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Cultivation of low tetrahydrocannabinol (THC) *Cannabis sativa* L. cultivation in Victoria, Australia: Do we know enough?

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Abstract

Late 2017, the ban on the cultivation and consumption of low tetrahydrocannabinol (THC) *Cannabis sativa* L. in Victoria, was lifted by the Federal Government of Australia. Its legalization presents the opportunity for Victoria to become a leading producer and distributer of these economically valuable hemp products. However, as a novel crop to Victoria, there is little information available for obtaining economically viable yields. Therefore, the objectives of this review were to firstly, develop an understanding of the environmental requirements shared by *C. sativa* cultivars, and what conditions promote fibre and grain yields. Secondly, it seeks to identify what farming practices have been conducted throughout Europe, Canada and China, and to explore whether these practices could be adapted to Victoria. Thirdly, the review will assist in making recommendations regarding which cultivars would be 'potential' candidates for commencing trials under Victorian climates so to find out the varieties that can provide high yields for fibre, grain and dual-purpose production. This review notes that Victoria shares a similar climate to central Europe, and has an ideal climate for the development of a successful hemp industry, as it has suitable lengths of daylight throughout spring and summer months and meets the precipitation requirements. This review has thus strongly suggested that the properties and attributes of European varieties of *C. sativa* should be further researched for site-specific cultivation in Victoria for fibre, grain and dual-purpose production in order to maximise harvest yields.

Keywords: Cannabis sativa, Crop, Hemp, fibre, seed, food source.

Introduction

On November 11 2017, the Federal Government of Australia legalized the cultivation and production of low tetrahydrocannabinol (THC) *Cannabis sativa L*. in Victoria (Agriculture Victoria, 2017). *Cannabis sativa* is a dioecious, summer annual belonging to the Cannabaceae family. This crop is native to central Asia, but there are now a wide range of different varieties found throughout the world, meaning that a vast number of environments are now suitable for its cultivation. It is the source of a diverse range of products and uses including fibre, grain, essential oils, biofuel, and phytoremediation services (Zatta et al., 2012), and this versatility makes *C. sativa* a valuable resource. Therefore, its legalization presents a great opportunity for Victorian agricultural and manufacturing industries to become leading producers and distributers of these economically valuable hemp products.

Cannabis sativa is considered to be a beneficial rotational crop as it improves the soil nutrient levels for subsequent winter crops, making it an ideal rotational plant (Amaducci et al., 2015). Mature plants have been identified to have a high resistance to pests and its broad leaves and fast growth rate repress weed invasions, thus requiring little or no herbicide or pesticide treatments (Nisson et al., 2010; Zatta et al., 2012; Mukhtar et al., 2013). It has high water and nitrogen use efficiency, requiring little irrigated water and lower quantities of fertilizers for production compared to other mainstream grain and fibre crops (Zatta et al., 2012; Tang et al., 2017). However, despite this crop being low maintenance, its fibre and grain yields are highly dependent on environmental cues, and as a consequence, the initial task of finding the optimal cultivar for a particular environment can take a considerable amount of time and effort. Nevertheless, this step is critical for obtaining economically viable crop yields and for maximising agricultural investments (Hall et al., 2012; Hall et al., 2014a).

