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Occupational health and safety in cannabis production: an Australian perspective

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ABSTRACT

The legal Australian cannabis industry has been rapidly expanding due to increased awareness of the plant's therapeutic potential, as well its diverse range of applications including biofuel, textiles, building materials, food, nutritional supplement, and animal feed. The objective of this paper is to describe the current landscape of the commercial Australian cannabis industry, summarise occupational health and safety (OHS) hazards in cannabis-related working environments, and provide suggestions for safeguarding worker health and well-being in this emerging industry.

A comprehensive search of peer-reviewed and grey literature published between 1900 and 2017 was undertaken to identify case studies and original epidemiological research on OHS hazards associated with the cannabis cultivation and the manufacture of cannabis-based products. The review found that the majority of OHS studies were undertaken in the hemp textile industry during the late twentieth century, with a small number of articles published from a variety of occupational environments including forensic laboratories and recreational marijuana farms. Cannabis harvesting and initial processing is labour intensive, and presents a physical hazard Depending on the operation, workers may also be exposed to a variety of biological, chemical, and physical hazards including: organic dusts, bioaerosols, pollen/allergens, volatile organic compounds, psychoactive substances (tetrahydrocannabinol [THC])), noise, and ultraviolet radiation.

Little research has been undertaken on the exposure to inhalable organic dust and other bioaerosols during the commercial cultivation and manufacture of cannabis-based products. Furthermore, there is an absence of Australian-based research and OHS guidance materials to help professionals develop risk management strategies in this evolving industry.

It is recommended that:

- Investigation into the toxicological properties of cannabis dusts, specifically in relation to potential occupational exposures during cultivation and manufacture, should be a priority.
- The interim adoption of the respirable cotton dust exposure standard of 0.2 mg/m^3 for workplace exposure in hemp facilities until a cannabis workplace exposure standard is developed, and that exposure to medicinal cannabis containing THC are kept as low as reasonably practicable.
- An industry partnership be established for the development of an Australian health and safety guideline for the production of medicinal cannabis and hemp.
- A classification to meet the requirements of the Global Harmonization Scheme should be undertaken to ensure consistency in the use of safety and risk phrases in cannabis-related industries.

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Introduction

Exposure hazards in the commercial production of *Cannabis sativa* L. (cannabis) is an emerging global public and occupational health issue with an increase in production due to a significant shift in attitudes towards the use of cannabis for therapeutic, recreational and industrial purposes. In 2016, cannabis was reclassified from a Schedule 9 prohibited substance to a Schedule 8 controlled drug [1,2], due to increases interest from government, scientific and commercial agencies in cannabis-based preparations for symptomatic treatment of chronic and debilitating health conditions including chronic pain relief, cancer, epilepsy and multiple sclerosis [3–5]. The Australian market demand for medicinal cannabis, hereafter referred to as cannabis, is estimated to be approximately A$100 million per year [6]. Its application as an environmentally sustainable source for building materials, food production and biofuel is also being explored [7]. Recreational cannabis remains prohibited in Australia, but in other countries such as the United States, has seen the rapid expansion of the recreational

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marijuana market generating substantial tax revenue and reported reductions of violent crime [8–10]. However, the impact of the legalisation of recreational marijuana from a public health perspective is still being evaluated and the consequences may take years to become evident [9–11]:

> The illicit status of cannabis over the majority of the 20th century has limited the investigation of the health issues associated with its cultivation, product manufacture and legal use, especially in relation to plants containing more than 1% tetrahydrocannabinol (THC) content. Existing studies provide insights into potential OHS issues, but contain limited toxicological and exposure data. Respiratory symptoms and impaired lung function in hemp workers have been reported in the last fifty years [12–18], along with cannabis related allergies in forensic laboratory workers [19]. Recent American OHS guidance materials for recreational cannabis may be relevant to Australia's emerging industry [20,21]. These could be integrated with existing Australia guidelines for commodities such as cotton and wool. However, there does need to be characterisation of Australian industry hazards associated with indoor cannabis production, broadacre cropping of industrial hemp, as well as the manufacture of goods to ensure that compliance with appropriate OHS legislation.

The purpose of this review is outline occupational health and safety (OHS) issues that may have associated with cultivation and/or product manufacture Australian cannabis, and provide suggestions on the way forward for ensuring worker health and well-being in this emerging industry. The review will include a brief history of Australian cannabis production, botany and phytochemistry, regulatory policies, and the OHS hazards.

