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Enhancing *Cannabis* Extraction Efficiency and Sustainability through Quantum Computing: (A-Review)

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ABSTRACT

The plant is also known as hemp, although this term is often used only to refer to varieties of *Cannabis* cultivated for non-drug use. *Cannabis* has long been used as hemp fiber, hemp seeds and their oil, hemp leaves as vegetable and juice, for medicinal purposes and as a recreational drug. It has been widely used specifically in incense, peaceful sleep for cancer affected patients and traditional medicine. Its common uses include treating knee joint pain, inflammatory-related complaints, diarrhea, and a tonic, sedative, and cardio caring agent. *Cannabis sativa* is the hemp plant from which marijuana and cannabinoids (leaves, stems, seeds) are derived. The most potent form of this plant's extracts is hash oil, a liquid. Quantum computing, on the other hand, offers unprecedented computational power and can revolutionize various scientific fields. The study's goal is to explore the potential of quantum computing to enhance the extraction process. By employing quantum algorithms, the project aims to optimize critical parameters such as pressure, temperature, and extraction time, leading to improved efficiency and higher yields. Quantum simulations will model the behavior of CO_2 as a supercritical fluid within the cannabis matrix, supplying insights into the complex dynamics of the extraction process. Finally, the use of quantum algorithms promises to ease the development of more efficient and sustainable extraction methods, resulting in the production of high-quality Cannabis-derived products with enhanced medicinal and industrial applications.

Kewwords: *Cannabis*, Phytochemistry, Tetrahydrocannabinol (THC), Quantum computing.

INTRODUCTION

Overview of *Cannabis sativa* as a medicinal plant

Cannabis sativa, also known as marijuana or hemp, is a versatile plant with a wide range of applications and significant medicinal potential. It has been used for centuries in various cultures for its therapeutic properties, and modern research

has shed light on its pharmacological effects[1,2]. From nutritional supplements to textiles, building materials, body care products, food, and medicines, *Cannabis sativa* offers a plethora of uses[1].

The plant has several bioactive compounds, including cannabinoids, terpenes, and flavonoids, which contribute to its favorable health effects[3]. The most well-known and studied cannabinoid is tetrahydrocannabinol (THC), which handles the psychoactive effects of *Cannabis*[6]. However, another prominent compound, cannabidiol (CBD), has gained attention for its potential therapeutic benefits without causing intoxication.

Medicinally, *Cannabis sativa* has been used to treat various conditions throughout history. It has been employed for relieving rheumatism, epilepsy, asthma, pain, and managing sexually transmitted diseases, among other ailments[4]. In recent years, scientific research has focused on its potential applications in chronic pain management, neurological disorders, such as epilepsy, and its anti-inflammatory, neuroprotective, and antioxidant effects[2,3].

It is important to note that while *Cannabis sativa* holds promise as a medicinal plant, caution should be exercised about its use. Different strains and formulations can have varying effects, and individual responses may also differ. Therefore, it is crucial to approach cannabis as a medicine under proper medical guidance and adhere to evidence-based practices[5].

Historical and cultural significance of cannabis use

Cannabis use holds a significant historical and cultural importance that spans centuries. Its popularity has grown, with notable increases among college students[7] and the general population[8]. Throughout history, cannabis has been valued for its medicinal and recreational purposes. Ancient Chinese records mention its analgesic properties, while Indian culture has long associated it with spirituality and rituals. Positive beliefs about cannabis effects have contributed to the formation of a *Cannabis* culture[9]. Societal attitudes and legal frameworks have influenced its perception, leading to periods of acceptance and stigmatization. Understanding the historical and cultural context of cannabis use is essential in appreciating its current significance. The enduring appeal of *Cannabis*, its association with rituals, counterculture, and changing societal views have shaped its position in society.

Importance of studying cannabis extracts for therapeutic benefits

Studying *Cannabis* extracts for therapeutic benefits is significant due to their potential in providing relief and managing various health conditions. By understanding the extraction methods used in the *Cannabis* industry, scientists can ensure the production of high-quality and effective *Cannabis* extracts[10]. Research has shown that cannabis-based medications primarily act through the activation of cannabinoid receptors (CB1 and CB2) in the body[11]. Two of the primary receptor types that comprise the endocannabinoid system, a sophisticated cell-signaling mechanism in the human body, are cannabinoid CB1 and CB2 receptors. These receptors, which are the main targets for *Cannabis* constituents including tetrahydrocannabinol (THC) and cannabidiol (CBD), play a critical role in regulating a number of physiological processes[78].

CB1 receptor: The brain and spinal cord, which make up the central nervous system, are the main locations of CB1 receptors, while they can also be found in some peripheral tissues. In the brain, they are the most prevalent kind of cannabinoid receptor[78]. Compounds such as THC can activate CB1 receptors, which can result in a variety of effects such as mood swings, increased hunger, pain modulation, and changed perception. THC's interaction with CB1 receptors is primarily responsible for its psychoactive effects.

CB2 receptor: Peripheral tissues, particularly those of the immune system, are the primary sites for CB2 receptors. They are also present in the skin, bones, and spleen, among other areas of the body. The regulation of pain, inflammation, and immunological responses is greatly influenced by CB2 receptors. The intoxicating effects linked to CB1 receptor activation are less likely to occur when CB2 receptors are activated[78].

Cannabis sativa, a widely recognized medicinal plant, has been historically employed for the treatment of a range of conditions, including rheumatism, epilepsy, asthma, skin burns, pain,

sexually transmitted diseases, difficulties during child labor, postpartum hemorrhage, and gastrointestinal issues[12]. However, further scientific investigation is necessary to elucidate the specific mechanisms by which *Cannabis* extracts exert their therapeutic effects and to determine optimal dosage and administration methods for different conditions.

