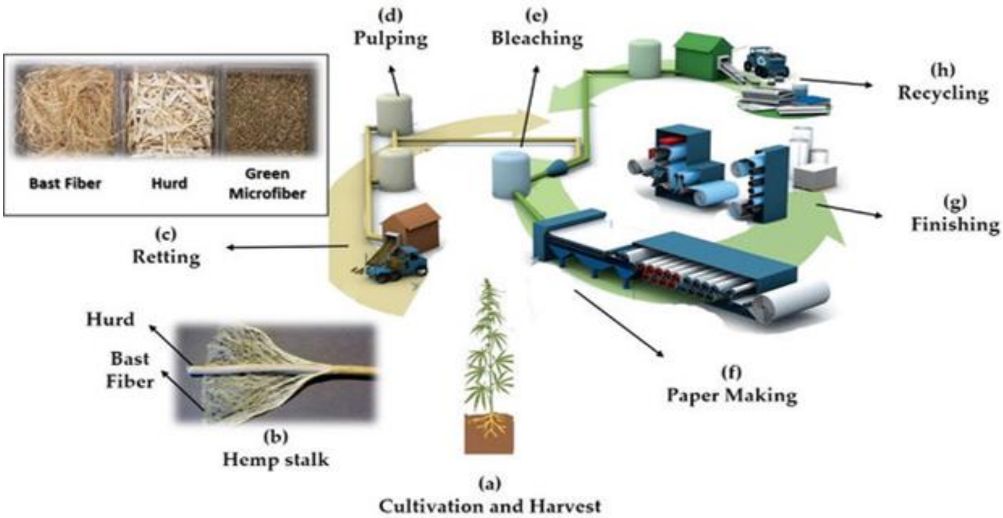


Figure 18.Boutique hemp paper production [163]

Biochemicals & Fuel

Hemp hurd, similar to leaves and roots, can be used as biomass feedstock to produce biochemical (bio-oils) intermediates. Established thermal and thermocatalytic deconstruction processes can be used to produce value-added chemicals from hurd [153].

Salami *et al.* used slow pyrolysis to produce biochemicals from hemp leaves, hurds and roots. Remarkably, 1-hydroxybutan-2-one (HO) could only be found in the pyrolysis products of hurds. If sold into the global market at a market price of EUR 20 - 100 per gram, each tonne of hemp hurd would have a potential value of EUR 1300 - 6500 as raw material (based on 95% HO purity and 50% production efficiency) [153].

Vertical integration to ensure product quality and supply may be a feasible route for NZ hurd products. Following international examples, hemp producers can use every part of the hemp plant with its product portfolio ranging from, for example, nutraceutical powders and oil to cannabidiol products to hemp hurd for animal bedding and construction materials [139].

Summary

- Significant amounts of hempseed straw are produced as a by-product of hemp seed production. When decorticated, this fibre can be used in composite materials. Decorticated, hempseed straw can also be processed into whole stalk composites.
- Wet preservation of green hemp straw allows stockpiling of raw material for later conversion into fibre boards or polymer composites while avoiding the uncertainties of retting.
- As a by-product from fibre or seed production, hemp hurd has been investigated for a raft of different applications and is already used in commercial products, some of which are already, or could also be, produced in New Zealand.
- While growing hemp hurd primarily for hurd ("hurd-first") is conceptually as feasible as currently used fibre-first concepts, further insights in how to optimise hurd properties for specific applications may be required.
- The fibre industry produces between 10 to 20% waste in the form of dust and fine particles from the decortication process and a stream of lignin rich material from the fibre degumming process.

BY-PRODUCT: ROOTS

Overview

Volume

Cannabis roots have not been traditionally harvested commercially. Subsequently, there is a considerable lack of information on the volume and characteristics of the root system.

A study published in 2008 [174] analysed the root system of a type III chemovar (var. *Futura75*) cultivated in Italy under different conditions in two subsequent growing seasons. The study found the total root dry matter to be 3.21 and 2.41 tons per Ha after approximately 16 weeks from sowing in the two years of trial, with 50% of this biomass concentrated in the first 20 cm of soil. Interestingly, the root dry biomass accounted for 15% of total dry biomass (root plus aerial) in both years.