Methods

A comprehensive search was undertaken to locate published peer-reviewed and grey literatures relating to OHS in cannabis-related industries including risk assessments, case studies for occupational disease and occupational epidemiological and exposure assessments. Searches of the PubMed, Science Direct, Web of Science Google Scholar, ProQuest, and Ovid databases were undertaken using the following keywords: work health and safety, occupational health and safety, occupational hygiene, industrial hygiene, exposure assessment, respiratory disease, hypersensitivity, allergen, cannabis, marijuana, marihuana, and hemp.

Botany and phytochemistry

Medicinal cannabis, marijuana, marihuana and industrial hemp are all variants of the same monotypic plant species (*C. sativa* L.). The herbaceous annual is a highly variable, predominantly dioecious (male and female flowering plants), occasionally hermaphroditic, wind pollinated plant, which grows between 0.2 and 6.0 m in height. The growth form of male plants is typically tall and skinny, while females are squat and dense [22]. The taxonomy of the cannabis genus is subject to ongoing debate with two primary schools of thought; either a monotypic (single) or polytypic (multiple) species genus [23,24]. Cannabis and hemp crops have distinct characteristics. Unfertilised female plants are cultivated for their THC rich inflorescences [25,26], while male plants typically produce superior fibre [27,28]. Fertilised plants are required for seed production, breeding programs, hemp seed cake, and oil [29]. THC, the psychoactive component, is produced by secretory glands call trichromes, epidermal appendages on the flowers, leaves and bracts (specialised leaves) of female plants [22,28]. The female flowers themselves do not contain THC, rather it is the bracts surrounding the flowers that may be densely covered with the secretory trichomes [28]:

> The distinction between medicinal cannabis and industrial hemp is based on tetrahydrocannabinol content. Similar to cannabis botany, the legal definition of industrial hemp in Australia also varies. The Commonwealth Poisons Schedule describes industrial hemp fibre as containing less than 0.1% tetrahydrocannabinol [2]. However, in State and Territory legislation, permissible tetrahydrocannabinol content ranges from 0.005% tetrahydrocannabinols in the Northern Territory, 0.1% in Victoria; 0.35% in Western Australia; and 1.0% in all other States and the Australian Capital Territory (Table 1). Although, Western Australia has recently proposed to amend permissible THC content from 0.35% to 1.0% (M Davies personal communication 28 February, 2018). Alternatively, the ratio of tetrahydrocannabinol to cannabidiol may also be used to differentiate between drug and fibre plants. Plants with high tetrahydrocannabinol to cannabidiol ratio (>0.5) may be classified as 'drug type', while plants with a lower ratio (<0.5) are classified as hemp. [25]

The cannabis plant contains over 600 chemical compounds [26,30], including phytocannabinoids and naturally occurring terpenophenolic plant metabolites [31]. Cannabinoids may be classed as sedative-hypnotic, mixed-stimulant depressant, mild hallucinogen, or psychedelic [28]. Therapeutic medicines include preparations of THC and cannabidiol. However, the therapeutic benefits are attributed to the synergistic actions of the phytocannabinoids, rather than the action of a single compound [32,33].

Australian perspective

Cannabis production is not a new Australian industry. Sir Joseph Banks gifted hemp seeds to the First Fleet, and cannabis-based medicines were sold over the counter in Australia until the early 1900s [34]. The cannabis legislation changed in the early 1900s. This commenced

Table 1. Legislation for the cultivation and manufacture of *Cannabis sativa* L. in Australia, current as of November 2017.