Studying *Cannabis* extracts allows researchers to explore their potential in addressing unmet medical needs, offering alternative treatment options for patients who may not respond adequately to existing therapies. Moreover, understanding the therapeutic benefits of *Cannabis* extracts can contribute to the development of novel medications with improved efficacy, reduced side effects, and potentially broader applications.

Phytochemistry of *Cannabis sativa*

Identification and characterization of major cannabinoids

Identification and characterization of major cannabinoids is an important area of research due to the growing interest in the potential health benefits of *Cannabis* and its derivatives. Cannabinoids are a class of chemical compounds that are found in the cannabis plant. The two most well-known cannabinoids are tetrahydrocannabinol (THC) and cannabidiol (CBD). THC is the primary psychoactive compound in cannabis, while CBD is non-psychoactive and has been shown to have potential therapeutic benefits[13].

There are several analytical techniques used for the identification and characterization of major cannabinoids. These include gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS), and high-performance liquid chromatography (HPLC)[13]. These techniques allow for the separation, identification, and quantification of individual cannabinoids in complex biological matrices such as plant material, blood, and urine[14].

In addition to these analytical techniques, researchers also use various extraction methods to isolate cannabinoids from plant material. These include solvent extraction, supercritical fluid extraction, and microwave-assisted extraction. Once the cannabinoids have been extracted, they can be further purified and characterized using techniques such as nuclear magnetic resonance (NMR) spectroscopy[13].

In conclusion, the identification and characterization of major cannabinoids is a rapidly evolving field with many exciting developments. Researchers are using advanced analytical techniques to better understand the chemical properties of these compounds and their potential health benefits.

Cannabidiol (CBD) and tetrahydrocannabinol (THC): key constituents

Cannabidiol (CBD) and tetrahydrocannabinol (THC) are two key constituents of the *Cannabis* plant. They are both phytocannabinoids but differ in their effects. THC is the primary psychoactive constituent of cannabis while CBD is non-psychoactive. There has been considerable scientific attention devoted to these common, but very different, cannabinoids[15].

Recent loosening of legal restrictions on cannabis and its chemical constituents has led to rapid proliferation and wide availability of products containing CBD. Although using pure CBD does not result in THC-like intoxication, it is not risk-free. Research is ongoing to clarify the legitimate therapeutic effects of CBD and to assure the quality, safety, and efficacy of CBD products[16].

THC, on the other hand, is known for its psychoactive effects and is responsible for the "high" associated with cannabis use. It binds to cannabinoid receptors in the brain and can produce feelings of euphoria, relaxation, and altered perception. However, it can also have negative side effects such as anxiety and paranoia in some individuals[17].

Both CBD and THC have potential therapeutic uses and are the subject of ongoing research. They are key constituents of the cannabis plant and have attracted significant interest from the scientific community[18].

Lesser-known cannabinoids and their potential therapeutic effects

Lesser-known cannabinoids are naturally occurring compounds isolated from the *Cannabis sativa* plant. While delta-9-tetrahydrocannabinol (THC) and cannabidiol (CBD) are the two best-known cannabinoids, there are over a hundred

other phytocannabinoids, each having their own unique pharmacological profile, biological effects and thus therapeutic potential[19].

Research has shown that cannabinoids have therapeutic applications for major depression, bipolar disorder, anxiety, posttraumatic stress disorder, and schizophrenia[20,21]. However, further experimental study is required to highlight the benefits and risks of cannabinoid use in the management of these illnesses[21].

Terpenes and other secondary metabolites in *Cannabis*

Terpenes and other secondary metabolites in *Cannabis* have been the subject of much research in recent years. Terpenes are a large and diverse class of organic compounds that are produced by a variety of plants, including cannabis. They are responsible for the characteristic aroma and flavor of many plants, including *Cannabis*. In addition to terpenes, *Cannabis* also produces other secondary metabolites such as cannabinoids and flavonoids[22].

These secondary metabolites have been found to have a wide range of therapeutic effects. For example, some terpenes have been found to have anti-inflammatory, analgesic, and sedative effects. Cannabinoids such as THC and CBD have also been found to have a wide range of therapeutic effects, including pain relief, anti-inflammatory effects, and anti-anxiety effects[23].

Research into the therapeutic potential of these secondary metabolites is ongoing, and new discoveries are being made all the time. As our understanding of these compounds grows, it is likely that we will continue to find new ways to use them to improve human health and well-being.

Traditional and ethnomedicinal use of cannabis
Cultural practices and historical use of cannabis extracts

Cannabis has been used for recreation and in traditional medicine in Africa for centuries since its introduction by Arab traders from India[24]. Though *Cannabis* contains a variety of phytochemicals, its psychotropic activity is attributed mainly to the psychoactive compound ∆-9-tetrahydrocannabinol (∆-9-THC). Additionally, cannabidiol (CBD) and cannabinol (CBN) are two main non-psychoactive cannabinoids present in *Cannabis*(marijuana). *Cannabis* leaves are predominantly used in herbal preparations to manage both human and animal ailments in Africa and elsewhere. Among humans, cannabis leaves are used to treat over 20 ailments, mainly including asthma, measles, diabetes, dysentery, tuberculosis, cancer, cough, malaria, also as an abortifacient. In animals, *Cannabis* is used to manage over 15 ailments, with the common ones being: East Cost fever, heartwater, pneumonia, dysentery, and trypanosomiasis. Pharmacological research has highlighted the benefit of *Cannabis* in managing chronic diseases like cancer, Alzheimer's disease, multiple sclerosis, and diabetes mellitus[25]. Despite its medicinal uses, prolonged use of unprescribed *Cannabis* in humans' results in social, psychological, physiological, and medical risks. This calls for regulated use and further pharmacological studies to show efficacious but safe dosages.

