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Cannabis sativa: Quality control testing measures and guidelines: An update

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Abstract

The use of Cannabis sativa as a herbal medicine is increasing due to its proven therapeutic values. However, in multiple countries today, its cultivation and usage are regulated by the interest in the medicinal potential of cannabis and have paved the way for the release of marketing authorization for cannabis-based products. The legalization of cannabis is an important source of economic growth as it contributes to the growing revenue tax, and the creation of new workplaces. However, cannabis products in the market have been found contaminated with microorganisms (pathogenic bacteria, yeasts, and molds) during any stage of production. Microorganism-contaminated cannabis products can be dangerous for medical patients, especially those with immunocompromising conditions or using immunosuppressive therapies, as they are at high risk of infection. Over-labeling of cannabis products may lead patients to use products that will not provide them with the expected medical benefit. Alternatively, under-labeling poses a safety risk from unexpected impairment or adverse events. In cannabis quality control testing, some of the most common tests included are, microbial, pesticide, heavy metal, potency, and residual solvent testing. Quality control testing measures is crucial for cannabis producers to meet market expectations and ensure the safety and efficacy of their products. Cannabis quality control testing measures, guidelines are responsible for inspecting, testing, verifying products, procedures against SOPs and specifications. Cannabis quality control is a vital aspect of the cannabis industry, ensuring consistent, safe, and compliant products. Rigorous testing for potency, contaminants, and other quality measures not only ensures regulatory compliance but also safeguards public health.

Keywords: Cannabis sativa; Contamination; Good Manufacturing Practices (GMP); Quality control testing measures; Standard Operating Procedures (SOPs); Wrong labeling

1. Introduction

In recent years, interest in phytocannabinoids, biologically active compounds that occur in Cannabis sativa L. plants, has increased enormously [1-2-38-137, 142, 144-147]. These unique secondary metabolites have the potential to bind to specific endocannabinoid receptors in the human body [1-35]. Interest in medical applications Medical Cannabis (drug or marijuana type) has increased dramatically during the past 20 years [1-2-38-137]. According to the study conducted by Pratt et al., (2019) [1] synthetic forms of Medical Cannabis (drug or marijuana type) such as **Dronabinol** and **Nabilone** are also available as prescriptions in the USA and Canada [1-38-125]. Over the last decade, there has been an increased interest in the use of medical cannabis products in North America [1]. It is estimated that over 3.5 million people in the USA are legally using Medical Cannabis (drug or marijuana type), and a total of USD $6.7 billion was spent in North America on legal marijuana in 2016 [1]. The number of Canadian residents with prescriptions to purchase medical marijuana from Health Canada–approved growers tripled from 30,537 in 2015 to near 100,000 in 2016 [1].

With the legalization of recreational-use Medical Cannabis (drug or marijuana type) in parts of the USA and in Canada in October 2018, the number of patients using marijuana for therapeutic purposes may become more difficult to track [1]. The likely increase in the numbers of individuals consuming cannabis also necessitates a greater awareness of its potential benefits and harms [1]. Cannabis-based medicine is a rapidly emerging field of study, with implications for both healthcare practitioners and patients [1-45].

Cannabis use for medical purposes is increasing [39]. According to the study conducted by MacCallum et el., (2023) [39], as demand grows, the number of available cannabis products from both regulated and unregulated sources [39]. MacCallum et el., (2023) [39], are of the opinion that the need for health care providers (HCPs) to properly evaluate the quality of any cannabis product presenting in clinical practice is warranted [39]. Regardless of whether clinicians are recommending cannabis, or patients are self-medicating, they must be aware of the basic product safety considerations to mitigate potential harm [39].

Additionally, the species *Cannabis sativa* L. and *Cannabis indica* are a potential source of fibre, food, oil, and protein [1-2-38-137]. However, cannabis research work remains years behind than other crops because of the long legacy of prohibition and stigmatization [1-38, 144-147]. Cannabis is the most commonly used illicit drug worldwide and the active constituents of the product were described several decades ago [1-38]. The legal status of *cannabis* is changing, fuelling an increasing diversity of *cannabis* derived products [1-38]. New laws leading to decriminalization and legalization have given rise to a global, multibillion dollar industry that is projected to continue to grow [1-38]. As of today, there are more than 40 countries have legalized medical cannabis (drug or marijuana type) [1-38, 144-147]. The legalization of cannabis is an important source of economic growth as it contributes to the growing revenue tax, and the creation of new workplaces [1-38, 144-147]. The maturity of the cannabis market varies across the globe mainly due to differing legal environments and public attitudes towards cannabis [1-38]. Some countries such as Canada and the United States have adopted fully regulated frameworks that allow the cultivation, consumption, and retail distribution of various cannabis products [1-38]. **Uruguay** became the **first country** in the world to legalize the production, distribution and consumption of cannabis in 2013 [1-38]. The cannabis market in Canada and the USA is experiencing rapid growth due to the country's legalization of recreational use. Regulations can also differ regarding how cannabis is used [1-38-125].

2. *Cannabis sativa*: Medical Applications

Today *Cannabis sativa* continues to be the most used drug in the world [1-38, 144-147]. Research showed that cannabis use is associated with a wide range of adverse health consequences that may involve almost every physiological and biochemical system including respiratory/pulmonary complications such as chronic cough and emphysema, impairment of immune function, and increased risk of acquiring or transmitting viral infections such as HIV, HCV, and others [1-38]. Both Medical Cannabis (Marijuana or drug type) and Industrial *Cannabis sativa* (hemp or fiber type) are used for controlling numerous diseases, such as chronic pain, asthma, rheumatoid arthritis (RA), wound healing, constipation, multiple sclerosis (MS), cancer, inflammation, glaucome, neurodegenerative disorders (Epilepsy-seizure disorder, Alzheimer's disease, Parkinson's disease, dengue viral disease, Huntington's disease, Tourette's syndrome, Dystonia, Lennox-Gastaut Syndrome (LGS) and Dravet Syndrome (DS), obesity, weight loss, anorexia, and emesis, osteoporosis, schizophrenia, cardiovascular disorders, sleep disorders, Traumitic brain injury (TBI), post traumetic stress injury, drug addiction (Marijuana), AIDS Wasting syndrome, Amyotrophic lateral sclerosis (ALS), depression and anxiety, diabetes, migraine (headache disorder), Covid-19 (SARS-CoV-2), Leishmaniasis (Kala‑Azar), dengue fever, monkeypox, Nipah virus, Lumpy skin vital disease of cattle, and metabolic syndrome related disorders, are being treated or have the potential to be treated by cannabinoid agonists/ antagonists/cannabinoid-related compounds [1-38, 144-147].