Product	Jurisdiction/register	Legislation	Permitted tetrahydrocannabinol content in industrial hemp
Medicinal Not	cannabis applicable	Commonwealth/Office of Drug Control	Narcotics Drugs Act 1967
	Single Convention of Narcotic Drugs 1961 (as amended in 1972)	Not applicable	
	Therapeutic Goods Administration	The Poisons Standard (SUSMP)	Processed hemp fibre containing 0.1% or less of tetrahydrocannabinol and hemp fibre products manufactured from such fibre. Hemp seed oil for purposes other than internal human therapeutic use containing 50 mg/kg or less of cannabinoids. When labelled "not for internal use" or "not to be taken."
Industrial Hemp	Australian Capital Territory/ Department of Environment and Heritage	Hemp Fibre Industry Facilitation Act 2004	Must not exceed 1% tetrahydrocannabinol in leaves and flower heads. Certified hemp seed must only be harvested from plants with no more than 0.5% tetrahydrocannabinol in leaves and flowering heads.
	New South Wales/Department of Primary Industries	Hemp Industry Act 2008	Must not exceed 1% tetrahydrocannabinol in leaves and flower heads. Certified hemp seed must only be harvested from plants with no more than 0.5% tetrahydrocannabinol in leaves and flowering heads. Licensee must not supply hemp with tetrahydrocannabinol content greater than 1%.
	Northern Territory/ Department of Primary Industry and Resources	Misuse of Drugs Act 2010	Cultivation not permitted. Exemptions exist for processed fibre hemp products, processed products made from hemp seeds as long as they are not whole, and hemp seed oil for external use containing less than 0.005% tetrahydrocannabinols
	Queensland/Department of Agriculture and Fisheries	Drugs Misuse Act 1986: Part 5B Commercial production of industrial cannabis	Commercial industrial cannabis plants grown for seed or fibre must not exceed 1% tetrahydrocannabinol under the Act, and may only be grown from seed certified to produce plants with no more than 0.5% tetrahydrocannabinol.
	South Australia/Office of Industrial Hemp and Medicinal Cannabis	Industrial Hemp Act 2017	Concentration of tetrahydrocannabinol in the leaves and flowering heads <1%, grown from certified seed.
	Victoria/Department of Economic Development, Jobs, Transport and Resources (DEDJTR)	Drugs, Poisons and Controlled Substances Act 1981	Cannabis may be cultivated from seed harvested from low-tetrahydrocannabinol cannabis, and may be sold or supplied when substantially free of flowering heads and leaves and containing no more than 0.1% tetrahydrocannabinol. Low-tetrahydrocannabinol cannabis is defined as containing no more than 0.35% in the leaves and flowering heads.
		Drugs, Poisons and Controlled Substances (Industrial Hemp) Regulations 2008	Processed fibre products may contain a maximum of 0.1% tetrahydrocannabinol, must not contain whole cannabis seeds, and must not be in a form suitable for ingestion, smoking or inhalation. Processed seed products may contain no more than 0.001% tetrahydrocannabinol and must not contain whole seeds
	Western Australia Department of Agriculture and Food	Industrial Hemp Act 2004 Industrial Hemp Regulations 2005.	Industrial hemp is defined as cannabis containing no more than 0.35% tetrahydrocannabinol in the leaves and flowering heads. Industrial hemp seed is that which is certified as having been produced from industrial hemp or that which will produce industrial hemp when cultivated. Crops must be grown from approved seed sources

with the signing of the Geneva Convention on Opium and Other Drugs in 1925 that restricted cannabis use to medicinal and scientific purposes. In 1938, cannabis was designated a noxious weed under the Local Government (Noxious Plants) Amendment Act 1938. Quarantine officers were instructed to eradicate every trace of the weed because "its effect upon the nation could be disastrous if evil-intentioned persons attempted to make use of it" [35]. Current legislation and conventions relating to cannabis include the Australian Narcotic Drugs Act 1967, United Nations Convention on Psychotropic Substances (1971), and the amended Single Convention on Narcotic Drugs (1972). Tasmania modified their legislation in the 1990s to enable legal hemp production [36]. Presently, hemp cultivation is permitted under license Australia wide with the exception of the Northern Territory. Table 1 outlines the legislative instruments regulating cannabis in Australia.

Cultivation in Australia

Cannabis cultivation is defined in Australia as inclusive of the "sowing of seeds, planting, growing, tending, nurturing or harvesting of plants, as well as their grafting, division and transplantation," but not "the separation of cannabis or cannabis resin from a cannabis plant" [1]. Growers of medicinal cannabis must have either a medicinal or a research cannabis license. Approval is dependent on their ability to demonstrate that they have a secure "chain of supply" to a licensed medicinal cannabis producer and/or manufacturer [37]. Three cultivation models have been identified for Australian production including: broad acre cropping, greenhouse, and indoor grow operations [6]. Of the three, indoor grow houses are the preferred model because they provide greater crop security, promote higher yields (6–8 week life cycle), and greater quality control of phytocannabinoid content, as well as limit potential for cross pollination with

other illegal and legal cannabis crops [6,38]. In contrast to medicinal cannabis, industrial hemp is traditionally a broadacre crop due to large volume requirements and minimising production costs [22].

> Each cultivation approach will present a unique combination of health and safety concerns that will need to be addressed. Glasshouses and indoor grow houses are hot, humid environments conducive to microbial growth and heat stress, as well as accumulation of gases (carbon dioxide, carbon monoxide), agricultural chemicals, biocides, cleaning agents or bioaerosols (plant particles and pollen, microorganisms, THC, etc.) if ventilation systems are poorly designed or maintained, and routine cleaning is not undertaken. In addition, workers may be exposed to ultraviolet radiation from the metal halide grow lamps. Outdoor operations present different health and safety hazards such as thermal stress, noise, agrichemicals, allergenic pollens and organic dust exposures.