A more recent study [175], comparing aeroponic cultivation with the more traditional soil cultivation, has found that the root dry biomass of a type III chemovar (var. Kompolti) after eight weeks of culture represents 29% of the total dry biomass of the plant when grown in soil, and 11% when grown in an aeroponic system.

Based on industrial hemp production in 2019-20 and percentage breakdown for each plant section (Figure 19) there could be around 900-1050 tonnes of available dry root biomass per annum.

Figure 19. Root structure of a C. sativa plant. Photo by Zoom Gardens

Composition

The use of roots from the *Cannabis sativa* plant to treat a myriad of ailments, including inflammation, joint pain, fever and skin burns [176], has been documented throughout history from as early as 2700 BC China [177]. Roots contain no cannabinoids or terpenes, but they contain other phytochemicals that provide potential industrial and therapeutic applications.

Several studies have focused on the chemical characterisation of cannabis roots since the early 1970s, when triterpenoids and sterols were found in the roots of mature *C. sativa* plants [178, 179]. The main components of interest are phytosterols (β-sitosterol, campesterol, and stigmasterol) and triterpenoids (friedelin and epifriedelanol).

Phytosterols, naturally occurring compounds found in plant cell membranes, are similar to cholesterol, both in structure and function, and compete with the latter for absorption in the digested system when ingested. Therefore, they have been associated with reducing plasma cholesterol levels and a lower risk of cardiovascular disease in humans [180].

Friedelin is one of the two main triterpenoids in cannabis roots, and it possesses anti-inflammatory, antioxidant, estrogenic, anti-cancer, and liver protectant properties [176]. Epifriedelanol is closely related to friedelin and is believed to inhibit cellular senescence in human cells, making it a candidate to modulate diseases associated with tissue aging [181].

Other minor compounds of interest include alkaloids (cannabisativine and anhydrocannabisativine), although there is currently no pharmacological information available on these [15], and lignans (phenolic amides and lignanamides), which are believed to protect the plant against pathogen attacks [182].

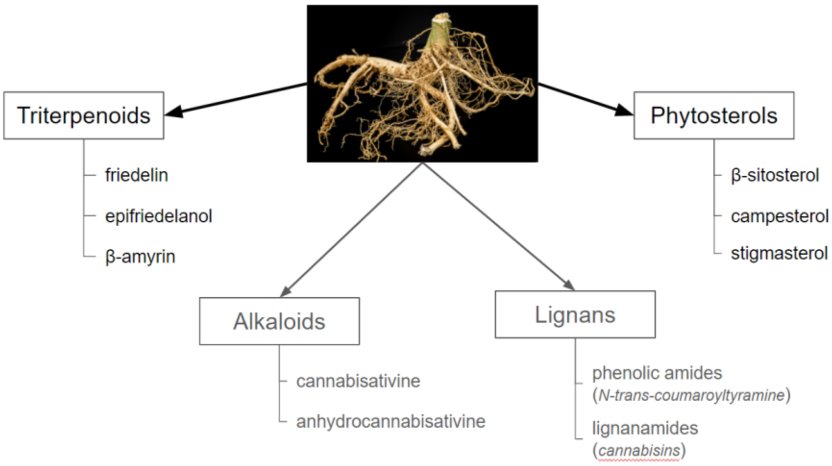


Figure 20. Bioactives found in C. sativa roots. Photo by GreenLab.

Several recent studies have reported the amount of these compounds in *C. sativa* roots of different chemovars (I, II and III) [175, 183, 184]. Roots from an undisclosed THC dominant strain (chemovar I) were found to contain approximately half the amount of total triterpenoids (friedelin, epifriedelanol, and β-amyrin) than roots from a CBD dominant strain (chemovar III): 1.3 vs 2.4 mg/g [183]. Friedelin was the main triterpenoid, with twice the amount of epifriedelanol, while β-amyrin is a minor component.

A separate study using Kompolti roots (chemovar III) found 2.0 mg friedelin and 0.9 mg epifriedelanol per g of dry roots (ie total triterpenoid content of 2.9 mg/g) [175]. A recent study analysed the roots of three different type III chemovars and found friedelin contents ranging from 0.1 to 0.7 mg/g, with the lowest values corresponding to samples that had been dried at 45°C and stored over several weeks directly after harvest [184].