3. Concern over lack of Quality Control Measures

According to the study conducted by MacCallum et el., (2023) [39], increase in Medical Cannabis (Marijuana or drug type) use along with available products, warrants the need for clinicians to be knowledgeable in evaluating the quality of any cannabis product presented in clinical practice [39]. MacCallum et el., (2023) [39] are also of the opinion that determining whether a product is regulated within the region is key in assessing overall quality and safety [39]. Therefore, regulated products are held to a higher standard including independent testing, contamination mitigation, and concentration limits [39]. According to the study conducted by MacCallum et el., (2023) [39], a clinical framework in evaluating cannabis products to ascertain the quality and regulation level of the product is very much essential as a part of quality control measures [39]. Evaluation includes assessing the source company, reviewing product details (e.g., type, cannabinoid content, and labeling), and assessing quality control variables such as manufacturing and

decontamination processes [39]. The quality of products used by the patients is an important part of mitigating cannabis-related harms, especially in medically vulnerable patients [39]. Currently, there is a great need to implement widespread standardization and regulations to ensure product quality and safety [39-41,81-86-135]. With thousands of cannabis products on the market, the lack of product standardization has contributed to confusion surrounding what cannabis meets the highest quality standards for safety [39-135]. Quality control variables such as risk of contaminants or pesticides and product details such as dose or product type play an equally important role in determining risk for the individual patient [39-135]. Increased cannabis product availability, combined with lack of standardization, has led to difficulties in determining whether a product meets adequate quality standards [39-135]. Regulated products have greater quality control including independent testing, contamination mitigation, and concentration limits [39-41,81-86-135]. Product labeling, product type, cannabinoid content, manufacturing processes, and region-specific product allowances should all be considered when evaluating patient-specific risks [39-41,81-86-135]. In the following section, quality control testing measures applied for cannabis has been discussed and updated.

4. *Cannabis sativa*: Quality Control Testing Measures

As cannabis gains broader acceptance for both medicinal and recreational use, consumers rightfully demand products that meet high safety and efficacy standards [39-41]. Hence make sure that products are consistent from one batch to another is incredibly determinative of consumer loyalty and overall brand success [39-41-135]. Quality control encompasses a series of processes and procedures implemented at various stages of the cannabis supply chain to guarantee product integrity [39-41-135]. For most companies in the cannabis industry, current good manufacturing practices (cGMP) certification is the best standard to follow [39-41-135]. It has been reported that cannabis derived products are often contaminated by microbes, heavy metals, pesticides, carcinogens, and debris, which must be addressed to ensure the safety of consumers [39-41-135]. The recent concerns about the possible contaminations of cannabis products with pesticides, fungicides, insecticides, heavy metals, microbial pathogens, and carcinogenic compounds during the cultivation, manufacturing, and packaging processes which must be addressed to ensure the safety of consumers [39-41-135]. These contaminants are usually introduced during cannabis cultivation and storage of cannabis products [39-41-135]. Growth enhancers and pest control chemicals are the most common risks to both the producer and the consumer [39-41-135]. These contaminants are imminent threats that directly impact public health and wellness, particularly to the immunocompromised and pediatric patients who take cannabis products as a treatment for numerous human disorders including cancer patients and those suffering from epileptic seizures [39-41-135].

The quality of cannabis products is an important part of mitigating patient harm [39-41-135]. The proposed framework has been translated into a free practical clinical tool to allow questionable products to be scored [39-41-135]. This can be found at (safe-cannabis.com) [39-41-135]. There is a greater need now more than ever to implement widespread standardization and regulation for cannabis products [39-41-135]. As demand increases and more countries head toward regulation, standardization will be a crucial component to ensuring product quality and safety [39-41-135]. In cannabis quality control testing, following are the some of the most common tests included [38- 39-41-135].

- **Microbial testing**: This involves testing for the presence of bacteria, fungi, and other microorganisms that can cause infections [38- 39-41-135].
- **Pesticide testing**: This involves testing for the presence of pesticides and other chemicals that may have been used during the cultivation process [38- 39-41-135].
- **Heavy metal testing**: This involves testing for the presence of heavy metals such as lead and arsenic, which can be harmful to human health [38- 39-41-135].
- **Potency testing**: This involves testing the levels of cannabinoids such as THC and CBD in the product to ensure that it is consistent with the label claims [39-41-135].
- **Residual solvent testing**: This involves testing for the presence of solvents such as butane or toxic chemicals that may have been used during the extraction process [39-41-135].

5. Cannabis Products Contamination Problems

Cannabis is associated with various types of microbes including moulds that have been shown to harm immunocompromised patients, as well as bacteria and viruses that have the potential of causing harm to humans [13, 39-55-135]. Previous studies have identified several fungal organisms in dispensary produced cannabis including Penicillium sp. (*P. paxilli*, *P. citrinum*, *P. commune*, *P. chrysogenum*, *P. corylophilum*, *P. citrinum*, and *P. steckii*), Aspergillus sp. (*A. terreus, A. niger, A. flavus, A. versicolor, A. ostianus*, and *A. sydowii*), and Fusarium sp. (*F. oxysporum*) [13, 39-55-135]. Both Penicillium sp. and Aspergillus sp. have been known to produce aflatoxins (e.g., aflatoxin B1) while Fusarium

species produce other **mycotoxins** such as **fumonisin** [13, 39-55-135]. Cannabis infected with Aspergillus, Penicilium, or Fusarium can severely affect human health as these toxins can all be carcinogenic, hepatotoxic, neurotoxic or nephrotoxic [13, 39-55-135]. In addition to pathogenesis in humans by these fungi, Penicillium, Aspergillus, and Fusarium sp. are known to produce both aflatoxins and mycotoxins that become especially problematic while drying and storing cannabis products in humid environments [13, 39-55-135].

Further, bacterial contamination has also been reported, reviewed and updated by Montoya *et al.,* 2020 and Dryburgh *et al.,* 2018 [13, 39-55]. These bacteria contaminate include various species of Pseudomonas, Cellvibrio, Oxalobacteraceae, Xanthomonadaceae, Actinomycetales, and Sphingobacteriales in the examined microbiomes [13, 39-55-135]. While dozens of bacterial species found to be present in cannabis plants, E.coli, Salmonella, and Clostridium are a few common potential human pathogenic species shown to be associated with cannabis ([13, 39-55-135]. There are also concerns for the contamination of cannabis food products by potentially harmful bacteria including Listeria [13, 39-55]. Viruses found to be associated with cannabis are purely plant pathogens, and it is not assumed that these could cause human related diseases (10-35, 36, 44). Most of the microbial contamination occurs during the improper preparation and storage of cannabis products. wet, drying and storage under wet, humid conditions can lead to fungal infections such as powdery mildew and botrytis, and budworm or mite infestations [13, 39-55-135]. The carcinogenic load of non-medicinal cannabis particularly when consumed via smoking is significant [13, 39-55-135].

Microbial testing is vital in preventing the distribution of cannabis products contaminated with harmful bacteria or fungi [13, 39-41-135]. This aspect of quality control protects consumers, particularly those with compromised immune systems, from potential infections [13, 39-41-135]. As the industry matures, testing standards for microbial contaminants are subject to refinement, emphasizing the need for businesses to stay informed and compliant [13, 39-41-135]. These contaminants are imminent threats that directly impact public health and wellness, particularly to the immunocompromised and pediatric patients who take cannabis products as a treatment for numerous human disorders including cancer patients and those suffering from epileptic seizures [13, 39-41-135]. For the safety and welfare of all cannabis users, both medicinal and recreational, there is a necessity for a standardized set of guidelines for cultivation and testing of cannabis products. This will help to improve the quality based cannabis products in the market and safe zone for the consumers [13, 39-41-135].