Harvesting

Depending on the cultivar, cultivation area, and growth habit of plants, harvesting may be undertaken manually by hand (medicinal and recreational cannabis), or using heavy machinery such as combine harvesters (hemp). The harvesting of industrial hemp is undertaken using traditional hay making equipment including rotary mowers and combined harvesters [29]. Anecdotal evidence indicates that harvesting machinery is prone to blockages and spot fires during hemp harvesting, and moisture control essential (dry low and slow) to prevent microbial storage of grain (J. Kostuik & B. Doyle, personal communication, iHemp Conference, 5 July, 2018). Workers operating plant may also be exposed to organic dusts, vibration and noise, biomechanical injuries, and heat stress.

Processing of medicinal cannabis

Once harvested, medicinal plants are dried to prevent microbial spoilage by suspending plants outdoors on wire or lines, or drying them in ovens or specially designed drying barns [20,26]. Flowers from medicinal cannabis are destemmed and trimmed by hand to obtain the resinous floral tissue [22], and may be rubbed through size selective screens to separate small stems and seeds, prior to packaging in sterile polyethylene bags. The packaged product is stored at 18–20°C (short term) or −10°C (long term) prior to final processing [26]. The essential oils can be extracted either by used carrier oil, solvent, carbon dioxide or light hydrocarbon processes [6,22]. The chosen extraction methods may vary depending on budget constraints, as well as size and capacity of the manufacturing operation. However, all of the extraction approaches present potential hazards to the workers.

Industrial hemp processing

Dependent on the end product a diverse array of methodologies are used in the processing and manufacture of hemp products, and only a limited number of processing methods will be presented here. Hemp fibre may be separated from the plant by either mechanical decortification or by retting (rotting) that can be undertaken in the paddock (dew) or submerged in water (traditional/enzymatic) [7]. Water retting is unlikely to be undertaken in Australian crops because it is environmental unsustainable, and is already banned in a number of countries. The separated bast fibre undergoes a series of refinements including cleaning, carding, matting (non-woven mats/fleeces), pulping (paper making), and steam explosion (weaving fibres).

Hemp concrete (hempcrete), an example of an emerging hemp product and industry, is produced by mechanically refining the woody fibres (shiv). The mixture of hemp and lime-based binders is consolidated with water and then tamped down into the formwork in layers. This process would expose worker to potentially hazardous mixtures of organic and inorganic dust. Hemp is grown for both seed and fibre. The seed used to for oil, therapeutic products and as food source, fibre for textiles and building materials amongst many other products. Hemp seed oil may be extracted through cold pressing of seeds [2], while cannabidiol oils containing less than 2% THC require more complex processes such as solvent or carbon dioxide-based extraction [1,22].

Occupational health

The relationship between occupational diseases and cannabis exposure is not a new phenomenon. In the 1700s, Bernardino Ramazzini observed in his Treatise on Diseases of Workers that hemp and flax workers were exposed to acrid and harmful dusts that caused ceaseless coughing, followed by asthma [38]. Known health effects of cannabis are predominantly based on the deliberate exposure by inhalation, ingestion, contact, or injection [39–45], but little is known of the potential health impacts from long-term occupational exposure, especially to THC in medicinal cannabis. Health impacts could relate to the unique chemical profile of cannabis, plant pollens and allergens, organic and inorganic dusts, bioaerosols, and volatile organic compounds. Additional insights could be drawn from the public health investigations into the allergenic potential of its pollen [46–48].

Organic dust

Knowledge of the causative agents of occupational respiratory disease is critical in the design and

implementation of controls. Agricultural workers can be exposed to complex biologically active dusts of both organic and inorganic origin, consisting of plant particles, glucans, viruses, bacteria and endotoxin, fungi and mycotoxins, pollen, insects, and compost. Depending on the mixture, exposure to dusts can cause respiratory infections, irritation, inflammation, allergies, toxic response, or combinations thereof [49,50] . The complexity of these aerosols obfuscates the identification of agents associated with occupational diseases. Organic dust exposure is predominantly associated with inflammatory respiratory conditions caused by the inhalation of fine particles with an aerodynamic equivalent diameter of 5–10 μm. This size fraction is prone to enter the upper airways, but not necessarily penetrate the alveoli region [50].