Cannabis sativa L. (hereafter *Cannabis*) is one of the most versatile plants known to man and has traditional roots among many cultures around the world[24]. Because of its exceptional phenotypic plasticity, *Cannabis* has played a key role in various aspects of human life. Even though people have used it for thousands of years, details about *Cannabis* origin are still not well known. The latest studies place its origin in Central Asia[25].

Traditional medicinal applications across diverse cultures

Cannabis has been used for medicinal purposes for thousands of years across diverse cultures. It has gone with the development of human culture from its very beginnings and can be found in the healing traditions of cultures throughout Africa, Asia, Europe, and the Americas.

One example of its traditional use can be found in Bangladesh[26], where folk medicine practitioners have been using *Cannabis sativa* to treat a variety of ailments such as sleep-associated

problems, neuropsychiatric and CNS problems, infections and respiratory problems, rheumatism, gastrointestinal issues, gynecological issues, cancer, sexual issues and other ailments including hypertension, headache, itchiness, increased bile secretion, abortifacient properties, dandruff, fever and urinary problems.

Another example can be found in the CANNUSE database[27] which holds data on traditional uses of *Cannabis*. Over two thirds of this data are made up of *Cannabis* medicinal uses–most of them human medicinal uses–being treatments for 210 human ailments.

These are just a few examples of the traditional and ethnomedicinal use of *Cannabis* for medicinal applications across diverse cultures. There is a wealth of information available on this topic in books such as "Marijuana Medicine: A World Tour of the Healing and Visionary Powers of *Cannabis*" by Christian Rätsch and journals such as the Journal of *Cannabis* Research and the Journal of Ethnopharmacology[28].

Exploration of traditional knowledge in modern research

Cannabis has been used for centuries in traditional medicine and recreation. Its leaves are predominantly used in herbal preparations to manage both human and animal ailments. Among humans, *Cannabis* leaves are used to treat over 20 ailments, including asthma, measles, diabetes, dysentery, tuberculosis, cancer, cough, malaria, and also as an abortifacient. In animals, *Cannabis* is used to manage over 15 ailments[24].

In Bangladesh, folk medicine practitioners (FMPs) from different districts have been using *Cannabis sativa* to treat cited ailments (Table 1)[26]. The higher frequency expresses the vast use of *Cannabis sativa* on the particular problems or ailments. Sleep-associated problems, neuropsychiatric/CNS problems, and infections and respiratory problems fall under frequency 5. Added that, rheumatism, gastrointestinal problems, and gynecological problems fall under frequency 4. And the rest are under frequency 1.

Table 1: Frequency of ailments treated with *Cannabis sativa*

Ailments	Frequency
Sleep-associated problems	5
Neuropsychiatric/CNS problems	5
Infections and respiratory problems	5
Rheumatism	4
Gastrointestinal problems	4
Gynecological problems	4
Cancer	1
Sexual problems	1
Hypertension	1
Headache	1
Itch	1
Increases bile secretion	1
Abortifacient	1
Dandruff	1
Fever	1
Urinary problems	1

Therapeutic potential of cannabis extracts

Efficacy of cannabis extracts in treating various medical conditions

Cannabis sativa L. is a pharmacologically important annual plant. The distribution of this plant parts (leaf, root etc.) has major contribution for the production of cannabis sativa (Table 2). Most productive part of the cannabis plant is leaf as it's 53.8% are being used for the production of the cannabis sativa. Moreover, it produces bioactive phytocannabinoids and other secondary metabolites that have proved therapeutic potential for a wide variety of human health conditions[27]. The last two decades have seen a dramatic shift in cannabis legislation around the world. *Cannabis* products are now widely available and commercial production and use of phytocannabinoid products is rapidly growing[28]. However, this growth is outpacing the research needed to elucidate the therapeutic efficacy of the myriad of chemical compounds found primarily in the flower of the female cannabis plant.

Table 2: Distribution of plant parts use for *Cannabis sativa*

Plant parts	Percentage (%)
Leaf	53.8
Root	23.0
Seed	7.7
Flower/Inflorescence	3.8
Resin	3.8
All parts	3.8

In general, data support a role for *Cannabis*/cannabinoids in pain, seizure disorders, appetite

stimulation, muscle spasticity, and treatment of nausea/vomiting[29]. Given the biological activities of the cannabinoids, there may be utility in treatment of central nervous system disorders (such as neurodegenerative diseases, PTSD, and addiction) or for the treatment of cancer[30]. However, those data are much less compelling.

On balance, there are reasons to support the potential use of medical *Cannabis* and *Cannabis* extract (∆9-THC-dominant or CBD-dominant), but much more careful research is needed[30].

Analgesic and anti-inflammatory effects

Cannabis extracts have shown potential for analgesic and anti-inflammatory effects. Several studies have investigated the use of cannabis extracts in the treatment of conditions such as neuropathic pain and acute or chronic inflammation. One study discusses the anti-inflammatory and analgesic effects of formulated full-spectrum *Cannabis* extract in the treatment of neuropathic pain associated with multiple sclerosis[31]. Another journal discusses the therapeutic potential of *Cannabis* and cannabinoids, saying that *Cannabis* preparations exert many therapeutic effects including antispastic, analgesic, antiemetic, neuroprotective, and anti-inflammatory actions[32].

While a plethora of studies have examined the biochemical effects of purified THC and/or CBD, only a few have focused on the effects of full-spectrum *Cannabis* plant extract. So, studies using purified THC or CBD may not accurately reflect the potential health benefits of full-spectrum *Cannabis* extracts. Indeed, the *Cannabis* plant produces a wide range of cannabinoids, terpenes, flavonoids, and other bioactive molecules which are likely to contribute to the different biological effects. The presence of all these bioactive molecules in *Cannabis* extracts has garnered much attention of late especially on their potential role in the treatment of neuropathic pain associated with multiple sclerosis.

