



A Comprehensive Review On Therapeutic Potential And Pharmaceutical Applications Of Bitter Gourd Seed Essential Oil

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Abstract: The essential oil derived from bitter gourd (*Momordica charantia*) seeds has garnered considerable interest due to its many pharmacological qualities, such as anti-diabetic, antioxidant, anti-inflammatory, antibacterial, and anticancer effects. This oil, abundant in bioactive components like flavonoids, alkaloids, phenolic acids, and conjugated linolenic acids, has significant medicinal promise. Recent improvements in extraction procedures, nanoencapsulation methods, and formulation strategies seek to improve its bioavailability and effectiveness in medicinal applications. Notwithstanding promising preclinical results, obstacles persist in standardization, extensive clinical validation, and molecular investigations to further corroborate its therapeutic efficacy. This study consolidates existing scientific information, underscores developing research trends, and delineates significant research gaps, establishing a basis for future inquiries into the pharmacological and nutraceutical uses of bitter gourd seed essential oil.

Key words: *Momordica charantia*, essential oil, bioactive compounds, pharmacological properties, clinical applications, nanoencapsulation

I. INTRODUCTION

Momordica charantia, often known as bitter gourd, is a medicinal plant that belongs to the family Cucurbitaceae and is widely cultivated. Its potential medicinal benefits have made it the focus of significant study. Though the fruit has garnered much notice, the seeds have significant bioactivity potential with their essential oils. These oils are particularly suited for therapeutic uses as they are rich in phenolic compounds, flavonoids, alkaloids, and fatty acids. In traditional medicine, bitter gourd has long been recognized for its anti-diabetic, anti-inflammatory, antibacterial, and hepatoprotective qualities. Moreover, modern pharmacological studies are validating these claims (Sharma et al., 2021). Essential oils produced from plant seeds have unique chemical compositions that drive a great variety of physiological actions. Particularly bitter gourd seed essential oil has been shown to be effective in lowering oxidative stress, improving insulin sensitivity, and controlling microorganism growth (Gupta & Kumar, 2020). Recent research has highlighted its significance in the management of metabolic diseases like diabetes as well as disorders linked to chronic inflammation and oxidative damage (Patil et al., 2019). Given the rising prevalence of these diseases, it is

very crucial to look at the therapeutic potentials of the essential oil derived from bitter gourd seeds. Singh et al.'s (2020) study claims the oil has two main fatty acids: oleic acid and linoleic acid. The control of inflammation and the improvement of lipid metabolism are significantly influenced by both these acids. Flavonoids and phenolic chemicals also have strong antioxidant properties that offset the effects of free radicals and help to protect cells. Kumar et al. (2021) claims that in the management of diseases linked with oxidative stress, these traits are especially significant. Among these conditions are neurological ones and cardiovascular issues. Bitter gourd seed oil's anti-diabetic advantages have received much attention in medical research. Research by Sharma et al. (2021) indicates that it has been demonstrated to enhance insulin production and glucose absorption, hence effectively controlling blood sugar levels. This makes it a suitable option for the management of diabetes by natural ways. Gupta and Sharma (2023) claims that its antibacterial activity against dangerous bacteria and fungi suggests it could be useful in treating infections and preventing wound healing. The presence of bioactive alkaloids, which inhibit the growth of bacteria, strengthens even more the role it plays in the formulation of therapeutic product. Due to its diverse pharmacological properties, bitter gourd seed essential oil has attracted significant attention from academics and pharmaceutical developers. Nonetheless, more research, including clinical trials and toxicological evaluations, is required to confirm its effectiveness and safety in human applications. This study intends to provide a comprehensive examination of its chemical composition, pharmacological mechanisms, and therapeutic uses, emphasizing its importance in contemporary medicine. This study will examine the potential of extant scientific material as a sustainable and effective natural medication for different ailments.

II. MORPHOLOGICAL AND PHYSIOCHEMICAL PROPERTIES

The essential oil derived from bitter gourd (*Momordica charantia*) seeds has unique morphological and physicochemical properties that enhance its medicinal and nutraceutical uses. The oil mostly consists of bioactive fatty acids, notably α -eleostearic acid, which forms a substantial part of its lipid composition, in addition to stearic acid, oleic acid, and linoleic acid. These fatty acids enhance the oil's oxidative stability and medicinal qualities (Sharma et al., 2021). The oil extracted from bitter gourd seeds is characterized by a light yellow to golden hue, a thick consistency, and a distinctive nutty fragrance. Oil is extracted by techniques including Soxhlet extraction and cold pressing, with Soxhlet extraction producing a greater oil yield. The oil also has phytosterols, chiefly β -sitosterol, which augment its therapeutic properties by promoting cardiovascular health and anti-inflammatory effects (Patil et al., 2019). The presence of conjugated linolenic acid in the oil has been associated with its potential anticancer capabilities, especially in triggering apoptosis in colon cancer cell lines. The physical and biochemical characteristics make bitter gourd seed essential oil a significant natural product for medicinal formulations and functional food applications.