> Bouhuys, Valic and Zuskin identified a high prevalence of byssinosis [51–53], as well as cross-shift respiratory reductions and accelerated decline of pulmonary function among hemp workers [13,15,54]. Byssinosis is a bronchoconstrictive disease, characterised by chest tightness, fever, headaches or muscle aches on the first workday, which eases with repeated exposure, only to return following a break in exposure [50,55]. The aetiology of byssinosis is still unclear with both bacterial (endotoxin) and plant components implicated in this possible health effect for cannabis workers. [14,56–58]

Fishwick et al. reported personal organic dust exposures ranging from 10.4 to 79.8 mg/m^3 for workers processing soft hemp, including high endotoxin (4734–59801 EU/m^3) and protein (0.18–1.78 mg/m^3) exposures. Background bioaerosol concentrations varied from 1 to 13 × 10^6 CFU/m^3 for fungi, 4.7 to 190 × 10^6 CFU/m^3 for bacteria, and 0.16 to 1.4 × 10^6 CFU/m^3 for Actinomycetes during the monitoring [56]. As a result of the high exposures, the workers exhibited a different profile of cell surface activation markers and antibodies in comparison to controls [14,56]. Similar to Fishwick et al., Zuskin et al. also observed high personal respirable dust exposures ranging from 1.3 to 38.4 mg/m^3 during production, but sampled a different size fraction [16,54]. Fishwick et al. sampled inhalable dust, endotoxin, and proteins [56], while Zuskin et al. sampled the respirable dust fraction [16,54]. Organic dust toxic syndrome is common in swine, poultry, and grain workers, and linked with dust generating farming practices such as chopping bedding straw, unloading grain silos, opening hay bales, and feed delivery [50,55]. High exposures to inhalable dusts of biological origin are a potential health risk in novel hemp applications including hemp-based concretes and insulation materials, processing of plant material in biofuel production, or manufacturing of food for animal or human consumption.

Allergens

Type 1 IgE hypersensitivy to cannabis may be on the increase [59], and cannabis pollen is considered as a potential allergen of public health significance [45,48,60]. The pollen, oils and leaves, can induce immune-mediated responses including allergic rhinitis, contact urticaria, allergic conjunctivitis, bronchial asthma, and angioedema [59,61]. The pollen release is seasonal, mainly during summer and autumn, coinciding with that of other local seasonal pollens such as grasses including rye grass, gumtrees, and acacias (wattle). The pollen is spherical and very light, enabling it to be dispersed over vast distances [46,62]. This could make it a potential public health, as well occupational health hazard, in Australia adding to atmospheric pollen loadings during the peak period for grasses to pollinate [63]. The current and proposed locations for growing hemp crops in regions known for thunderstorm asthma events, such as Melbourne Victoria and the Riverina Region of NSW (Wagga Wagga) [64], should be avoided.

> Bronchial asthma is associated with inhalation of seed dust [65], while anaphylaxis reactions are linked to smoking and injection of cannabis [39–41]. There is anecdotal evidence of allergic responses from contact to cannabis by law enforcement personnel [66]. Workers, who handle cannabis, particularly naïve atopic workers with no previous exposure or individuals sensitizsed to other allergens including fungi, may have an increased risk of hypersensitivity reactions [61]. Seed dust and aerosolised plant material may be a health concern in feed and oil production, fibre processing, biofuel or construction industries. For medicinal cannabis production, consideration should be given to minimising direct contact with plant materials during manicuring and refining processes to reduce the potential for contact dermatitis or allergic urticaria. Screening for hypersensitivity reactions in workers to cannabis should be undertaken, with sensitised employees reassigned to activities or locations with reduced exposures to cannabis plants and their aerosols [67]. As well as development of emergency response plans in the event of hypersensitivity reaction in a worker or visitor to the site.