Because of this sensitivity to its growing milieu, considerable research is required for identifying and developing cultivars that are suitable for dual-purpose production in order to meet the economic demands of the *C. sativa* industry (Bertoli et al., 2010; Tang et al., 2017), and currently, such work is being widely undertaken throughout Europe (Multihemp, 2017). Similar work in the Mediterranean has found that suitable dual-purpose *C. sativa* varieties differed between locations, highlighting that site-specific research is essential for obtaining optimal grain and fibre biomass (Tang et al., 2016; Campiglia et al., 2017). Of concern here is that cultivation of *C. sativa* is a relatively new idea, and research to date has shown there is generally a trade-off with varieties producing high yields of either fibre or grain but not both, or moderate yields of both fibre and grain (Tang et al., 2016; Campiglia et al., 2017). Therefore, in order for Victoria to establish a competitive *C. sativa* industry, it is imperative that extensive research is conducted to identify suitable cultivars for maximum grain, fibre and dual-purpose production. In this respect, this review aims to firstly, develop an understanding of the environmental requirements shared by *C. sativa* cultivars, and what conditions promote fibre and grain yields. Secondly, it seeks to identify what farming practices have been conducted throughout Europe, Canada and China, and to explore whether these practices could be adapted to Victorian climatic conditions. Thirdly, the review will assist in making recommendations regarding which cultivars would be 'potential' candidates for commencing trials under Victorian climates so to find cultivars that can provide high yields for fibre, grain and dual-purpose production.

Biology

Lifecycle

Cannabis sativa is a short-lived, summer annual, with germination, growth, reproduction and senesce all occurring within about 70 to 120 days (Cosentino et al., 2012; Agrifutures, 2017). Its growth and sexual maturity is tightly synchronised with environmental cues, particularly temperature and photoperiod, making it critical to develop a good understanding of this species' ecology and lifecycle prior to its cultivation.

Germination

Germination can occur from mid-Spring to Autumn as a response to changes in temperature and photoperiod and while this plant can germinate in some disturbed areas, such as roadsides, germination is highest in well-drained, fertile soils (Rana and Chaoudhary, 2010; Agriculture Victoria, 2017). High competition for soil nutrients and light inhibits *C. sativa* germination, suggesting that this plant is also photoblastic positive (Doorenbos et al., 1971). The timing during which sowing takes place has been identified to influence the gender of the plants, with *C. sativa* crops sown earlier in the season having a higher proportion of masculine plants than those sown later in the season (Faux et al., 2013). Gender can also be influenced chemically, as increased levels of gibberellic acid enhances the number of masculine plants, while higher levels of abscisic acid, auxin and/or cytokinins promotes femininity (Hall et al., 2012). These factors can have important implications on final yields of fibre or grain, with male plants usually producing higher quality stems for fibre production and female plants producing higher volumes of grain (Amaducci et al., 2015).

Seedling and subsequent growth

The dichotomous seedlings will emerge from the soil within one week from sowing under favourable environmental conditions (Doorenbos et al., 1971). The seedlings are highly competitive as they germinate earlier than most summer annuals, grow rapidly and shade-out completion with dense, broad leaves (Zatta et al., 2012; Tang et al., 2017). During the seedling stage, *C. sativa* exhibits higher susceptiblity to pathogens, diseases and more established competition (Doorenbos et al., 1971; Rana and Chaoudhary, 2010). *C. sativa* can grow over 60cm a week under optimal conditions, and can reach a total height of over 180cm (Rana and Chaoudhary, 2010). Competition plays a critical role in determining stem height and width, as plants grown under intense inter- or intraspecific competition tend to be taller with finer stems, and those grown in a less competitive environment are shorter but with thicker, sturdier stems (Zatta et al., 2012; Hall et al., 2014; Campiglia et al., 2017). This rapid growth stage will continue until it enters the reproductive stage (Cosentino et al., 2012; Hall et al., 2013; Hall et al., 2014a).

Reproduction

Flowering is triggered when daily hours of daylight and darkness become similar in length, this being usually around 14 hours of daylight or less (Cosentino et al., 2012; Hall et al., 2013; Hall et al. 2014a). While monoecious varieties of *C. sativa* are now widely available, it is traditionally a dioecious plant, with individuals producing either female (pistilate) or male (staminate) flowers (Doorenbos et al., 1971; Rana and Chaoudhary, 2010; Cosentino et al., 2012; Hall et al., 2012). Pollination occurs via wind, and to promote cross-pollination staminate flowers open and release their pollen approximately half an hour prior to the pistilate flowers, when they then become receptive to pollination (Rana and Chaoudhary, 2010). Downwind, pollen grains can be successfully carried up to 5km away from the parent plant (Doorenbos et al., 1971; Small and Antle, 2003; Amaducci et al., 2015). This wind-assisting pollination is critical, because while insects have been observed to visit males, they do not visit females, therefore making exogenous intervention an ineffective pollination method (Doorenbos et al., 1971; Rana and Chaoudhary, 2010). It has been estimated that each female plant can propagate up to 2000 seeds (Agriculture Victoria, 2017).