Contaminants pose a significant threat to consumer safety, which makes thorough contaminant testing a cornerstone of quality control [13, 39-41-135]. This includes screening for pesticides, heavy metals, residual solvents, and other harmful substances that may compromise the safety of cannabis products [13, 39-41-135]. Continuous advancements in testing technology contribute to the cannabis industry's ability to detect contaminants at lower concentrations, ensuring a higher level of product safety [13, 39-41-135]. In many countries, the regulations regarding contaminate testing are updated based on risks found throughout the growth of the industry [13, 39-41-135]. New products and processes pose different risks, and it has been challenging for regulators to keep up with this innovative and fast-moving industry [13, 39-41-135].

While many claim that cannabis is naturally a pest resistant crop, there is still abundant use of various types of pesticides to provide protection, including insecticides, fungicides, and plant growth regulators [13, 39-80-135]. As many of these pesticides are lipophilic, they are soluble in the solvents used for extraction of cannabinoids, including Cannabidiol (CBD) oils and other products using extracted cannabinoids [13, 39-80]. Naturally, this leads to concerns about contamination of cannabis with pesticides and the potential health risks that would accompany concentrating these pesticides in an extract (10-43). In addition to this, two commonly identified insecticides (Bifenazate, and Abamectin) found on cannabis products that are known to be harmful to mammals [13, 39-80]. Several fungicides have been reported in samples of cannabis all over the world including known endocrine disruptors and hepatoxic compounds like imazalil and myclobutanil [13, 39-80]. These fungicides should not be considered safe to use for any cannabis cultivation, and their application should be avoided to protect the health of the consumer [13, 39-80-135]. The toxicity of plant growth regulators (Daminozide and paclobutraxol) are also commonly found in cannabis, including carcinogens and compounds that have been shown to be detrimental to mammals [13, 39-80]. Polycyclic aromatic hydrocarbons (PAH) are ubiquitous environmental pollutants usually generated by the incomplete combustion of organic materials are also found in some Cannabidiol (CBD) oils and may come either from uptake by the plant during growth or from contaminated carrier oils during product preparation [13, 39-80-135]. Polycyclic aromatic hydrocarbons (PAH) (benzo anthracene, chrysene, benzo fluoranthene, benzo pyrene) are known to be hazardous, deemed as carcinogens, and can found in cannabis products worldwide [13, 39-80]. Other debris such as metal fragments, hairs, dusts, machine oils, or insect parts can be found in some cannabidiol (CBD) oil products as is seen in other foods or food products [13, 39-80-135].

One of the fundamental aspects of quality control is **Potency testing** [13, 39-41-136]. This crucial step ensures that cannabis products consistently deliver the intended levels of cannabinoids, such as tetrahydrocannabinol (THC) and cannabidiol (CBD) [13, 39-41-136]. Proper potency testing not only satisfies regulatory requirements but also provides consumers with accurate information for informed decision-making [13, 39-41-136]. As regulatory frameworks evolve, businesses must stay abreast of any changes in potency testing standards to maintain compliance [13, 39-41-136]. When it comes to flower potency in the industry and encountered some issues. Because testing laboratories are not standardized, potency inflation can be an issue [13, 39-41-136]. Hence potency testing is required to ensure consumers will be able to manage the effects of any product they decide to consume [13, 39-41-135]. The cannabis industry is dynamic, responding to both scientific advancements and regulatory developments [13, 39-41-135]. Stakeholders in the industry must remain vigilant about changes in testing standards to adapt their practices accordingly [13, 39-41-135].

The emerging interest in cannabis, and cannabis products is increasing throughout world. However, concerns have arisen about the possible contaminations of hemp with pesticides, heavy metals, microbial pathogens, and carcinogenic compounds during the cultivation, manufacturing, and packaging processes [13, 39-80-135]. For nearly a century, cannabis has been stigmatized and criminalized across the globe, but in recent years, there has been a growing interest in cannabis due to the therapeutic potential of phytocannabinoids [13, 39-80-135, 144-147]. For the safety and welfare of all users, both medicinal and recreational, there is a necessity for a standardized set of guidelines for cultivation and testing of cannabis products [13, 39-80-135]. The lack of a comprehensive evidence base suggests that the study of cannabis contaminants is an emerging field of clinical pharmacology [13, 39-80-135]. Unfortunately, the classification of cannabis as a schedule 1 drug throughout the world makes the development and implementation of nationwide standards impossible at the moment [13, 39-41-135]. Thus, it is imperative to develop universal standards for cultivation and testing of products to protect those who consume cannabis [13, 39-80-135]. International consensus is needed to establish quality control and product standardization [13, 39-80-135]. The development of the requisite analytical standards for quality testing of global medicinal cannabis preparations requires a more comprehensive evidence base of the contaminants of cannabis [13, 39-80-135].

6. Key Components of Cannabis Quality Control

- **Good Manufacturing Practices** (GMP): Following GMP guidelines ensures that all aspects of cannabis cultivation, processing, and manufacturing are conducted in a controlled and standardized manner [39-41, 81-135]. This includes sanitation, facility cleanliness, personnel training, record-keeping, and quality assurance protocols [13, 39-41, 81-135]. Good manufacturing practices, also known as good production practices, are crucial for cannabis producers in order to ensure the quality and safety of their products. By adhering to these practices, producers can run their businesses more efficiently and effectively, while also fostering trust among stakeholders [39-41, 81-135].
- **Standard Operating Procedures** (SOPs): Developing and implementing SOPs ensures consistency and compliance with defined processes. SOPs cover various aspects of production, including cultivation techniques, extraction methods, product formulation, packaging, and labeling [39-41, 81-135].
- **Quality Assurance Testing**: Conducting comprehensive testing for potency, terpene profiles, pesticides, residual solvents, heavy metals, and microbial contaminants is a crucial component of quality control. This testing ensures that products meet safety and quality standards before reaching consumers [39-41, 81-135].
- **Batch Tracking and Documentation**: Tracking and documenting the entire production process from cultivation to distribution is essential for traceability and quality control. This includes recording batch numbers, ingredient lists, manufacturing dates, and testing results for each product [39-41, 81-135].
- **Supplier Qualification and Verification**: Establishing rigorous supplier qualification processes helps to ensure that all raw materials, including cannabis biomass and ingredients, meet specified quality standards. This includes verifying certificates of analysis (COAs) and conducting supplier audits when necessary [39-41, 81-135].
- **Product Sampling and Analysis**: Random product sampling and analysis are conducted to verify the consistency and quality of cannabis products. This helps to identify any deviations or non-compliance issues that need to be addressed [39-41, 81-135].

7. Compliance and Regulatory Considerations

- **Testing Requirements**: Adhering to testing requirements mandated by regulatory authorities is essential for ensuring complianc [39-41,81-86-135]. . This includes testing for potency, contaminants, and labeling accuracy [39-41,81-86-135].

- **Record-Keeping and Reporting**: Maintaining accurate and detailed records of quality control testing, results, and compliance activities is crucial. These records demonstrate regulatory compliance and facilitate audits and inspections [39-41,81-86-135].