Bioaerosols

Workers in cannabis cultivation can be exposed to high bioaerosol concentrations [20,56,68,69]. Depending on the crop and production processes, workers could also be potentially exposed to elevated aerosol concentrations of volatile organic compounds (VOCs) such as terpenes or mycotoxins. Inhalation of bacteria and fungi can cause pulmonary infections, and respiratory diseases including non-allergic organic toxic dust syndrome or hypersensitivity pneumonitis [50,55]. Inhalation of antigens such as

plant dusts, animal, and insect dander may also cause occupational asthma [50]:

> The optimal growing environment for Cannabis is 21°C to 32°C, with a relative humidity of 50% to 70% [22,28]. These are also optimal conditions for microbial growth, which can elicit allergic and irritant health reactions in workers. The potential for microbial proliferation of indoor cultivation situations is reflected in the high airborne fungi concentrations of 50,000 to >500,000 spores/m^3 recorded in indoor illicit grow houses [69], as well as in other enclosed intensive food crop production facilities [70–72]. In contrast, bioaerosol exposure on broadacre farms may be considerably lower. A study of outdoor recreational cannabis farms found very low bacterial endotoxin exposures ranging from 0 to 37 EU/m^3 [20]. However, further study across a broader range of cannabis production operations, both indoor and broadacre, as well as seasons is needed to better characterise bioaerosol exposures (bacteria, endotoxin, fungi, mycotoxins, etc.).

Fungi species identified from aerosols at outdoor recreational farms include *Aspergillus* sp., *Penicillium* sp., *Alternaria* sp., and *Botrytis cinerea* [20]. These species are associated with hypersensitivity pneumonitis diseases including farmers' lung (*Aspergillus* sp.), suberosis from mouldy cork dust (*Penicillium* sp.) woodworker's lung = (*Alternaria* sp.), and wine makers' lung (*B. cinerea*) [72]. Bioaerosol sampling at outdoor cannabis operations identified abundant bacterial phyla including Actinomycetes (45%), Proteobacteria (26%), Firmicutes (15%), and Bacteroidetes (9%) [20]. Actinomycetes are also well-known agents of hypersensitivity pneumonitis, as well as chronic bronchitis, organic dust toxic syndrome and asthma in agricultural environments [50,73,74]. Mycotoxins of *Aspergillus* sp. and *Penicillium* sp. can be found in inhalable cotton and grain dusts [75], and may also present a health hazard in inhalable hemp-based dusts.

Bacteria species identified during hemp processing include *Enterobacter aerogenes* and *E. cloacae* (Proteobacteria), *Citrobacter* spp. (Proteobacteria), *Pseudomonas aeruginosa* (Proteobacteria), *Staphylococcus albus* (Firmicutes), *Escherichia coli* (Proteobacteria), *Proteus mirabilis* (Proteobacteria), and *Enterococcus* spp. (Firmicutes) [16]. Exposure to opportunistic pathogens such as *Enterobacter* spp., *Pseudomona* spp., and *E. coli* could lead to infections in vulnerable populations including elderly farmers and immunocompromised individuals, while inhalation of their cellular components such as endotoxin can trigger immune system-mediated responses. *Pseudomonas* spp. can colonise the airways of patients' chronic obstructive pulmonary disease, leading to pseudomonal pneumonia [76]. This is of concern given the potential for respiratory disease in agricultural workers exposed to plant and grain dusts.

Volatile organic compounds

Medicinal cannabis cultivars produce and emit a wide range of VOCs. It is the terpenes that give the cannabis plant its unique aroma. Russo et al. report over 200 terpenoids isolated from cannabis, some of the most abundant being limonene, α-pinene, β-myrcene, linalool, β-Caryophyllene, caryophyllene oxide, nerolidol, and phytol [32,33,77]. Cases of terpene-related occupational illness have been reported in hop and timber production [78–80]. Terpenes are pharmacologically of interest as they are often lipophilic, and readily absorbed through the skin and gastrointestinal track that could have occupational health implications [32,33]. In the European Union (EU) eight-hour time weighted average (TWA_{8hour}) exposure standards ranging from 20 to 100 parts per million (ppm) have been established for terpenes in a number of countries, along with short-term exposure limits (STELs) of 40–100 ppm [81]. In the absence of an Australian exposure limit, an EU standard could be adopted until an Australia standard for phytocannabinoids and/or terpenes is prepared.

> Inadvertent tetrahydrocannabinol exposure in acute doses may cause anxiety, panic or psychotic episodes. Abundant surface contamination with tetrahydrocannabinol observed at illicit indoor grow houses, outdoor recreational cannabis farms and during cannabis seizures and processing by law enforcement personnel [20,69,82,83]. The widespread contamination in these operations presents a potential biological hazard through ingestion, absorption and inhalation. Biological sampling for tetrahydrocannabinol exposure has been undertaken with law enforcement personnel that may experience high level short term exposures during large volume cannabis seizures [82]. However, little has been published on the potential long-term health effects from chronic occupational exposure to tetrahydrocannabinol, such as those working in the cultivation and preparation of medicinal/recreational cannabis or working in forensic laboratories. Precautionary steps should be implemented to reduce worker exposure. There are no occupational exposure limits published for phytocannabinoids such as tetrahydrocannabinol or, and exposures should be kept as low as reasonably practicable (ALARP) until limits are published.