It is important to note that while *Cannabis* extracts have shown potential for therapeutic use, further research is needed to fully understand their effects and potential benefits. Additionally, it is important to consult with a healthcare professional before using cannabis extracts for medicinal purposes.

Anticonvulsant and neuroprotective properties

The therapeutic potential of *Cannabis* extracts for anticonvulsant and neuroprotective properties has been a topic of interest in recent years. *Cannabis* and its extracts have been explored for their potential health benefits, including their potential use in preventing selected neurodegenerative diseases and possible amelioration of cognitive impairments. *Cannabis*-based medicines have shown safety, efficacy, and consistency sufficient for regulatory approval in spasticity in multiple sclerosis (MS), and in Dravet and Lennox-Gastaut Syndromes (LGS)[33]. Research has also examined the potential of *Cannabis*-based medicines in the treatment of other neurological disorders such as intractable epilepsy, brain tumors, Parkinson disease (PD), Alzheimer disease (AD) and traumatic brain injury (TBI)/chronic traumatic encephalopathy (CTE).

While there is still much research to be done on the topic, the potential benefits of *Cannabis* extracts for anticonvulsant and neuroprotective properties are promising[34].

Potential applications in mental health disorders

Cannabis extracts have shown potential therapeutic applications in mental health disorders. Research has found that CBD and CBD-containing compounds such as nabiximols were helpful in alleviating psychotic symptoms and cognitive impairment in patients with a variety of conditions[35]. Several studies supplied evidence of effectiveness in the treatment of *Cannabis* withdrawal and moderate to severe *Cannabis* use disorder.

Another area of research has focused on the role of the endocannabinoid system, which appears deregulated in psychiatric patients[36]. This system is recognized as a fundamental modulator of many physiological processes, including neurodevelopment, emotional states, stress responses, and cognition.

While there is growing evidence supporting the potential therapeutic uses of *Cannabis* extracts in mental health disorders, more research is needed to fully understand their effectiveness and safety[37].

Extraction methods for Cannabis extracts

Overview of conventional extraction techniques

Extraction methods for *Cannabis* extracts are used to concentrate target components for product development. There are several conventional extraction techniques that have been applied to extract phytochemicals from *Cannabis* using various solvents[38]. One such method is solvent extraction, which is the most common method for *Cannabis* plants. Although solventless and hydrodynamic extraction are known for their high yield and feasibility, more investigation is needed in these areas.

Regarding the drying process, hang-drying is the most convenient method; however, it may be substituted by freeze-drying soon. There are important parameters that can affect the yield of the *Cannabis* extract such as mean particle size, size distribution, temperature, rate of agitation, and extraction time[39]. Some common cannabinoids and their molecular formulas are given in Table 3.

Table 3: Common cannabinoids and their molecular formulas[40]

Cannabinoid name	Usual abbreviation	Molar mass (g mol^{-1})	Molecular formula
(-)-trans-Δ9-tetrahydrocannabinol	Δ9-THC	314.472	$C_{21}H_{30}O_2$
(-)-trans-Δ8-tetrahydrocannabinol	Δ8-THC	314.472	$C_{21}H_{30}O_2$
(-)-trans-Δ9-tetrahydrocannabinolic acid A	THCA	358.482	$C_{22}H_{30}O_4$
Cannabidiol	CBD	314.472	$C_{21}H_{30}O_2$
Cannabidiolic acid	CBDA	358.482	$C_{22}H_{30}O_4$
Cannabinol	CBN	310.440	$C_{21}H_{26}O_2$
Cannabinolic acid	CBNA	354.450	$C_{22}H_{26}O_4$
Cannabigerol	CBG	316.488	$C_{21}H_{32}O_2$
Cannabigerolic acid	CBGA	360.498	$C_{22}H_{32}O_4$

Supercritical fluid extraction for efficient extraction

Supercritical fluid extraction (SFE) is a clean and cost-effective method of extracting cannabinoids from cannabis. Carbon dioxide supercritical fluid extraction (CO_2 SFE) is one such method. A study published in Scientific Reports in 2020[40] used design of experiment methodologies to optimize the CO_2 SFE extraction process for medicinal Cannabis bud material at a scale of one kg per extraction. Key variables investigated were CO_2 flow rate, extraction time, and extraction pressure. The study found that CO_2 flow rate had the most influence on the overall yield and recovery of key cannabinoids, particularly CBD. The highest extraction weight of 71 g (7.1%) was obtained under high flow rate 150 g (about 5.29 oz)/min, with long extraction time (600 min) at high pressure (320 bar). This method also gave the best recoveries of THC and CBD.

Another journal[38], mentions that green approaches such as SFE are used to displace conventional methods of pressing and organic solvent extractions. These procedures decrease environmental impacts and reduce toxic residue on products by using supercritical fluids.

Comparison of extraction methods in terms of yield and purity

Extraction methods for *Cannabis* extracts vary in terms of yield and purity. One of the most common methods for cannabis plants is solvent extraction. Solvent extraction involves using a solvent to dissolve the desired compounds from the plant material. The solvent is then evaporated, leaving behind the extracted compounds. Solventless and hydrodynamic extraction are also known for their high yield and feasibility, but more investigation is needed in these areas.

Another method for extracting *Cannabis* extracts is supercritical fluid extraction (SFE). SFE uses supercritical carbon dioxide as a solvent to extract the desired compounds from the plant material. SFE is known for its high yield and purity, but it can be more expensive and complex than other methods[38].

Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) are also alternative methods that have been proposed for the extraction of cannabis extracts[41]. These methods use ultrasound or microwave energy to help the extraction process.