As for total sterols, total contents of around 0.7 – 0.9 mg/g have been reported, without significant difference between chemovar types [175, 183]. In all cases, β-sitosterol was the predominant compound, with concentrations ranging between 0.4 and 0.6 mg/g.

Cannabis roots have a tap root as well as branched roots. The tap root has been found to represent around 42% of the total root dry matter [174], but it is unknown if there are compositional differences between this and the branched roots.

The composition of the roots will vary with other factors, such as seasonality, age, cultivation system and indoor vs outdoor growth. For instance, a recent study has shown that the relative proportion of phytochemicals in cannabis root was significantly affected by the cultivation system [175]. It found that aeroponic cultures resulted in a significant modification in the yield of plant biomasses and the net and relative abundance of bioactive root compounds, as compared to conventional soil cultivation. However, further research is required to understand the full effect of these variables in the composition of the root system.

Restrictions

In New Zealand, industrial hemp is regulated by the Misuse of Drugs (Industrial Hemp) Regulations 2006. There are permissions within the regulations defining the activities that are not required to be licensed, such as possession, use and trade in hemp products, hulled hemp seeds, and stalks of industrial hemp (as long as those stalks are without leaves or fruit).

However, these permissions do not apply to hemp root as the root is a discrete part of an industrial hemp plant (i.e. the root does not form part of the stalk). As the root has not been processed into a product, it is not considered a hemp product. Therefore, an industrial hemp licence is required to procure, supply, process, or possess hemp root.

Hemp root could be processed into a hemp product by the holder of an industrial hemp licence that authorises processing. However, hemp products must comply with the regulations and any other restrictions imposed by law, including, for example, the Medicines Act 1981, Misuse of Drugs Act 1975, Food Act 2014 and Agricultural Compounds and Veterinary Medicines Act 1997. Processed hemp root that contains medicines and/or controlled drugs (such as CBD or THC) would not comply with the Medicines Acts requirements and/or the Misuse of Drugs Act.

Available insights and existing research

The potential antioxidant activity of cannabis roots and/or its bioactives has been reported in several scientific papers, although results are still scarce. Ryz *et al*. [176] reviewed the antioxidant and anticancer activity of friedelin and epifriedanol extracted from other vegetable matrices as previously reported in the literature and found mixed and inconclusive results.

Kornpointner *et al*. [184] determined the antioxidant activity of ethanolic hemp root extracts by *in vitro* ABTS and FRAP assays and cellular antioxidant activity assay using *S. cerevisiae* as a model system for studying aspects of oxidative stress in eukaryotic cells. They observed moderate *in vitro* antioxidant activity, whereas the cellular antioxidant activities were more promising. However, these strongly depended on chemovar and external factors such as harvest time. A direct relationship between the antioxidant activity and individual compounds was not established. The authors also did not observe a correlation between the antioxidant potential and the targeted triterpenoids, so the antioxidant activity was attributed to other secondary metabolites, e.g., phytosterols.

In terms of antimicrobial activity, Elhendawy *et al*. [177] isolated ten different compounds from *C. sativa* roots and studied their antifungal and antibacterial activities. They found campesterol (a phytosterol) to be active against a pathogenic fungus (*C. neoformans*) with an IC_{50} value of 13.7 µg/mL, while N-*p-trans*-coumaroyltyramine (a phenolic amide) was active against *E. coli* with an IC_{50} value of 0.8 µg/mL.

Required technologies and innovation

The technological hurdles to commercially utilise the roots would mainly sit around harvesting and cleaning the roots. Further processing (drying, grinding and/or extraction) is relatively straightforward, and the required technology is likely to overlap with the processing of other parts of the plant (i.e. leaves and flowers).

Little is known about harvesting methods for cannabis roots; however, this is expected to be similar to other commercially harvested roots such as ginger, turmeric or ginseng. In these roots, harvesting is done manually using a sharp spade, shovel or digging fork, and washing is carried out by soaking in water and gently removing the dirt. In a commercial operation, harvesting is done with dedicated harvesting machinery.