Chemical hazards

Carbon dioxide may be added to the atmosphere of indoor grow houses as a growth promoter. This procedure may expose workers to potentially hazardous levels (TWA = 5000 ppm, or STEL = 30,000 ppm) which may create oxygen deficient atmospheres if not controlled effectively, as well as the hazards associated with handling of compressed gases [21,69]. Other chemical hazards that may be encountered during cultivation include the use of potentially corrosive and irritant propagation hormones, such as

naphthaleneacetic acid or indolebutyric acid. The herbicide, 2,4-dichlorophenoxyacetic acid, used for weed control is also a potential mutagen [69]. Cannabis plants are also prone to the fungal diseases such as powdery mildew which may require application of fungicides [69]. However, the use of chemical pesticides, herbicides, and fungicides reportedly would not be permitted in organic crops, its residues in medicinal crops could cause medical complications for patients [84]. However, agrichemicals weed suppression and pest control may be applied for hemp production. Inorganic fertilisers for promoting plant growth and flower development are a corrosive and/or irritant hazard, while organic fertilisers may expose workers to biological hazards [50]. The extraction of volatile oils from cannabis may also expose workers to hazardous chemicals, and explosive atmospheres, especially use of solvent extraction methods using petroleum-ether, naphtha, or ethanol [85,86]. Supercritical CO_2 extraction of cannabis oil requires the application of pressure, heat, and CO_2 which can create physical as well as asphyxiation hazards [87,88].

Occupational safety

Physical hazards encountered may include biomechanical hazards, electrical, mobile and fixed machinery, working at heights, confined space, thermal stress, lighting, and noise. Recreational marijuana farm workers have indicated that their chief concern regarding physical hazards was associated with the bud trimming and harvesting processes as well as limited training [20]. However, conversely, the workers also expressed little interest in receiving health and safety training in spite of reporting health symptoms, such as skin irritation, eye irritation, and headache and dizziness associated with pesticide application [20]. The study of illegal indoor cannabis growing operations identified defective power supplies for lighting, high humidity, and poor indoor ventilation as key safety hazards [69]. Sterilisation of product to inhibit microbial growth may be undertaken using gamma irradiation, which is the process used in the Netherlands [89]. This represents a physical hazard to which workers in the Netherlands may be exposed.

As previously noted, hemp harvesting equipment is prone to spot fires and equipment blockages, placing workers at risk of physical injuries, as well as exposure to noise, vibration, biomechanical/ergonomic hazards. The carrying of fire fighter equipment is essential to put out spot fires as they occur, as are safety procedures for the clearing of equipment blockages. The silo storage of hemps seed also presents OHS risks associated improper management including silo gas, confined spaces, bioaerosols, entrapment, and engulfment.

The way forward

Indoor medicinal cannabis cultivation

The likelihood that medicinal cannabis will be grown as a broadacre crop is low, with the preference given to indoor grow environments to control security, quality, and consistency of product. An enclosed environment is more susceptible to accumulation of hazardous substances, and can create optimal growing conditions for not just plants, but also biological hazards. A risk management plan will need to be developed for each operation, and in the absence of an Australian guides. The Colorado Guide to Worker Safety and Health in the Marijuana Industry could be adapted for Australia, subject to the local broadacre farming and indoor growing models, as well as Australian legislation and standards. The adaption would require the identification of, and establishment of suitable controls for specific biological, physical and chemical hazards in the Australian industry. Notable health hazards that may be encountered in indoor grow environments include compressed gases, i.e. carbon dioxide used to create optimal grow conditions; UV exposure from metal halide grow lights; biological hazards including mould, pollen, and other plant phytocannabinoids; and potential ergonomic issues associated with facility design and the tending and harvesting crops [20,21]. A cleaning schedule should be established as part of the plan to reduce accumulation of debris and biohazards. Sweeping or use of compressed air should not be used for cleaning, rather wet cleaning process or HEPA vacuuming should be undertaking to prevent aerosol generation. Personal protective equipment that may need to be worn by workers includes; UV eye protection in artificially lighted grow houses compliant with AS1337:2010, gloves (AS2161:2016); and coveralls where there is risk of contact with plant and agrichemicals. Protective coveralls also limit contamination of personal clothing from biological and chemical contamination, which could then be transferred into home environments. The supply and use of an approved respirators must be in accordance with AS1715:2009 for specific tasks, i.e. a P2 respirator may be used to limit pollen exposure during flowering.