There are several methods for extracting *Cannabis* extracts, each with its own advantages and disadvantages in terms of yield and purity. More research is needed to decide the best method for different applications.

Advances in extraction technology and future prospects

Advances in extraction technology have allowed for more efficient and effective methods of extracting compounds from various materials, including *Cannabis*. These advances have led to the development of new techniques and equipment that can improve the yield and purity of extracted compounds.

One focus in extraction technology is developing green and sustainable methods[38]. This includes using environmentally friendly solvents and techniques that minimize waste and reduce the environmental impact of extraction processes.

In the future, it is likely that we will see continued advancements in extraction technology, leading to even more efficient and effective methods. This could include developing new solvents and techniques and improvements to existing methods. These advancements will likely have a significant impact on a wide range of industries, including pharmaceuticals, food production, and cosmetics.

Standardization and quality control of cannabis extracts

Importance of quality control measures in *Cannabis* research

Quality control measures are essential in cannabis research to ensure consumer safety and mitigate public health risks. Rigorous testing of *Cannabis* derivatives in medicinal and recreational cannabis-based products can help achieve this goal. For example, Canada has implemented stringent quality control and quality assurance measures for all classes of cannabis, which include requirements such as labeling THC and CBD content per product and limiting THC doses[42].

Exposure to toxic substances, pathogenic microorganisms, and adulterants such as synthetic compounds that are designed to mimic the effects of phytocannabinoids can result in patient harm or confound research efforts[43]. Gaps in quality control have resulted in recalls where cannabis for medical purposes is sold, such as in Canada and some U.S states[44].

Quality control measures stand for a key safety feature that can enable informed purchasing and provide consumers with necessary information about various *Cannabis* products. As the cannabis market continues to grow, standardized testing and regulation become increasingly important to ensure consumer safety and minimize harms[45].

Regulatory considerations and challenges in standardization

As the use of cannabis for medicinal and recreational purposes becomes more widespread, there is a growing need for standardized processes and quality control measures to ensure the safety and efficacy of cannabis products.

One challenge in standardizing and regulating *Cannabis* extracts is the lack of federal legalization in some countries. Where medical *Cannabis* is still illegal, and even in countries where *Cannabis* is only legal at the state level, there are frequent gaps in quality control processes. Federal legalization and implementation of standards of practice for growing and testing *Cannabis* may help overcome these gaps[46].

Another challenge is the variability in the composition of *Cannabis* extracts. *Cannabis* plants can vary widely in their chemical makeup, including the levels of cannabinoids such as THC and CBD. Standardization of testing methods and quality control measures can help ensure that cannabis extracts are accurately labeled and consistent in their composition[47].

Overall, regulatory considerations and challenges in standardization for standardization and quality control of *Cannabis* extracts are complex issues that require ongoing research and collaboration between industry, regulators, and researchers.

Analytical techniques for finding cannabinoid content

Some common analytical techniques for finding cannabinoid content include gas chromatography (GC) and high-performance liquid chromatography (HPLC). GC is often used with mass spectrometry (MS) or flame ionization detection (FID), while HPLC can be used with MS or ultraviolet (UV) detectors[48]. These techniques allow for the separation and identification of individual cannabinoids in a sample, allowing for exact quantification.

In addition to these techniques, there are also various sample preparation methods that can be used

to extract cannabinoids from *Cannabis* plant material[49]. These methods can include solvent extraction, solid-phase extraction, and supercritical fluid extraction. The choice of sample preparation method will depend on the specific requirements of the analysis, such as the desired sensitivity and selectivity[50].

Overall, the use of analytical techniques for deciding cannabinoid content is essential for ensuring the quality and consistency of *Cannabis*-based products. These techniques supply exact and reliable data that can be used for standardization and quality control purposes[50].

Ensuring product consistency and safety

Ensuring product consistency and safety for standardization and quality control of *Cannabis* extracts is a prominent issue that has been discussed in several books and journals. It is imperative that both healthcare providers and patients are educated on all aspects of *Cannabis* treatment, including product safety and quality control[51]. There are a few quality control variables to consider when choosing medical *Cannabis* products including contaminants, microorganisms, and pesticides. Quality control standards reduce exposure to harmful chemicals and contaminants such as pesticides, extraction solvents, microorganisms, diluents, and fillers[52]. These may be in a wide range of potential products which patients are considering or already using, including dried flower, oils, and concentrated products such as vapes. These are important considerations when selecting *Cannabis* products and should not be overlooked by healthcare providers, patients, and *Cannabis* consumers in general. Healthcare providers should be aware of which products patients are using and carefully inspect labelling[52]. Quality control is most stringent for products that are obtained from a legal, licensed, and regulated source.

Current research and clinical trials

Overview of recent studies on *Cannabis* extracts for therapeutic purposes

Recent studies and clinical trials have been conducted to analyze the therapeutic use of *Cannabis* extracts. One such study[53] analyzes the current legislation in countries that allow the use of medical *Cannabis* and its impact on clinical trials. The study found that there is still considerable controversy on this topic in the scientific community, particularly concerning the plant species to be used, the pathologies that can be treated, the efficacy and safety of use, the routes of administration, the methods of preparation, the type and dosage of cannabinoids to be used, and the active molecules of interest[54].

Another study[55] aimed to find, characterize, appraise, and organize the current available evidence surrounding therapeutic use of *Cannabis* and cannabinoids using evidence maps. The study found that evidence on medical uses of *Cannabis* is broad but due to methodological limitations, conclusions were weak in most of the assessed comparisons.

These studies provide valuable insights into the current state of research on *Cannabis* extracts for therapeutic purposes. However, more research is needed to fully understand the potential benefits and risks associated with their use.

Clinical trials investigating the efficacy and safety of *Cannabis*-based treatments

Clinical trials investigating the efficacy and safety of *Cannabis*-based treatments have been conducted and published in various journals and books. These trials aim to evaluate the potential benefits and risks associated with using *Cannabis* for medical purposes.