The best cannabis quality assurance practices play a vital role in ensuring that every step is executed with precision and care [39-41,81-86-135]. Cannabis quality control is a vital aspect of the cannabis industry, ensuring consistent, safe, and compliant products [39-41,81-86-135]. By implementing robust quality control measures, including GMP, SOPs, comprehensive testing, batch tracking, and supplier qualification, businesses can demonstrate their commitment to producing high-quality cannabis products that meet the expectations of consumers and regulatory authorities [39-41,81-86-135]. Quality control and testing are non-negotiable elements in the cannabis industry's pursuit of legitimacy and consumer trust [39-41,81-86-135]. Rigorous testing for potency, contaminants, and other quality measures not only ensures regulatory compliance but also safeguards public health [39-41,81-86-135]. As testing standards continue to evolve, businesses must stay informed and invest in third parties to maintain a competitive edge [39-41,81-86-135]. By prioritizing quality control, the cannabis industry can continue to thrive, providing consumers with safe, reliable, and effective products in this rapidly changing landscape [39-41,81-86-135]. Terpenes, the aromatic compounds in cannabis, play a crucial role in the plant's effects, taste, smell, and therapeutic properties [39-41,81-86-135]. In some states testing standards have evolved to incorporate terpene profiling, allowing consumers to choose products based on their desired flavor profiles and potential synergies between cannabinoids and terpenes [39-41,81-86-135]. Recent updates in testing standards reflect a growing interest in expanding the scope of cannabinoid analysis [39-41,81-86-135]. This includes assessing minor cannabinoids like cannabigerol (CBG), cannabinol (CBN), and tetrahydrocannabivarin (THCV), providing consumers with a more comprehensive understanding of product composition [13, 39-41, 81]. There are also a number of hemp-derived cannabinoids that are joining the market, such as Λ 8 THC, Λ 10 THC (Λ10), and hexahydrocannabinol (HHC) [39-41,81-86-135].

8. Cannabis: Good or Poor quality

Good quality cannabis refers to a product that meets or exceeds certain standards in terms of its appearance, aroma, taste, potency, and overall effects [39-41,81-86-135]. On the other hand, poor quality cannabis generally falls short in one or more of these areas, whether it's due to subpar cultivation practices, lack of proper curing and storage, or even contamination with harmful substances [39-41,81-86-135]. Here are some examples to illustrate the difference between good-quality cannabis, and bad-quality cannabis

- **Appearance**: Good quality cannabis will have vibrant colours, dense and well-formed buds, and an abundance of trichomes (small resin glands) visible to the naked eye.
- **Aroma**: It will emit a strong and pleasant aroma that reflects its strain's unique terpene profile. The aroma might range from citrusy and fruity to earthy or floral.
- **Taste:** When consumed, it will have a rich and complex flavour profile that matches its aroma. The taste should be smooth and enjoyable on the palate.
- **Effect**: The effects of good quality cannabis should align with its expected strain characteristics. Sativa strains might provide uplifting and energizing effects, while indicas might offer relaxation and sedation.
- **Potency**: Lab-tested results will confirm its potency and cannabinoid content, showing accurate levels of THC, CBD, and other cannabinoids.
- **Clean Burn**: When smoked, good quality cannabis will burn evenly and smoothly, leaving minimal ash and producing a satisfying smoke.

8.1. Bad Quality Cannabis

- **Appearance**: Poor-quality cannabis may appear brownish, dull, or discolored. Buds might be airy, loosely formed, or damaged.
- **Aroma**: It could emit an off-putting or overly grassy smell, lacking the distinctive and appealing scent of well-cultivated cannabis.
- **Taste:** The taste might be harsh, bitter, or unpleasant, possibly indicating poor curing or improper growing practices.
- **Effect:** The effects might be weak, inconsistent, or not aligned with the expected characteristics of the strain.
- **Potency**: Lab-tested results might reveal inaccurate or inconsistent cannabinoid levels, potentially indicating unreliable cultivation practices.
- **Harsh Smoke**: Smoking bad-quality cannabis might produce harsh and uncomfortable smoke, causing coughing and irritation.

- **Presence of Contaminants**: Poor quality cannabis might contain visible impurities like stems, seeds, or excessive trim.

9. Quality Control Measure Protocol

Quality control is crucial for cannabis producers to meet market expectations and ensure the safety and efficacy of their products [39-41,81-86-135]. Here are some of the most important quality control measures that cannabis producers should consider and proposed guidelines.

9.1. Cannabis Cultivation Management

Implementing proper cultivation practices is essential for producing high-quality cannabis [39-41,81-86-135]. This includes maintaining optimal growing conditions, monitoring and controlling humidity and temperature levels, and using organic and sustainable farming methods [39-41,81-86-135]. A cannabis producer implements a controlled indoor cultivation environment with precise temperature and humidity control, optimized nutrient solutions, and carefully monitored light cycles to ensure consistent plant growth and high-quality yields [39-41, 81-86-135]. Cannabis producers must have appropriate equipment for cultivating and growing cannabis plants [39-41, 81-86-135]. This includes items such as lighting systems, climate control devices, irrigation systems, and ventilation equipment [39-41, 81-86-135, 141]. These tools are crucial for maintaining the optimal environment for cannabis cultivation, ensuring healthy growth and maximum yield. For example, in Canada, the Cannabis Regulations specify that cultivation areas must have suitable artificial lighting that provides a minimum of 500 lux of light intensity at the plant level [39-41, 81-86-135]. Ventilation systems must also be in place to ensure proper air circulation and exchange [39-41, 81-86-135].

9.2. Efficient Production

Implementing good manufacturing practices (GMPs) also improves operational efficiency for cannabis producers [39-41,81-86-135]. By streamlining processes and ensuring that each step is carefully planned and executed, producers can reduce waste, minimize errors, and increase productivity [39-41,81-86]. This leads to cost savings, improved overall performance, and ultimately, higher profitability [39-41,81-86-135]. Moreover, efficient production processes helps to meet consumer demand more effectively, ensuring that products are readily available and delivered in a timely manner [39-41,81-86-135].

9.3. Facility Design and Maintenance

Regulators often require cannabis producers to design and maintain their facilities in a way that prevents pest infestations [39-41,81-86-135]. This includes implementing proper sanitation practices, maintaining structural integrity, and ensuring proper ventilation and airflow within the facility [39-41,81-86-135]. It is crucial to create an environment that minimizes the risk of pests entering and thriving in the cultivation area [39-41,81-86]. In Canada, the Cannabis Act sets out specific requirements for the design and maintenance of cannabis production facilities [39-41,81-86-135]. These regulations include provisions for pest control, such as ensuring that the facility has secure doors and windows, proper airflow systems, and adequate waste management procedures [39-41,81-86-135].

9.4. Facility Requirements

Cannabis producers need to have adequate facilities for storing and distributing their products [39-41,81-86-135]. These facilities should comply with specific guidelines regarding security, cleanliness, temperature, and humidity control [39-41,81-86-135]. For example, in Canada, licensed producers must comply with Health Canada's Good Production Practices (GPP) requirements, which include guidelines for facility design, maintenance, and security [39-41,81-86-135].