Senescence

When *C. sativa* enters the reproductive stage, the composition of the stem begins to alter. The bast fibre quality becomes depleted while cellulose levels and secondary fibres increase, a situation which is unfavourable for high quality harvested material (Zatta et al., 2012). This process occurs more rapidly in male plants, which tend to produce superior bast fibre compared to female plants (Hall et al., 2012; Amaducci et al., 2015). As the female plants produce grain, they maintain a more turgid stem throughout the flowering process than is found with males (Hall et al., 2012). Male plants therefore become senescent soon after pollen release, while females live longer while the seeds mature and ripen for harvest (Hall et al., 2012). This onset of staggered senescence is clearly problematic for harvesting operations, and adds to the necessity for careful variant selection in different climate regimes.

Current growing regions

China, Canada, and Europe are the leaders in *C. sativa* production, and by understanding what varieties, farming

Table 1. Common varieties of *Cannabis sativa.*

Region	Variety	Country/ Provence	Sexual Type	Maturity Group	Reference
Australia	BundyGem	Queensland	Dioecious	Early	Hall et al., 2013; Hall et al., 2014
	Futura 77	Tasmania	Monoecious	Late	Lisson et al., 2000
	Kompolti	Tasmania	Dioecious	Late	Lisson et al., 2000
China	Yunma 1	Southern China	Dioecious	Late	Hu et al., 2012
	Yunma 2	All regions	Dioecious	Early-Intermediate	Hu et al., 2012; Amaducci et al., 2015
	Yunma 3	All regions	Dioecious	Early-Intermediate	Hu et al., 2012; Amaducci et al., 2015
	Yunma 4	All regions	Dioecious	Early-Intermediate	Hu et al., 2012; Amaducci et al., 2015
	Yunma 5	Southern China	Dioecious	Late	Hu et al., 2012; Amaducci et al., 2015
	Yunma 6	Southern China	Dioecious	Late	Hu et al., 2012; Amaducci et al., 2015
	YunMa 7	Southern China	Dioecious	Late	Hu et al., 2012; Amaducci et al., 2015
Europe	Chamaleon	Italy	Monoecious	Intermediate	Zatta et al., 2012
	C.S.	Italy	Dioecious	Late	Zatta et al., 2012
	Carmagnola	Italy	Dioecious	Late	Nisson et al., 2010; Zatta et al., 2012
	Dioica 88	Italy	Dioecious	Late	Zatta et al., 2012
	Eletta Campana	Italy	Dioecious	Late	Zatta et al., 2012
	Epsilon 68	Italy	Monoecious	Intermediate	Zatta et al., 2012
	Fedora 17	France, Italy	Monoecious	Early	Zatta et al., 2012
	Fedora 19	Italy, The Netherlands	Monoecious	Early	Amaducci et al., 2015
	Fédrina 74	Italy, The Netherlands	Monoecious	Early	Zatta et al., 2012; Amaducci et al., 2015
	Felina 34	France, Italy	Monoecious	Early	Cosentino et al., 2012; Zatta et al., 2012
	Férimon	Italy	Monoecious	Early-intermediate	Zatta et al., 2012; Tang et al., 2016; Campiglia et al., 2017
	Fibranova	Italy	Dioecious	Late	Nisson et al., 2010; Cosentino et al., 2012; Zatta et al., 2012
	Fibrimon 56	Italy	Monoecious	Early	Zatta et al., 2012
	Futura 75	France, Italy	Monoecious	Intermediate	Amaducci et al., 2008; Nisson et al., 2010; Zatta et al., 2012; Cosentino et al., 2014; Amaducci et al., 2015; Tang et al., 2016; Campiglia et al., 2017
	Kompolti Hybrid TC	Italy, The Netherlands	Dioecious	Intermediate	Zatta et al., 2012; Amaducci et al., 2015
	Kozuhara zairai	The Netherlands			Amaducci et al., 2015
	Lovrin	Italy	Dioecious	Intermediate	Zatta et al., 2012
	Santhica	Italy	Monoecious	Early-Intermediate	Faux et al., 2013; Campiglia et al., 2017
	Superfibra	Italy	Dioecious	Late	Zatta et al., 2012
	Tiborszallasi	Italy	Dioecious	Intermediate	Zatta et al., 2012
	Uso 31	Italy	Monoecious	Very Early	Faux et al., 2013; Campiglia et al., 2017
North America	Alyssa	Canada	Dioecious	N/A	Vonapartid et al., 2015; AAF, 2017
	CanMa	Canada	Dioecious	N/A	Vonapartis et al., 2015; AAF, 2017
	CFX1	Canada	Dioecious	N/A	Vonapartis et al., 2015; AAF, 2017
	CFX2	Canada	Dioecious	N/A	Vonapartis et al., 2015; AAF, 2017
	CRS1	Canada	Dioecious	N/A	Vonapartis et al., 2015; AAF, 2017
	Delores	Canada	Monoecious	N/A	Vonapartis et al. 2015; AAF 2017
	Finola	Canada	Dioecious	N/A	Vonapartis et al., 2015; AAF, 2017