One article reviews the evidence from clinical trials and human laboratory studies evaluating the efficacy of CBD as a therapeutic for various medical conditions, including epilepsy, anxiety, pain/inflammation, schizophrenia, various substance use disorders, post-traumatic stress[54].

One book[53] analyzes the current legislation in countries that allow the use of medical *Cannabis*, in relation to the impact that this legislation has had on clinical trials. It also provides an overview of the different legislation in these countries and analyzes the results of clinical trials published in the last 3 years.

These resources supply valuable information on current research and clinical trials investigating the efficacy and safety of *Cannabis*-based treatments. They can be used to gain a better understanding of the potential benefits and risks associated with using *Cannabis* for medical purposes.

Understanding the limitations and challenges of *Cannabis* research

Understanding the limitations and challenges of *Cannabis* research for current research and clinical trials is important for advancing our knowledge of the potential benefits and risks of cannabis use. One of the primary challenges in conducting *Cannabis* research is the regulatory status of *Cannabis* and cannabinoids in the United States. This can make it difficult to obtain study medications and can limit funding and resources for research. Additionally, there are often constraints associated with clinical trials that can make it difficult to conduct research on *Cannabis*.

There are three primary barriers that contribute to the difficulty in initiating research geared toward answering the most pressing public health questions: the US regulatory status of *Cannabis* and cannabinoids, sources for *Cannabis* and cannabinoid study medications, and limited funding and resources to support studies[56].

Despite these challenges, there is a growing body of research on cannabis and its potential medical uses. By understanding and addressing these limitations and challenges, researchers can continue to advance our knowledge of *Cannabis* and its potential benefits and risks.

Potential constructive collaboration with quantum computing

Introduction to quantum computing and its applications

Quantum computing is a technology that promises to overcome the drawbacks of conventional computing for high density and high-performance applications. It can revolutionize today's computing world and attract more researchers towards this field. Quantum computers exploit principles of quantum mechanics, such as superposition and entanglement, to be data and perform operations on them. Both principles enable quantum computers to solve specific, complex problems 2much faster than standard computers[57].

Some potential application areas of quantum computing include the financial, chemical, pharmaceutical, and automotive sectors. The world's largest technology companies, such as Google, IBM, Microsoft, Amazon, and Alibaba are already investing billions in research and development of their quantum computing. Governments are also investing in this technology[58].

Quantum computing can solve problems currently intractable with classical computers. For example, quantum computers could be used to simulate quantum systems, which could lead to breakthroughs in materials science and drug discovery[59]. Quantum computers could also be used to solve optimization problems, which have applications in fields such as finance and logistics.

Quantum computers could also have a significant impact on cryptography. Many of the encryption methods used today are because factoring large numbers is exceedingly difficult for classical computers. However, a quantum computer could factor large numbers much more quickly using an algorithm known as Shor's algorithm[60]. This means that many of the encryption methods used today could become insecure if a large-scale quantum computer were to be built.

There is still much work to be done before quantum computers become practical for widespread use. Researchers are working on developing new algorithms and error-correction techniques to make quantum computers more robust. There is also ongoing research into developing new hardware technologies to build larger and more powerful quantum computers.

Exploring the potential of quantum computing in *Cannabis* research

Quantum computing can handle certain kinds of computational tasks exponentially faster than today's conventional computers. This could potentially allow for faster and more exact characterizations of molecular systems than existing quantum chemistry methods. Furthermore, algorithmic developments in quantum machine learning offer interesting alternatives to classical machine learning techniques, which may also be useful for the biochemical efforts involved in early phases of drug discovery[61].

Figure 1 illustrates the different *Cannabis* extraction methods, external factors, drying methods, necessary parameters, solvent classifications and

different types of solvents considering for the quantum computing based research for the simulation.

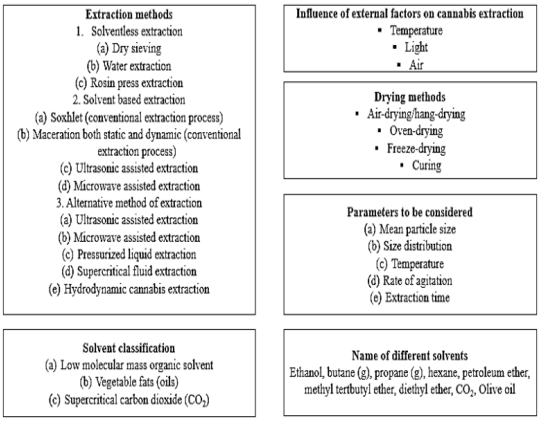

Fig. 1. *Cannabis* extraction methods, external factors, drying methods, necessary parameters, solvent classifications and different types of solvents considering for the quantum computing based simulation[30]

In the context of *Cannabis* research, quantum computing could potentially be used to simulate and predict the structure, properties, and behavior of *Cannabis* molecules more effectively than conventional computing can[62]. This could lead to new insights and breakthroughs in our understanding of *Cannabis* and its potential medical uses.

Quantum computing is a novel way to improve the sustainability and efficiency of *Cannabis* extraction, and it can have a number of advantageous effects on the economy and environment. Fig. 2 shows some methods that the use of quantum computing in *Cannabis* extraction can lead to sustainability.