9.5. Standard Operating Procedures (SOPs)

Developing and implementing SOPs for every stage of production is critical for maintaining consistency and quality control [39-41,81-86-135]. SOPs should cover everything from cultivation, extraction methods to testing and packaging protocols [39-41,81-86-135]. A cannabis extraction facility establishes SOPs for their CO_2 extraction process, detailing parameters, equipment calibration, and safety measures [39-41,81-86-135]. Following these SOPs consistently ensures that each batch of extracted oil meets quality and potency standards [39-41,81-86-135].

9.6. Quality Control Testing

To ensure product safety and quality, cannabis producers must conduct regular testing on their products [39-41,81-86-135]. This includes testing for potency, contaminants, and microbial activity [39-41,81-86-135]. Producers should work with accredited laboratories to perform these tests and ensure compliance with regulatory standards [39-41,81-86-135]. In Australia, cannabis producers must comply with the Therapeutic Goods Administration's (TGA) quality control testing requirements, which include testing for potency, pesticides, heavy metals, and microbial contaminants [39-41,81-86-135]. If a cannabis producer plans to extract oils or other compounds from the plant material, they must have the necessary extraction equipment that meets safety and quality standards [39-41,81-86-135]. This may include closed-loop extraction systems, solvent recovery equipment, filtration devices, and distillation apparatus [39-41,81-86-135]. In the United States, regulations set by states such as California require cannabis extraction facilities to use equipment that is certified by a licensed engineer and to ensure that all extraction solvents are stored and used safely [39-41,81-86-135]. Additionally, these facilities must have proper ventilation systems to prevent the accumulation of volatile gases [39-41,81-86-135].

9.7. Lighting Systems

Proper lighting is essential for the growth and development of cannabis plants [39-41,81-86-135, 141]. Regulatory requirements often specify the type of lighting systems that producers must use to ensure optimal plant growth [39-41,81-86-135, 141]. High-quality lighting systems not only provide the right spectrum of light for photosynthesis but also help maintain a consistent light cycle that mimics natural sunlight [39-41,81-86-135, 141]. This is crucial for the plant's health and can directly impact the quality of the final product [39-41,81-86-135, 141]. For instance, in the United States, many states have regulations that require cannabis producers to use energy-efficient lighting systems, such as LED lights, which not only reduce energy consumption but also provide the right spectrum of light for cannabis cultivation [39-41,81-86-135, 141].

9.8. Genetic Testing

Conducting genetic testing helps to ensure the consistency and stability of cannabis strains [39-41,81-86-135]. Testing for genetic markers can help to identify specific traits and characteristics, allowing producers to produce consistent and reliable products [39-41,81-86-135]. A cannabis cultivator uses genetic testing to confirm the genetic stability and authenticity of a specific strain [39-41,81-86-135]. By identifying unique genetic markers, they can ensure that each batch of the strain exhibits consistent characteristics in terms of appearance, aroma, and effects [39-41,81-86-135].

9.9. Pest and Disease Management

Implementing integrated pest management strategies to control pests and diseases is crucial for maintaining the health and quality of cannabis plants [39-41,81-86-135]. Regular monitoring, proper sanitation, and the use of natural pesticides can help to prevent infestations and disease outbreaks [39-41,81-86-135]. An organic cannabis farm employs beneficial insects like ladybugs and predatory mites to control pests naturally [39-41,81-86-135]. They regularly inspect plants for signs of pests or diseases and promptly address many issues using integrated pest management techniques to prevent infestations [39-41,81-86]. One of the primary regulatory requirements for cannabis producers is to have a comprehensive pest management plan in place [39-41,81-86-135]. This plan outlines the steps and strategies that the producer will implement to prevent, monitor, and control pests throughout the cultivation and production process [39-41,81-86-135]. It should also include details about pest identification, prevention measures, monitoring techniques, and corrective actions to be taken if pests are detected [39-41,81-86-135]. This involves using a combination of cultural, mechanical, physical, biological, and chemical control methods to manage pests effectively [39-41,81-86-135].

9.10. Testing for Contaminants

Regularly testing cannabis products for contaminants such as pesticides, heavy metals, and microbial organisms is crucial for ensuring product safety [39-41,81-86-135]. These tests helps to identify potential health hazards and ensure compliance with regulatory standards. A cannabis testing lab conducts thorough tests on a batch of harvested cannabis flowers [39-41,81-86-135]. The lab tests for pesticides, heavy metals, and microbial contaminants to ensure that the product is safe for consumption and meets regulatory standards [39-41,81-86-135]. Accurate testing and quality control processes are essential for ensuring the safety and potency of cannabis products [39-41,81-86-135]. Regulatory requirements typically include mandatory testing for contaminants such as pesticides, heavy metals, and microbial organisms [39-41,81-86-135]. Additionally, cannabis products are often required to be accurately labeled with information about potency, strain, and any potential allergens [39-41,81-86-135].

Determining whether a product has been obtained from a regulated or unregulated source is a key factor in assessing its overall quality and safety [39-41,81-86-135]. Assessment is complicated when cannabis is not regulated federally, as it is in Canada. For example, in the United States, some individual states have regulated cannabis, but it remains unregulated and illegal at a federal level [39-41,81-86-135]. This has resulted in a lack of standardization [39-41,81-86-135]. This makes the assessment of regulated products more difficult as they may differ per region. Regulations influence the risk of contamination, product quality, and labeling accuracy [39-41,81-86-135].

9.11. Quality Assurance Testing

Conducting comprehensive quality assurance testing is essential to verify the potency, purity, and consistency of cannabis products [39-41,81-86-135]. This includes testing for cannabinoids, terpenes, residual solvents, and other compounds to ensure accurate labeling and dosing information [39-41,81-86-135]. A cannabis manufacturer tests their CBD-infused tinctures for accurate cannabinoid content using high-performance liquid chromatography (HPLC) [39-41,81-86-135]. This ensures that the product contains the specified levels of CBD, THC, and other cannabinoids, providing consumers with accurate dosing information [39-41,81-86-135]. One of the main benefits of implementing good manufacturing practices is that it helps cannabis producers to maintain consistency in their products [39-41,81-86-135]. Consistency is key in the cannabis industry, as consumers rely on the same experience every time they purchase a particular strain or product. By following standardized production methods and protocols, producers can ensure that their products are consistent in terms of potency, flavour, and overall quality [39-41,81-86-135]. This not only helps build trust among consumers but also leads to increased brand loyalty and repeat business [39-41,81-86-135].

9.12. Regulatory Requirements

Good manufacturing practices also help producers to meet regulatory requirements and ensure compliance with industry standards [39-41,81-86-135]. The cannabis industry is heavily regulated, with strict guidelines for cultivation, extraction, processing, packaging, and labeling [39-41,81-86-135]. By following these practices, producers can demonstrate that they are committed to producing safe and high-quality products [39-41,81-86-135]. This not only helps them to avoid legal issues and penalties, but also builds trust with regulators and other stakeholders, such as retailers, distributors, and investors [39-41,81-86-135].