Table 2. Cultivation requirements for C*annabis sativa.*

Temperature	15-27^{O}C	Cole and Zurbo, 2008; Hall et al., 2013; Agrifutures, 2017
Day length	14-16 hours daylight	Hall et al., 2014
Rainfall	600-700mm per year	Agrifutures, 2017
Soil type	Neutral to slightly alkaline (pH 7-7.5), well drained sandy loam or clay loam soils	Amaducci et al., 2015; Agrifutures, 2017; Hemp University, 2018
Irrigation (without rainfall)	3-6ML per ha	Cole and Zurbo, 2008; Agrifutures, 2017
Nitrogen	60kg per ha	Tang et al., 2017
Days required for growth	Fibre: 70-90 Grain: 105-125	Agrifutures, 2017
Plant density	120-250 per ha, over 150ha is unsuitable for fibre	Agrifutures, 2017; Campiglia et al., 2017; Tang et al., 2017
Sowing rates	50-70kg/ha	Agrifutures, 2017
Inter row spacing	0.5m	Campiglia et al., 2017
Retting time	50-70 days	Lui et al., 2015

techniques and manufacturing processes these regions have adopted could improve the developing hemp industry in Victoria (Amaducci et al., 2015; Salentijn et al*.,* 2015). *C. sativa* is currently grown in at least 28 countries around the world and there are an estimated 2000 varieties available, allowing this crop to be cultivated almost anywhere between the equator to 60^{O} latitude (Salentijn et al., 2015; Johnson, 2017). *C. sativa* has been farmed throughout China for over 3,000 years, and is an important crop for the economic security for Chinese farmers, as one hectare of the crop currently sells for $1,500 USD (Amaducci et al., 2015; Chen, 2017). In 2011, China designated 11,400ha of land to *C. sativa* cultivation, and thereby contributed almost half of the global hemp fibre production, making it the world's leading hemp fibre producer (Salentjin et al., 2015). Table 1 shows that there are currently seven widely used varieties of *C. sativa* throughout China, with certain varieties (YunMa 1, 5, 6 and 7) being tolerant to shorter day lengths and thus being able to grow well in southern China (Hu et al., 2012; Amaducci et al., 2015). All seven Chinese varieties recorded in Table 1 are dioecious, although due to China's long history with this crops cultivation, it is likely that monoecious varieties are also available.