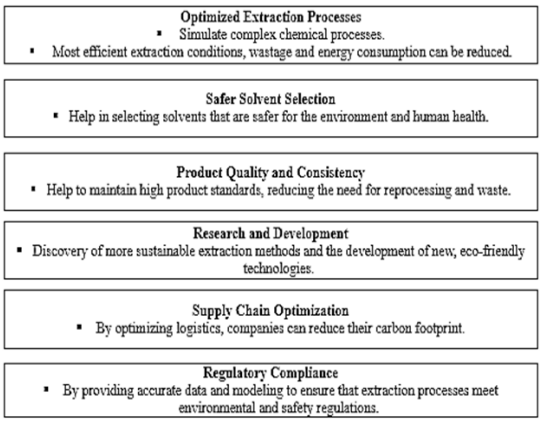

Fig. 2. Some methods that the use of quantum computing in *Cannabis* extraction can lead to sustainability

Quantum simulations for understanding cannabinoid interactions

Quantum simulations can be a powerful tool for understanding the complex interactions between cannabinoids and their receptors. By using advanced computational techniques, scientists can model the dynamics and molecular interactions of cannabinoid receptors, such as CB1 and CB2, to gain a deeper understanding of their function and behavior.

Cannabinoid receptors are part of the G-protein coupled receptor (GPCR) family and are involved in various physiological and homeostatic processes. These pathways include metabolism and hunger, locomotion, memory processing, and the onset of psychoactive effects. In recent decades, it has been uncovered that both endogenous and exogenous ligands and protein-CB1 interactions can elicit specific cellular pathways via biased intracellular signaling[63].

Biased signaling is commenced by inducing various receptor conformations through protein/ligand-based interactions. These receptor conformations promote CB1 coupling with different G-proteins. Coupling to various G-proteins mediates potential therapeutic or adverse side effects. However, the full details on how CB1 controls these pathways and produces its psychotropic effects (upon *Cannabis* consumption) are not fully understood[64].

Quantum simulations can help to fill these knowledge gaps by providing detailed models of the interactions between cannabinoids and their receptors[65]. By leveraging advanced computational techniques such as molecular docking and molecular dynamics simulations, scientists can gain a deeper understanding of the complex dynamics and molecular interactions involved in cannabinoid signaling.

Overall, quantum simulations can provide valuable insights into the complex interactions between cannabinoids and their receptors. By leveraging advanced computational techniques, scientists can gain a deeper understanding of these interactions and their implications for human health[66].

Quantum-inspired algorithms for optimizing extraction and synthesis processes

Quantum algorithms have shown great potential in optimizing extraction and synthesis

processes, including those related to *Cannabis*. These algorithms leverage the principles of quantum mechanics to perform calculations and simulations that can significantly enhance the efficiency and effectiveness of these p2rocesses.

Figure 3 shows the architectural framework for the efficient extraction of Cannabis through quantum computing. It is classified into five phases. The detail descriptions of the phases are given below[79].

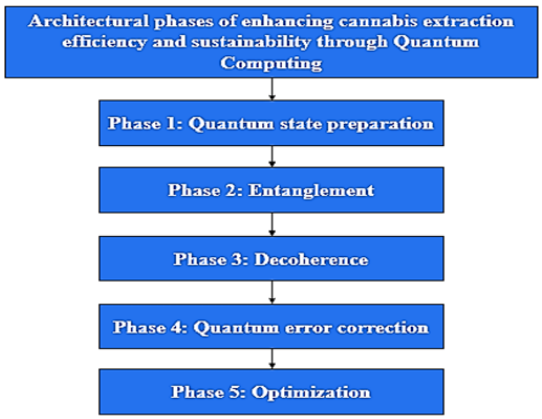

Fig. 3. Architectural framework for the efficient extraction of Cannabis through Quantum Computing (recreate from[79]

Phase 1: Quantum state preparation

Creating a quantum system and initialize it for the sustainable quantum computation of the *Cannabis* extraction, is the preliminary phase. It would be also a necessary phase for any other computation like drug discovery and molecular simulation. For controlling the trustworthiness of the quantum state preparation, research is still going on to find the better physical platform including optimize the control parameter rather than qubits or trapped ions.

Phase 2: Entanglement

After the quantum state preparation, the next step is quantum entanglement that allows expeditious and speedy computation. For the processing of the information from the *Cannabis* extraction computation result, for metrology and sensing, and communication, this phase is the secondary steps. Measuring one particle can destroy the entanglement so that it important to develop new technique for the measurement. In this regard, researchers are trying to scaling up the particle numbers of entanglement.

Phase 3 Decoherence

Due to the molecular interaction with environment and other unmanageable factors, the loss of quantum coherence occurs and researchers call it as quantum decoherence. It is quite challenging to keeping entangled states over faraway or for enough time. Researchers are trying to establish decoherence suppression technique to solve this issue. By minimizing this effect and developing better noise models, it will revolutionize the efficient *Cannabis* extraction process.

Phase 4: Quantum error correction

For reliable *Cannabis* extraction computation, quantum error correction is mandatory due to the decoherence. It allows to preserve quantum information. Researchers are working to develop different quantum fault tolerant schemes and improved hybrid quantum error codding with lower percentage of error, and low overhead.

Phase 5: Optimization

To improve the efficiency of *Cannabis* extraction, resource utilization and performance, optimization of the data set is crucial. Research is going on to explore efficient methods by synthesizing and decomposing quantum gates into a minimal set of elementary gates. No only that but also minimizing gate output and depth. Moreover, developing hybrid algorithm as well as revolutionary algorithm, researcher can find out the optimum values for the *Cannabis* extraction.

One notable approach in this field is the use of variational quantum algorithms (VQAs). VQAs utilize parameterized quantum circuits combined with classical optimizers to tackle complex optimization problems[67]. By encoding the optimization task into a parameterized cost function and iteratively updating the circuit parameters, VQAs aim to find the optimal solution.

In the context of *Cannabis* extraction and synthesis, VQAs can be employed to optimize various aspects of the process. For example, they can be used to determine the optimal conditions for extracting specific compounds from *Cannabis* plants, such as cannabinoids and terpenes. By encoding the extraction parameters into the cost function and leveraging the quantum processing capabilities, VQAs can efficiently explore a large parameter space to identify the most effective extraction conditions.