9.13. Packaging and Labeling Compliance

Adhering to proper packaging and labeling requirements is crucial for meeting market expectations and regulatory compliance [39-41,81-86-136]. Proper packaging helps to protect the product from contamination and degradation, while accurate and informative labeling provides consumers with essential information about the product [39-41,81-86-136]. A cannabis edibles producer follows local regulations by packaging their products in child-resistant containers and including accurate labeling with ingredients, dosage information, and necessary warnings to ensure consumer safety and regulatory compliance [39-41,81-86-136]. Proper packaging and labeling are critical for consumer safety and regulatory compliance [39-41,81-86-136]. Regulations often stipulate specific requirements for packaging materials, child-resistant packaging, and labelling information [39-41,81-86-135]. Proper packaging and labelling are crucial for ensuring consumer safety and regulatory compliance [39-41,81-86-135]. Cannabis products should be packaged in child-resistant containers to prevent accidental consumption [39-41,81-86]. Additionally, accurate and comprehensive labelling is essential, including information on potency, ingredients, allergens, and appropriate warnings [39-41,81-86]. To comply with regulations regarding consumer safety and product identification, cannabis producers must have proper packaging and labeling equipment [39-41,81-86-135]. This ensures that products are securely sealed and clearly labeled with accurate information about their contents, dosage, and potential risks [39-41,81-86-135]. In countries like Uruguay, cannabis products must be packaged and labeled according to strict guidelines set by the Institute for the Regulation and Control of Cannabis (IRCCA). This includes using child-resistant packaging and clearly displaying the product's THC and CBD content [39-41,81-86-135]. The National Institute of Standards and Technology (NIST) is now selling a hemp reference material that will help laboratories accurately measure key components in cannabis plant products [39-41,81-86-135]. This will help law enforcement agencies accurately distinguish between hemp and marijuana and will help manufacturers and regulatory agencies ensure that cannabis products are safe and accurately labelled [39-41,81-86-135].

9.14. Continuous Improvement

Regularly reviewing and analyzing quality control data and feedback from customers and regulators is crucial for identifying areas for improvement [39-41,81-86-135]. By continuously evaluating and refining their processes, cannabis producers can stay in line with market expectations and deliver high-quality products [39-41,81-86-135]. A cannabis manufacturer regularly analyzes consumer feedback and testing data to identify areas for improvement. Based

on feedback, they adjust their formulations, packaging, and cultivation practices to enhance product quality and consumer satisfaction [39-41,81-86-135].

9.15. Cannabis Document Control

Establishing a robust document control system helps to ensure the traceability and accountability of every aspect of the production process [39-41,81-86-135]. This includes maintaining detailed records of cultivation practices, testing results, and product distribution [39-41,81-86-135]. A vertically integrated cannabis company maintains detailed records of each plan's cultivation journey, including growth stages, nutrient schedules, and pest management interventions [39-41,81-86-135]. This documentation allows for traceability and accountability throughout the production cycle. Maintaining thorough and accurate records is a crucial aspect of regulatory compliance for cannabis producers. This includes documenting cultivation and production processes, testing results, inventory management, and sales records [39-41,81-86-135]. Authorities may conduct regular inspections to ensure that records are being properly maintained. The cannabis producers are required to keep detailed records of production activities and be able to provide them upon request from the Office of medicinal cannabis [39-41,81-86-135].

9.16. Record Keeping

Accurate record-keeping is essential for traceability and quality control purposes [39-41,81-86]. Cannabis producers must maintain detailed records of their products, including cultivation, processing, packaging, and distribution information [39-41,81-86-135]. This includes documenting batch numbers, testing results, and any recalls or returns [39-41,81-86-135]. In the United States, the Cannabis Tracking System (CTS) is used in several states to track cannabis from seed to sale, ensuring compliance with regulatory requirements [39-41,81-86-135].

9.17. Cannabis Growth Staff Training

Providing thorough training to employees on quality control procedures and protocols is essential for maintaining consistency and product integrity [39-41,81-86-135]. Regular training sessions help to ensure staff is well-informed and up-to-date on best practices [39-41,81-86-135]. A cannabis producer provides comprehensive training to its staff on product knowledge, customer interaction, and compliance with local laws. Well-trained staff can confidently answer customer questions and ensure a positive consumer experience [39-41,81-86-135]. Cannabis producers must invest in ongoing training and education for their staff to ensure compliance with storage and distribution requirements [39-41,81-86-135]. This includes training on proper handling, storage, and transport procedures, as well as knowledge of applicable regulations and quality control practices [39-41,81-86-135]. The producers must undergo training and certification by the Institute for the Regulation and Control of Cannabis (IRCCA) to ensure compliance with storage and distribution regulations [39-41,81-86-135].

9.18. Security and Transportation

Cannabis producers must prioritize security measures to prevent theft, diversion, or unauthorized access to their facilities and products [39-41,81-86-135]. This includes implementing surveillance systems, access controls, and transportation protocols [39-41,81-86-135]. Transporting cannabis products may require additional permits and adherence to specific security requirements [39-41,81-86-135]. The cannabis producers must transport their products in sealed and labeled containers while complying with security protocols established by the Institute for the Regulation and Control of cannabis [39-41,81-86-135]. The transportation of cannabis products from the production facility to the retail location must also meet strict regulatory standards [39-41,81-86-135]. This includes proper handling, tracking, and security measures to prevent theft and diversion [39-41,81-86]. Transport vehicles should be equipped with GPS tracking systems and maintained at appropriate temperatures to preserve product quality [39-41,81-86-135].

9.19. Documentation and Pest Monitoring

Cannabis producers are required to regularly monitor their cultivation areas for signs of pest activity and maintain detailed records of these inspections [39-41,81-86-135]. This includes documenting the types of pests observed, the extent of the infestation, and any actions taken to address the issue [39-41,81-86-135]. Regular monitoring allows producers to detect and address pest problems promptly, minimizing the risk of crop damage and contamination. For instance, in Australia, the Office of Drug Control requires cannabis producers to maintain accurate records of pest management activities [39-41,81-86]. This includes records of pest monitoring, identification, control measures used, and any pest-related incidents [39-41,81-86-135].

9.20. Safe Pest Control Products

Regulations often specify the types of pest control products that can be used in cannabis cultivation and production [39-41,81-86-135]. Producers must ensure that they use only authorized pest control products that are safe for cannabis and comply with applicable regulations [39-41,81-86-135]. This involves following label instructions, adhering to recommended application rates, and keeping detailed records of all pest control product usage [39-41,81-86-135]. In the Netherlands, cannabis producers must comply with the Dutch Plant Protection Act, which regulates the use of pest control products in agriculture, including cannabis cultivation [39-41,81-86-135]. This ensures that only authorized products are used and that they are applied safely and responsibly [39-41,81-86-135]. Quality control is a vital aspect of cannabis production, and accurate testing of cannabis products is essential. Cannabis producers need to invest in reliable testing equipment to assess the potency, purity, and safety of their products [39-41,81-86-135]. For instance, in Germany, the Cannabis Agency requires cannabis products to undergo extensive testing for contaminants, including heavy metals, pesticides, and microbiological impurities [39-41,81-86-135]. This necessitates the use of sophisticated analytical equipment such as gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC) systems [39-41,81-86-135].