In 2011, Canada allocated 15,720ha to the production of *C. sativa*, which was the highest dedicated area in the world at that time (Salentijn et al., 2015; Vonapartis et al., 2015). There are currently 46 cultivars approved for the 2017 growing season and Table 1 shows the seven varieties that are most widely used (AAF, 2017). Canada's climate makes fibre production somewhat less productive than that of China, however it is the world leader for hemp oil and grain, which are highly sort after health products due to their richness in good fats and easily digestible proteins (Vonapardis et al., 2015). Whilst *C. sativa* cultivation and research is permitted throughout 22 states of the USA (Johnson, 2017), the USA nevertheless imports the majority of its raw hemp materials from Canada, China and France and then manufactures a variety of hemp based products on-site. Currently, the USA hemp industry is annually worth an estimated $700 million USD (Johnson, 2017).

Europe grows *C. sativa* for both fibre and grain and is leading the research for dual purpose hemp varieties. While France, the Netherlands and Italy are the leading European hemp producers and researchers, *C. sativa* is also grown in Austria, Denmark, Finland, Germany, UK, Hungary, Poland, Slovenia, Switzerland and Spain. In 2011, these countries combined to allocate 14,344ha to hemp production (Salentijn et al., 2015). Due to the variety of different climates throughout Europe, there are at least 51 registered cultivars, each suitable for grain, fibre, or dual purpose and having slightly different environmental requirements to suit specific regions (Tang et al., 2016). Table 1 shows 22 common varieties that are used in France, Italy and the Netherlands.

The Köppen-Geiger climate classification map suggests that France, Italy and the Netherlands share similar climatic conditions to south eastern Australia, therefore it is likely that the cultivars listed for these regions in Europe (Table 1) could have the potential to grow well in Victoria (Kotteck et al., 2006; BoM, 2016). It is noted that research for cultivation of *C. sativa* has previously been conducted in Tasmania and Queensland, and as a result Tasmania is currently the leading hemp producing state in Australia (Lisson et al., 2000; Hall et al., 2013; Hall et al., 2014a). Although information regarding suitable varieties in Australia is limited, however there are three varieties of *C. sativa* that have been closely explored for cultivation in Australia; the dioecious BundyGem from Queensland (Hall et al., 2013; Hall et al., 2014a), and the monoecious Futura 77 and dioecious Kompolti from Tasmania (Lisson et al., 2000). While BundyGem was promising for oil and grain, it was deemed unsuitable for fibre production in Queensland due to the day lengths not reaching the critical requirement, which resulted in premature flowering and stunted growth (Hall et al., 2013; Hall et al., 2014a). The two varieties in Tasmania are common European varieties, Kompolti being grown in Italy and the Netherlands, and Futura being more popular in Italy and France (Lisson et al., 2000; Tang et al., 2016; Campiglia et al., 2017). Table 1 demonstrates that under a Mediterranean climate, these two cultivars are considered to reach maturity within an intermediate time frame, whilst under Tasmanian climates, they are considered to reach maturity some time later (Lisson et al., 2000; Amaducci et al., 2015). This is likely a result of Tasmania having a slightly higher latitude than Mediterranean countries, which equates to longer day lengths over summer, potentially promoting greater fibre yields (Campigilia et al., 2017).