Similarly, VQAs can aid in optimizing the synthesis processes involved in cannabis production. They can assist in designing and optimizing chemical reactions and reaction conditions to maximize the yield of desired compounds or to minimize unwanted by-products. Quantum algorithms can explore different reaction pathways, identify optimal reaction parameters, and even simulate the behavior of complex chemical systems, providing insights that can lead to improved synthesis processes[65].

It is important to note that while quantum algorithms hold promise for optimizing extraction and synthesis processes, the current state of quantum computing is still in its early stages. Practical implementation of these algorithms on quantum hardware with sufficient qubit resources and low error rates is a significant challenge[68]. However, advancements in quantum hardware and algorithmic development are rapidly progressing, paving the way for future applications in the cannabis industry and beyond.

In conclusion, quantum algorithms, particularly variational quantum algorithms, offer exciting prospects for optimizing extraction and synthesis processes in the *Cannabis* industry. They have the potential to revolutionize the field by enabling more efficient and sustainable methods for extracting valuable compounds from cannabis plants and optimizing the synthesis of desired compounds. Continued research and development in this area are crucial for realizing the full potential of quantum algorithms in *Cannabis* processing and production.

Future perspectives and challenges

Unexplored areas and potential avenues for future research

Unexplored areas and potential avenues for future *Cannabis* research include targeted cannabinoid therapies through randomized controlled trials[69], novel delivery systems to enhance bioavailability[70], and *Cannabis's* capacity for neuroprotection[71]. Additionally, studying interactions with other medications, investigating *Cannabis* use in pediatric medicine, and exploring its impact on mental health disorders are crucial areas. These avenues would contribute to understanding the safety, efficacy, and optimal dosages of standardized *Cannabis* preparations, identifying specific cannabinoids for various medical conditions, and expanding the therapeutic potential of *Cannabis*-based medications. By delving into these areas, researchers can unlock the full medical benefits of *Cannabis* while ensuring its safe and sustainable utilization.

Overcoming legal and regulatory barriers to cannabis research

Several challenges and barriers have been found that contribute to the difficulty in initiating research geared toward answering the most pressing public health questions[72,73]. These include the US regulatory status of cannabis and cannabinoids, sources for cannabis and cannabinoid study medications, limited funding and resources to support studies, and federal restrictions on clinical cannabis research resulting from its legal status as defined by the Controlled Substances Act (CSA) and international treaties.

To promote research on *Cannabis* and cannabinoids, these barriers must first be found and addressed. Some proposed solutions include an objective and evidence-based analysis of *Cannabis* policy to better inform policy makers, exploring and characterizing the full scope of political and nonpolitical strategies for resolving regulatory barriers to *Cannabis* research, and addressing these regulatory barriers so that researchers will be better able to address key public health questions about the therapeutic and adverse effects of *Cannabis* and cannabinoid use[74].

Ethical considerations and patient access to cannabis-based therapies

The use of *Cannabis* for medical purposes has been legalized in many countries and states, leading to an increase in the number of patients seeking access to cannabis-based therapies. However, there are several ethical considerations that need to be considered when prescribing medical *Cannabis*.

One of the main ethical considerations is ensuring patient safety and access to effective treatments. Due to weak or limited evidence of safety and effectiveness, regulatory and cost obstacles to accessing Good Manufacturing Practice (GMP) *Cannabis* medicines, and an absence of unbiased clinical guidance on how to use medical cannabinoids, there is a need for further research and unbiased clinical guidance on the use of medical *Cannabis*[75].

Another ethical consideration is the potential for conflicts of interest between the physician, the patient, and commercial interests. Physicians have an ethical obligation to develop competency to supply cannabis to proper patients and to recommend cannabis only for conditions that have the strongest evidence base[76].

Integration of traditional knowledge and modern scientific approaches

Traditional knowledge systems (TKS) are largely local community-dependent practices that have been passed down through generations. These practices can supply valuable insights into the use of *Cannabis* for medicinal and therapeutic purposes. However, weaving traditional knowledge into modern science perspectives can be challenging as both differ in their characteristics and views. Acceptance and recognition of traditional knowledge, such as folk remedies for illnesses, through modern perspectives needs a multidisciplinary approach. Initiatives towards linking TKS with modern standards of testing may prove to be a useful, relevant, and inexpensive source of potentially therapeutic compounds for human well-being[77].

Integrating Indigenous knowledge into modern science and addressing the gaps in traditional knowledge for science-policy assessments should be set as a high priority. By combining the strengths of both traditional knowledge and modern scientific approaches, we can gain a deeper understanding of *Cannabis* and its potential uses.

CONCLUSION

Cannabis extracts from *Cannabis sativa*, such as ganja fruits and leaves, have extensive therapeutic benefits. Their phytochemical composition, including cannabinoids and terpenes, contributes to diverse therapeutic properties. Throughout history, *Cannabis sativa* has been used for traditional medicine, recreation, and industry, showing promise in pain management, reducing inflammation, neuroprotection, cancer therapy, and mental health. THC and CBD, the primary cannabinoids, have proven efficacy in addressing various health conditions. Cultural and spiritual significance is attributed to *Cannabis saliva's* ethnomedicinal use across cultures. Quantum computing can make the extraction process perfect, enhancing efficiency and yield through quantum algorithms and simulations. Challenges for the future of *Cannabis*-based medicine include legal frameworks, clinical trials, and collaboration between researchers, clinicians, and quantum computing experts. Continued research and collaboration are essential to unlock the full therapeutic potential of *Cannabis* extraction for sustainable production.

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Conflict of interest

The author declare that we have no conflict of interest.

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