9.21. Pest Exclusion Measures

Cannabis producers are required to implement measures to prevent pests from entering their cultivation areas [39-41,81-86-135]. This may involve using physical barriers, such as screens or nets, to keep pests out or installing air filtration systems to remove airborne pests [39-41,81-86-135]. Additionally, cannabis producers may need to establish protocols for inspecting and quarantining incoming plant material to prevent the introduction of pests into the facility [39-41,81-86-135]. In Germany, the German Medicinal Products Act requires cannabis producers to implement measures to prevent pests from entering the cultivation area [39-41,81-86-135]. This includes using pest-resistant building materials, installing insect screens on windows, and implementing strict plant quarantine measures [39-41,81-86-135].

9.22. Cannabis Software for Cannabis Producers

Cannabis producers can leverage seed-to-sale cannabis software to guarantee compliance with all storage and distribution-related regulatory requirements [39-41,81-86-135]. By implementing seed-to-sale cannabis software, producers can track and monitor their entire supply chain, from seed to sale [39-41,81-86-135]. They can ensure that every step, whether it is cultivation, harvesting, processing, or distribution, adheres to strict quality control standards [39-41,81-86-135]. Using this software allows for the seamless integration of inventory data, lab results, and compliance [39-41,81-86-135].

9.23. Seed-to-Sale Cannabis Software

GrowerIQ's seed-to-sale cannabis Quality Management Software is a game-changer for cannabis producers looking to meet compliance standards not only in Canada but also in Europe and the rest of the world [39-41,81-86-135]. This software ensures that every step of the production process is closely monitored and documented, allowing producers to maintain the highest quality standards and comply with regulations [39-41,81-86-135].

One of the key features of GrowerIQ's software is its ability to track and trace the entire lifecycle of each cannabis plant, from seed to sale [39-41,81-86-135]. This level of transparency is crucial in meeting compliance standards, as it allows producers to accurately report on the origin and movement of every plant, ensuring that all legal and regulatory requirements are met [39-41,81-86-135]. Additionally, the software automates many of the tedious and time-consuming tasks associated with quality control, such as data collection, analysis, and reporting, streamlining the process and reducing the risk of human error [39-41,81-86-135].

Another advantage of GrowerIQ's software is its comprehensive quality management system [39-41,81-86-135]. This system includes features such as real-time monitoring of environmental conditions, quality inspection checklists, and the ability to integrate processes & SOPs [39-41,81-86-135]. This allows cannabis producers to implement constraints with digital sign-off so that SOPs are followed exactly and that proper reviews are conducted throughout each phase of production [39-41,81-86-135].

9.24. Security Measures

Cannabis production facilities are required to have robust security systems in place to prevent unauthorized access and protect against theft or diversion of the product [39-41,81-86-135]. This includes surveillance cameras, alarm systems, access control, and proper record-keeping [39-41,81-86-135]. Adequate security measures help to ensure the integrity

of the supply chain and prevent the illicit market from infiltrating the legal cannabis industry [39-41,81-86-135]. In European countries, Australia, USA and Canada, producers are required to have a comprehensive security plan that includes measures such as 24/7 video surveillance, alarm systems, secure storage areas, and strict access control [39-41,81-86]. These measures are aimed at preventing unauthorized access and safeguarding the product from theft or diversion [39-41,81-86-135]. Cannabis production facilities required robust security measures to prevent unauthorized access and theft. This may involve installing surveillance cameras, alarm systems, access control mechanisms, and secure storage solutions [39-41,81-86-135]. The cannabis producers are required to implement comprehensive security measures, including the use of cameras that provide continuous surveillance of cultivation areas, processing areas, and storage areas [39-41,81-86-135]. Access to these premises must be restricted to authorized personnel only [39-41,81-86-135].

9.25. Waste Management Protocols

Proper waste management is crucial for cannabis producers to comply with environmental regulations and prevent the contamination of soil, water, or air [39-41,81-86-135]. Regulatory requirements often specify how producers should handle and dispose of plant waste, packaging materials, and other byproducts of the cultivation process [39-41,81-86-135]. The cannabis producers must have appropriate waste management protocols in place, such as proper storage, handling, and disposal of plant waste [39-41,81-86-135]. This includes ensuring that waste is stored in a secure and controlled manner, and using approved containers and disposal methods to minimize the impact on the environment [39-41,81-86-135].

9.26. Sanitation and Hygiene Protocols

Maintaining cleanliness and hygiene within the production facility is essential to prevent the growth of mold, bacteria, or other contaminants that can affect the quality and safety of the cannabis [39-41,81-86]. Regulatory requirements often include guidelines on sanitation practices, such as regular cleaning and disinfection of equipment, surfaces, and work areas [39-41,81-86]. In European countries, USA, Canada, cannabis producers must comply with strict hygiene regulations, which include regular cleaning and disinfection of all areas and equipment used in the cultivation process [39-41,81-86]. This will help to prevent the spread of diseases, pests, and contaminants that can compromise the quality of the product [39-41,81-86].

9.27. Developing Trust with the Public

Good manufacturing practices help to protect the health and safety of both consumers and employees [39-41,81-86-15]. By implementing strict quality control measures, producers can identify and eliminate potential hazards, such as pesticide residues, microbial contaminants, and heavy metals [39-41,81-86-135]. This not only ensures that consumers are consuming safe and reliable products but also creates a safe working environment for employees [39-41,81-86-135].

9.28. Quality Control and Quality Assurance (QC/QA) measures

In the past decade, the predominant prohibition model for cannabis use has shifted towards a regulated legal model, most widely in the context of medical purposes [39-41,81-86-135]. In 2018, Canada became the first G7 country to legalize cannabis for adult use, implementing a two-phase roll-out of cannabis regulations [39-41,81-86-135]. A stated goal of the new legal framework is to minimize harms by providing a safe supply of cannabis to Canadian consumers. One way that this can be achieved is through appropriate Quality Control and Quality Assurance (QC/QA) measures [39-41,81-86-135]. Canada has implemented stringent QC/QA measures for all classes of cannabis, which include requirements such as labelling THC and CBD content per product and limiting THC doses [39-41,81-86-135]. QC/QA standards represent a key safety feature that can enable informed purchasing and provide consumers with necessary information about various cannabis products [39-41,81-86-136]. As Canada continues to progress its cannabis policies, QC/QA measures provide a key consideration for ensuring Canada meets its objective of providing a safe supply of cannabis to Canadian consumers [39-41,81-86-135].