Table 3. Common weeds, pests and diseases of *Cannabis sativa*

Type	Scientific Name	Common Name	Locations Recorded	Impact	Management	Reference
Weeds	*Orobanche ramose*	Boomrape	Europe	Displace crops reducing yield	No registered herbicides for hemp	Hall et al., 2014; Innvista, 2016; Agrifutures, 2017
	Urochlea panicoides	Liverseed grass	Australia			
	Sonchus oleraceus	Common thistle	Australia			
	Chenopdium album	Fat hen	Australia			
	Cynodon dactylon	Couch grass	Australia			
	Urtica dioica	Stinging Nettle	Australia			
Fungus	*Pythium debaryanum*	Pythium disease	Europe	Attacks seeds and seedlings	Maintain well drained soils	DAF, 2012; Innvista, 2016; Agrifutures, 2017; CHTA, 2017b;
	Sclerotina sclerotiorum	Hemp canker	Europe	Attacks roots and plant base	Maintain well drained soils	
	Botrytis cinerea	Grey mould	Canada; Europe	Weakens stems causing plants to topple over, also affects retting process	Breeding resistance, crop rotation, soil rejuvenation, well drained soil	
	Malampsora cannabina	Grey mould	Europe	Attacks hemp fibre	Usually treated with thiocarbamate (Zineb-Maneb) but no fungicides are registered for hemp	
	Sclerotium rolfsii	Southern blight disease	Australia	Rots roots, crown and lower stem of plant	Crop rotations, deep ploughing	
Invertebrates	*Ostrina nubilalis*	European corn borer	Canada; Europe	Graze on the internal stem, weakening the plant and reducing fibre quality	No registered insecticides are registered	McPartland, 1997; DAF, 2012; Innvista, 2016; Agrifutures, 2017; CHTA, 2017b;
	Grapholita delineana	Hemp borer/ Hep moth	Canada; Europe	Larvae feed on stem, leaves and flowers		
	Psylliodes attenuate, Phyllotreta pusilla Systena blanda	Hemp flea beetles	Europe; USA	Larvae graze roots		
	Heliothis armigera Heliothis viriplaca	Bud worms	Australia	Feed on vegetative and flower buds		
	Tetranychus urticae	Two sported spider mite	India	Suck sap reducing yield by up to 50%		
	Loxostege sticticalis	Beet webworm	Europe			
	Melanoplus differentialis, Melanoplus bivittatus, Melanoplus lakinus	Grasshoppers	Canada; USA	Graze seeds and seedlings		
	Phorodon cannabis	Cannabis aphid	Canada; USA	Cause wilting by sucking out fluid		
	Noctuidae	Cutworms	Australia; Canada	Graze seeds and seedlings		
	Thyanta custator	Red-shoulder stink Bug	Canada	Feed on flower buds and seeds		
	Monolepta australis	Red shouldered leaf beetles	Australia	Adults graze leaves and flowers, larvae graze roots		
	Nezara viridula	Green vegetable bug	Australia	Attack seeds		
	Austrasca alfalfae	Jassid	Australia	Feed on sap, also inject toxin results in hopper burn		
	Sminthurus viridis	Lucerne flea	Australia	Graze on leaves		
Vertebrates		Birds	Australia, Canada, Europe	Birds will strip seeds from plants. Dropping from birds can result in contaminated product. Larger mammals will graze on almost the whole plant		McPartland, 1997; Innvista, 2016; Agrifutures, 2017; CHTA, 2017b;
		Deer	Canada			

Cultivation requirements

C. sativa's growth and development is tightly synchronised to environmental cues, particularly temperature and photoperiod (Hall et al., 2012). As this crop is a summer annual, it has a preference for warm temperatures averaging between 15-27^{O}C as well as long periods of daylight (Cole and Zurbo., 2008; Hall et al., 2013; Hall et al., 2014a; Agrifutures, 2017). Temperatures above 27^{O}C can accelerate maturity, inducing flowering and stunted growth and this crop is intolerant to frosts (Cole and Zurbo, 2008; Hall et al., 2012). For economically viable fibre production, *C. sativa* needs to be in its growth stage for 70-90 days, and since daylight hours in Victoria on average exceed 14 hours per day from early November through to the start of February, Victoria could be suitable for quality fibre production (Agrifutures, 2017, timeanddate.com, 2017). The most favourable growing conditions for *C. sativa* are further outlined in Table 2.