Potential products and paths to market

Commercial hemp root products are usually in the form of salves or balms (Figure 21), to be applied directly onto the skin. This approach targets a wide array of ailments such as migraines, bruising, sore muscles, inflammation, joint pain, insect bites, skin conditions (psoriasis, eczema) and skin regeneration (i.e. burns, tattoo care).

It is possible to purchase dried, clean hemp roots online, with prices ranging from around $180 (when purchased in small quantities) to $100 (when purchased in bulk) per kg, for both European grown‡‡ and American grown, certified organic§§ hemp. Dispensaries in the US and Canada stock root remedies, but there are also multiple online tutorials on using cannabis roots for the recreational grower, with products such as teas, butter, and balms often being recommended.

However, certain alkaloids present in the root, such as pyrrolidine and piperidine, can be toxic when consumed in excess, and therefore long-term use of root products is generally discouraged. Another important safety consideration when using cannabis roots is the possible presence of heavy metals such as cadmium, iron and chromium if the roots have been used for phytoremediation [176].

There are a few online retailers of hemp root balms in NZ. Balms usually contain either powdered hemp root or a hemp root extract combined with an oil base (coconut, olive, hemp seed or sunflower oils), beeswax and essential oils. In some cases, they also contain terpenes or other herbal components (kawakawa, lemon grass, calendula). The price of existing root balm products in NZ products ranges from $25 to $45 for a 60 mL pot. However, details on the exact composition of the products are scarce, and it is hard for consumers to assess their quality and efficacy.

Figure 21. Commercial C. sativa root balms available online from overseas retailers

Marketing of these products in NZ is still a regulatory grey area. New Zealand's Ministry of Health allows the use of hemp seed oil in cosmetic products; however, there is no specific regulation around the use of roots. These balms would be considered cosmetics unless they claim any curative effects for a medical condition, in which case they would need to be registered as medicines through Medsafe.

Cosmetic products in NZ are regulated under the Cosmetic Products Group Standard under the EPA. The standard is aligned to the EU Cosmetic regulations which specifies those banned or restricted ingredients but does not state approved ingredients. Hemp is not in the current list of ingredients in terms of any restrictions.

In the US, topical products like balms can similarly be considered cosmetic or drug products based on the product's intended use (as per the label claims). Cosmetics are regulated by the FDA, with regulations covering

‡‡ https://navarahemp.eu/product/dried-hemp-roots-dry-cannabis-root-hanfwurzeln-hanfwurzel-radice-di-canapa-racine-de-chanvre/
§§ https://oshalafarm.com/shop/hemp-root/

everything from quality to labelling. Anyone meeting the requirements can manufacture a product, but they need to be able to keep the product from being "adulterated" by foreign hazards (like microbes). The manufacturer is required to ensure safety, and some ingredients are banned or require pre-approval.

It is possible that if a wider use of hemp roots was eventually enabled, cannabis roots might follow a similar path to market as ginseng roots have. Similarly to cannabis, ginseng roots have been used in traditional medicine for centuries to help with energy levels and cognitive function, as well as for their antioxidant and anti-inflammatory effects. In fact, Charles Linnaeus named the genus Panax (Πάναξ), which derives from the Greek meaning “total healing” (*panacea*) [185]. Nowadays, ginseng is commercially available in 35 countries. Asia (particularly China and Korea) are the main markets, where it is widely used in food, beverages, and as a dietary supplement. Ginsenosides or panaxosides are the main phytochemical constituents of ginseng, and have been proven to possess antitumor, anti-inflammatory, antioxidation, and inhibition of cell apoptosis activity [186].

Summary

- Roots are known to represent around 15% of the dry mass of the cannabis plant, which equates to 900-1050 tonnes of dry root biomass per year in NZ.
- Roots have been used in traditional medicine for thousands of years due to its anti-inflammatory and antioxidant effects. The main phytochemicals present in roots are phytosterols and triterpenoid, plus minor amounts of alkaloids and lignans.
- An industrial hemp licence is required to procure, supply, process or possess hemp root. Such licence would allow the holder to process hemp root into a hemp product, as long as the root does not contain medicines and/or controlled drugs (such as CBD or THC).
- The most common commercial use of hemp roots is to add them (either ground up or as an extract) into salves or balms to be applied on the skin, but they can also be consumed in the form of teas or butters.

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