9.29. Wrong Labeling and Contaminated Products

Recently one of the study conducted by Gidal et al., (2024) [95] demonstrated that the majority of commercially available CBD products tested within the current study are inaccurately labeled [95,136]. Heavy metals, residual solvents, and pesticides were found in several products, some of which violated regulatory thresholds [95]. Thus, uniform compliance with CBD quality control measures is lacking and raises consumer protection concerns [95]. Improved regulatory oversight of cannabis industry is recommended [95]. MacCallum et al., (2023) [39] are also of the opinion that an investigation on labeling accuracy in the United States uncovered that cannabinoid content (THC and

CBD) was under labeled in 25% and over labeled in 60% of products tested (75 total) [39]. Overlabeling of products may lead patients to use products that will not provide them with the expected medical benefit [39, 136]. Alternatively, under-labeling poses a safety risk from unexpected impairment or adverse events [39, 136]. In regulated markets, such as Canada, products from regulated sources must uphold strong government-mandated regulations and pass standardized testing [39]. These products must accurately display cannabinoid content and be free of or within the acceptable range for contaminants, pesticides, microorganisms, and diluents or fillers [39]. Unfortunately, many cannabis products, especially from unregulated sources, lack standardized laboratory testing to ensure a final product meeting safety standards is produced [39]. Companies have started to use terminology such as "sustainably grown" or "pesticide-free" on their products, but in many cases these terms do not reflect efficacy or purity due to lack of regulated testing [39]. Without regulations and standardized testing, it is often up to the company's internal quality assurance and processes [39].

Chemical and microorganism contaminants are one of the primary concerns regarding unregulated products [13, 39-41]. Cannabis can be contaminated with microorganisms (pathogenic bacteria, yeasts, and molds) during any stage of production [13, 39]. Microorganism-contaminated products can be dangerous for medical patients, especially those with immunocompromising conditions or using immunosuppressive therapies, as they are at high risk of infection [39]. Owing to the risk of microorganism contamination, decontamination processes using pesticides are not uncommon throughout the growth process [39]. This is worrisome in unregulated markets, where regulations and testing requirements may not be followed to ensure the type of pesticide and levels are within acceptable ranges [39]. Pesticide-contaminated products are also of concern, especially for young patients with neurological conditions [39-41-135]. Adherence to regulations limits the risk of contamination while also improving clarity and reliability within products [39].

9.30. Problems in Cannabis Quality Assurance and Quality control

- Many laboratories falsify test results. They hide the report of high cannabinoid content or cover pesticide use. Thus, this poor enforcement of lab standards are need to be taken care of while auditing the labs for quality assurance [39-41,81-86-136].
- Currently, companies self-sample and are expected to adhere to the required sampling methods [39-41,81-86-135]. This is a major weakness in cannabis quality control. A system third party, such as a testing lab, is needed to collect samples and analyze them to obtain reliable and credible results [39-41,81-86-136].
- Regulatory expertise is insufficient for robust audits at the production, processing, and laboratory levels [39-41,81-86-136].

In order to ensure that manufacturers and laboratories are using best practices and supplying accurate results, regulatory bodies should spot-check the accuracy of final products on retail shelves [39-41,81-86-135]. There are only a few countries that regularly test products directly from retail shelves. Thus, the incorporation of auditing final product testing is also a major requirement of cannabis quality control measures [39-41,81-86-136].

9.31. Use of Toxic Solvents for Extraction

Traditionally, the extraction of phytocannabinoids is performed using organic solvents, including hydrocarbons (e.g., hexane) and alcohols (e.g., ethanol, methanol) [138-140, 144-147]. This method of extraction is cheap, easy to operate, and does not require sophisticated equipment [138-140, 144-147]. However, the solvents used are flammable, toxic, and non-biodegradable, risking human health, besides having a huge environmental impact [138-140, 144-147]. Extraction using these solvents can be efficient but depending on the final product, can impact regulation, and require additional testing [138-140, 145-147]. For instance, residual solvent is strictly regulated and must be defined for medicines under good manufacturing practice [138-140, 144-147]. These solvents due to their toxicity, environmental risk, and flammability are less desirable for large scale extractions. The extracted sample is collected, and the solvent is evaporated [138-140-147]. The process of pressurizing these flammable and potentially explosive gases poses safety hazards. In addition, the gases used in cannabis extractions are often industrial grade and contain impurities that end up in the cannabis extracts [138-140-147]. Moreover, the solvents themselves may become a residue in the final extract [138-140, 144-147].

9.32. Use of Vegetable oils as Solvent

Another trend is the use of vegetable oils such as coconut, canola, sunflower, walnut, palm, or hemp oil for cannabinoid extraction, avoiding the use of toxic and hazardous hydrocarbon solvents in addition to the high pressures involved in the supercritical extraction with CO_2, a technique that is further explained later [138-140, 144-147]. Thus, extraction with vegetable oils or lipids is considered to be solvent-free, safer, and more environmentally friendly compared to

traditional extraction methods using butane or alcohols since it can be performed using certified organic solvents and a post-processing step for solvent removal is not needed as the cannabinoid product is diluted in oil [138-140]. Obtaining an oily cannabinoid product can be convenient since most commercialized CBD products are diluted in an oily medium like hemp seed oil [138-140, 144-147].

10. Conclusion

Cannabis quality control and quality assurance plays an important role for many cannabis industries growth, particularly when they are selling cannabis products on a large scale. Failure to comply with quality assurance tests can lead to major problems for product marketing. However, product seizures and recalls due in part to contamination or the use of incorrect pesticides. These events not only put consumers at risk but often result in sizable losses for cannabis business owners as well, both in the reputation they maintain with consumers and the financial blows they suffer as a result. In recent years, as the demand for high-potency THC continues to grow, cannabis growers are relying on testing labs more than ever before. With potential inaccuracies in pesticide reporting and profit-driven lab practices that prioritize revenue over consumer health, it is imperative to ensure accurate results as well as informed consumers who know what they are consuming. To stay competitive without compromising safety or quality standards, testing labs must set a standard of excellence when serving their customers.

 When those processes are well defined as a part of cannabis business model, it ensures that the cannabis products handled and send out into the world will be consistent in quality and alignment with industry standards. Much in the same way that other consumable products, like water and food, are regulated, cannabis products have to be regulated as consumables to ensure the safety of consumers. With quality assurance systems in place, cannabis industries can identify potential problems quickly and take corrective measures to prevent them from escalating into costly mistakes or product recalls. Often, cannabis businesses assumed that an investment in quality control is just another expense, yet it ultimately maximizes business profitability and acts as an essential investment that will continue to benefit cannabis business even in a regulated world. Cannabis quality assurance and quality control teams play a vital role in ensuring product safety, consistency, and compliance. To optimize quality assurance processes and scale effectively, it is important to address inefficiencies and bottlenecks within team. Additionally, investing in tools like MES software such as Elevated Signals can streamline operations, eliminate inefficiencies, and enhance overall productivity. With improved efficiency and accurate quality management, one can deliver safe and reliable cannabis products that satisfy customers' expectations.

Cannabis quality control is responsible for inspecting, testing and verifying products and procedures against SOPs and specifications. They identify and address defects or issues with the final product. Cannabis quality control teams are responsible for everything from sampling to weighing to validating. They ensure that cannabis edibles are mixed uniformly, dosed at a max 10 mg THC and that all of the equipment used when producing the cannabis edible is verified and calibrated. If a cannabis product is flagged during production, the cannabis quality assurance and quality control teams collaborate to trace it back to the root cause, quarantine it, test it, and make the necessary decisions to destroy or release it. The quality team is essential in ensuring product safety, compliance, and consistency, which leads to satisfied customers who will return for more. Developing quality control processes for cannabis products is crucial to ensuring that cannabis business's QC process is as automated, efficient, and consistent as possible.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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