Cannabis sativa is considered to have modest water requirements compared to other crops as a result of its taproot being able to reach water tables two metres below the soil surface (Amaducci et al, 2008; Multihemp, 2017). It requires 600-700mm of rainfall annually, which most regions within Victoria exceed and can grow well with minimal irrigation if rainfall is sufficient (Agrifutures, 2017; BoM, 2017). Without rainfall, this crop will require between 3-6ML of water per hectare (Zatta et al., 2012; Agrifutures, 2017). *C. sativa* has been identified to grow best in soils that offer good drainage, such as sandy loam or clay loam soils, as water logging can damage this crops root system (Amaducci et al., 2015; Agrifutures, 2017). It prefers soils that have a neutral to slightly alkaline pH levels, and the soil should not be tightly compacted, as this can stunt the growth of the taproot (Agrifutures, 2017).

The deep taproot improves soil quality by drawing deeper buried nutrients up to the top soil, where the majority of its root system is located (Amaducci et al., 2008; Zatta et al., 2012; Agrifutures, 2017; Tang et al., 2017). These enhanced nutrient levels provided by *C. sativa* improve the quality of the soil for the subsequent winter crops (Amaducci et al., 2015), and thus make it a desirable rotational crop. *C. sativa* also has exceptional nitrogen use efficiency compared with other crops such as linseed, maize, or cotton (Tang et al., 2017). It is recommended that nitrogen fertilizer be applied at a concentration of 60kg per hectare; however, depending on the soil quality and nutrient availability, this may need to be adjusted accordingly (Tang et al., 2017).

The seeds of *C. sativa* generally germinate within two days of planting, and within four weeks will have grown to a height of approximately 30cm (Agrifutures, 2017; CHTA, 2017a). Therefore, in Victoria the seeds should be planted in early to mid-October so that the crop is in its growth stage when the optimal temperature and daylight hours begin in mid-November (Agrifutures, 2017; timeanddate.com, 2017). Sowing rates of 50-70kg per hectare have been recommended, and suggested plant densities range between 120 to 250 plants per hectare, although some natural thinning will occur at higher densities (Campiglia et al., 2017). Plant density can vary slightly between systems depending on the need for fibre or grain production, as densities exceeding 150 plants per hectare have been identified to reduce stem diameter and reduce bast yield, thus reducing fibre quality (Agrifutures, 2017; Campiglia et al., 2017; Tang et al., 2017). It is recommended that only half a metre spacing between rows is required, and this tight spacing is effective at reducing weed competition (Campiglia et al., 2017). For fibre crops, the stems must undergo a period of retting to reduce variability in fibre quality in order to improve its economic worth and to soften the fibre for processing (Liu et al., 2015). If the climate allows, retting occurs in the field. While retting is a cheap and effective method for priming this crop for processing, it is limited to regions with climates that are suitable for maintaining the required fungi (Henriksson et al., 1997; Lui et al., 2015). Therefore, identifying which regions of Victoria these fungi thrive will help to determine the appropriate regions for cost effective fibre production.

Weed and pest management

The most effective way for reducing weeds in *C. sativa* systems is to maintain intense competition with high plant densities of approximately 200 plants m^{-2}, with inter row spacing kept close at 0.5m (Hall et al., 2014b; Campiglia et al., 2017). As a result of *C. sativa's* exceptionally fast growth rate and broad, overlapping leaves, it can generally out-shade and outcompete most other plant species, making this crop considerably weed resistant (McPartland, 1997). Additionally, this crop also produces allelochemicals that supress the growth and establishment of other plants, making it a highly competitive, low-maintenance crop and over consecutive years of *C. sativa* cultivation, the seedbanks for probematic weeds will be significantly reduced (Campiglia et al., 2017). While this exceptional competitiveness makes *C. sativa* an ideal crop, in some cases industrial hemp has escaped the cropping system and established itself in the natural environment (Reisinger et al., 2005). *Cannabis sativa ssp. spontanea* (wild hemp) is considered to be a highly threatening weed to natural and agricultural system in some regions of Europe and America, outcompeting important crops and natives for water and soil nutrients (Reisinger et al., 2005). A weed risk assessment was conducted on *C. sativa* for Victoria and it identified that this plant could pose a moderate threat to Victoria's biodiversity, particularly due to its aggressive growth, early sexual maturity, high seeds production, and human aided dispersal (Agriculture Victoria, 2017).