The most notable difference between the health risk associated with medicinal cannabis and hemp is the presence of the psychoactive THC. Exposure to THC can cause mood disturbance, diminished memory, and disorientation. Surface contamination with THC has been observed in commercial recreational cannabis farms [20], forensic botany laboratory (unpublished data), and in illegal indoor grow houses [69]. Air sampling for THC resulted in a considerable number of samples below the limit of detection, indicating this may be a less common exposures pathway [21,69]. The health impacts from long-term occupational exposure to THC are

unknown, and there are no published exposures limits for aerosols or surfaces contaminated with THC. Workplace THC exposures should be kept ALARP, and workers should report any changes to mood, memory, or disorientation to supervisors that may result from working in either the cultivation or production facilities. Worker exposure to THC can be minimised through implementation of routine cleaning programs, promotion of good personal hygiene (washing hands prior to eating or drinking), and the supply and use of appropriate PPE (gloves, respirator, and coveralls) for tasks where exposure could be significant.

Broadacre hemp production

Agriculture is one of the most dangerous global industries to work in, and new entrants may be particularly at risk of injury or illness as workers, supervisors, or owners. New workers may experience significant exposures to biological agents, for which their body may have limited or no adaptive immunity. Additionally, new workers may have limited awareness of the inherent physical and chemical health and safety risks associated with these environments, which could result in serious injury or death. Potential for accident and injury associated with use of industrial machinery, transport, and storage of product. Agricultural extension specialists could be engaged to develop outreach programs in conjunction with industry groups to help educate new entrants to the field. These may include the development of training materials, field day presentations, and site visits to promote safe and healthy workplaces and practices.

Occupational exposure limits, health surveillance, and best practice guidelines

Worldwide there are only two occupational exposure standards for *C. sativa* L. These include the Austrian standard TWA_{8hour} of 2 mg/m^3 measured as inhalable fraction, and the French standard of 0.2 mg/m^3 TWA_{8hour} measured as the thoracic fraction [81]. It is recommended that Australia adopt one of these standards for cannabis production in the absence of a current Australian Standard. The proposed occpational exposure standard reflects the current Australian raw cotton dust standard of 0.2 mg/m^3 TWA_{8hour} [81]. The Australian cotton dust standard could be used as an interim exposure standard for occupational assessments until a hemp standard is adopted. However, this measure would not be appropriate for medicinal cannabis with its THC rich phytocannabinoid profile. Furthermore, a cannabis TWA_{8hour} should be investigated because it has been indicated that hemp has a higher proinflammatory potential in comparison to cotton dust [90], which suggests that exposure standards of cannabis related dust may need to be further reduced. Further investigation into the toxicological property of cannabis-based dusts is needed to determine appropriate exposure standards. A cannabis exposures standard based on the inhalable fraction is recommended because the plant-based dust is likely to elicit a biological response across all parts of the respiratory tract, and not just be confined to the gas exchange/small airways region of the lungs. It is also recommended that the classification of cannabis meets that the requirements of the Global Harmonization Scheme (GHS) should be undertaken to ensure consistency in the use of safety and risk phrases in cannabis-related industries.

Conclusion and recommendations

The Australian cannabis industry is continuing to expand exposing workers to both familiar and novel OHS hazards. This review has highlighted a variety of occupational diseases including dermatitis, respiratory disease, and physical injuries that may arise in commercial cannabis production. Consideration of the allergic and respiratory health impacts associated with exposure cannabis-based aerosols and plant exposure needs further characterisation and study to ensure there are no potential long-term health effects occur for workers in this new emerging industry. In the interim, it is recommended that exposure to cannabis-based aerosols in medicinal operations be kept as low as reasonably possible because the long-term health consequences are unknown. It is recommended that consideration be given in the following:

- Investigation into the toxicological properties of cannabis dusts, specifically in relation to potential occupational exposures during cultivation and manufacture, should be a priority.
- The interim adoption of the Australian cotton dust standard of 0.2 mg/m^3 for workplace exposure in hemp facilities until a cannabis workplace exposure standard is developed, and that exposure to medicinal cannabis containing THC are kept as low as reasonably practicable (ALARP).
- An industry partnership be established for the development of an Australian health and safety guideline for the production of medicinal cannabis and hemp.
- A classification to meet the requirements of the GHS should be undertaken to ensure consistency in the use of safety and risk phrases in cannabis-related industries.

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