C*annibis sativa* produces a germination inhibiting essential oil, which has proven to be an effective botanical herbicide against common agricultural weeds including reedroot, pigweed and rye broome (Agnieska et al., 2016). This essential oil has minimal effect on crop seedlings such as rapeseed and oat which demonstrated high resistance to the oil (Agnieska et al., 2016). The essential oil was identified to be more effective on dicot weeds than monocot's, suggesting some grass weeds may remain problematic in these systems if careful weed management practices are not implemented (Agnieska et al., 2016). Furthermore, as a result of *C. sativa* having earlier germination than other summer annuals, rapid growth rate and high density, light dependent weeds are generally outcompeted (Amaducci et al., 2015; Campiglia et al., 2017), and within two to four weeks, *C. sativa* will have a groundcover of up to 90%, repressing the establishment of competing weed species (Zatta et al., 2012; CHTA, 2017a). Unlike most modern-day crops, *C. sativa* has not yet built up any herbicide resistance, and residual herbicides commonly used on many grass species inhibit *C. sativa* germination and seedling development. Herbicides therefore should be avoided in these cropping systems, as even when they are used in rotational crops, it will affect the quality and yield of the *C. sativa* product (Amaducci et al., 2015). Table 3 shows the common weeds in *C. sativa* agricultural systems. To date, there are no registered herbicides for use with this crop, thus making cultural control methods essential for obtaining economically viable yields.

Cannabis sativa also is considered to be a natural repellent to a variety of pests such as insects and molluscs (Bedini et al., 2016), nematodes, including the globally significant root-rot (Kayani et al., 2012; Mukhtar et al., 2013), fungi and other microorganisms (Novak et al., 2001; Nisson et al., 2010). Essential oils extracted from the *C. sativa* cultivar Futura were found to have highly effective antimicrobial properties against both gram (+) and gram (-) bacteria when compared to other cultivars (Nisson et al., 2010). This was suspected to be a result of this variety having double the concentration of terpinolene, which is also identified as a natural antifungal chemical (Novak et al., 2001; Nisson et al., 2010). Studies have identified hemp oil and other concentrated extracts from the crop as an excellent natural pesticide that could be a suitable substitution of the more toxic and socially unfavourable synthetic pesticides (Kayani et al., 2012; Zatta et al., 2012; Mukhtar et al., 2013: Bedini et al., 2016). Botanical-based pesticides are also beneficial as they are readily available, they biodegrade naturally within a timely manner and are a renewable resource. THC is often untraceable in industrial hemp oil and concentrations of other cannabinoids are negligible, making the essential oils safe for mammal consumption and further favouring botanical pesticides as a more ethical option (Novak et al., 2001; Kayani et al., 2012; Mukhtar et al., 2013). While this crop is tolerant to many pests and diseases, it is not immune, and Table 3 lists common pest and disease threats to *C. sativa* agricultural systems.

Conclusion

This review notes that Victoria shares a similar climate to central Europe and therefore, highlights the possibility that research into European cultivars might be useful for Victorian growing regions. Tasmania has developed a successful hemp industry using the European varieties Futura and Kompolti, which further supports the potential of success of European cultivars in south eastern Australia. Furthermore, Victoria has an ideal climate for the development a successful hemp industry, as it has suitable lengths of daylight throughout spring and summer months and meets the precipitation requirements. This review has thus strongly suggested that the properties and attributes of European varieties of *C. sativa* should be further researched for site-specific cultivation in Victoria for fibre, grain and dual-purpose production.

Conflict of Interest

The authors declare they have no conflict of interest.

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