III. CHEMICAL CONSTITUENTS

The essential oil of bitter gourd (*Momordica charantia*) seed is rich in bioactive phytochemicals that provide enormous proof of medicinal properties. The oil is primarily composed of fatty acids, flavonoids, alkaloids, phenolic compounds, and phytosterols, each playing a crucial role in its pharmacological effects.

3.1. Fatty Acid Content: α -eleostearic acid, one of the most dominant phytochemical present in bitter gourd seed essential oil, constitutes approximately 56–58% of the total lipid content. This compound is known for its antioxidant and anticancer properties, particularly in inducing apoptosis in cancer cells. Other significant fatty acids include stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2), which play roles in anti-inflammatory and cardiovascular health.

3.2. Flavonoids and Phenolic Compounds: Flavonoids and phenolic compounds are abundant in bitter gourd seed oil, contributing to its strong antioxidant activity. These compounds help neutralize free radicals, reducing oxidative stress and inflammation. Key flavonoids include quercetin, which is known for its anti-inflammatory and neuroprotective effects, and catechins, which contribute to antimicrobial and anticancer properties. Additionally, tannins and polyphenols enhance the oil's ability to prevent cellular damage and support wound healing.

3.3. Phytosterols and Their Role: Bitter gourd seed oil contains high levels of phytosterols, particularly β -sitosterol, which has been linked to cholesterol-lowering effects and anti-inflammatory activity. The total phytosterol content in the oil is approximately 886 mg/100 g, making it a valuable component for cardiovascular health. Phytosterols are known to modulate lipid metabolism and improve immune function, further enhancing the oil's medicinal value.

3.4. Alkaloids and Their Pharmacological Significance: Bitter gourd seed oil contains alkaloids such as momordicine, which has demonstrated anti-diabetic and hepatoprotective effects. These alkaloids regulate insulin sensitivity and liver detoxification mechanisms, making the oil a promising candidate for metabolic disorder management. The presence of bioactive alkaloids also contributes to its antimicrobial properties, inhibiting the growth of pathogenic bacteria and fungi.

IV. PHARMACOLOGICAL PROPERTIES

4.1. Anti-diabetic mechanism: The essential oil of bitter gourd (*Momordica charantia*) seeds has been well investigated for its anti-diabetic effects, mostly attributed to its abundant bioactive components that modulate glucose metabolism and enhance insulin sensitivity. Studies demonstrate that the oil has momordicine, a significant alkaloid that stimulates insulin production and promotes pancreatic β -cell functionality, therefore lowering blood glucose levels (Gayathry & John, 2022). The presence of α -eleostearic acid and linoleic acid activates the AMPK pathway, which is essential for glucose absorption and energy homeostasis (Saha et al., 2024). Research has shown that bitter gourd seed oil suppresses NF- κ B and MAPK pathways, hence diminishing inflammation and oxidative stress, which are associated with insulin resistance and type 2 diabetes (Saha et al., 2024). Moreover, experimental investigations on diabetic animal models indicate that supplementation with bitter gourd seed oil markedly reduces fasting blood glucose levels and improves lipid profiles, indicating its potential as a natural therapeutic agent for diabetes control. Bitter gourd seed essential oil, due to its diverse pharmacological properties, is being extensively investigated for incorporation into functional foods and nutraceutical products for diabetes prevention and management. Additionally, more clinical studies are required to determine its effectiveness and safety in human populations (Saha et al., 2024).

4.2. Antioxidant and Anti-Inflammatory: The essential oil of bitter gourd (*Momordica charantia*) has considerable antioxidant and anti-inflammatory properties, mostly attributable to its abundant flavonoids, phenolic compounds, and unsaturated fatty acids. The oil contains α -eleostearic acid, a conjugated linolenic acid essential for neutralizing free radicals and diminishing oxidative stress, therefore averting cellular harm. Research indicates that bitter gourd seed oil has significant free radical scavenging ability, especially against DPPH and ABTS radicals, demonstrating its robust antioxidant potential (Saha et al., 2024). The inclusion of quercetin, catechins, and tannins augments its capacity to mitigate oxidative damage, rendering it advantageous for ailments associated with aging, neurological illnesses, and cardiovascular problems. Bitter gourd seed oil also regulates inflammatory pathways, namely by decreasing NF- κ B and MAPK signalling, which are implicated in chronic inflammation. This technique aids in mitigating inflammation-related conditions such as arthritis, metabolic problems, and cardiovascular issues (Yoshime et al., 2016). Moreover, studies indicate that the phytosterols in the oil, especially β -sitosterol, have a role in its anti-inflammatory properties by downregulating pro-inflammatory cytokines, thereby diminishing systemic inflammation. Due to its diverse pharmacological characteristics, bitter gourd seed essential oil is being extensively investigated for its potential use in nutraceuticals and pharmaceuticals targeting oxidative stress and inflammatory disorders (Gayathri and John, 2022).

4.3. Anticancer activity: The essential oil extracted from bitter gourd (*Momordica charantia*) seeds has notable anticancer properties, mostly attributable to its abundant bioactive components that promote apoptosis and suppress tumour growth. Research has identified conjugated linolenic acids, especially α -eleostearic acid, as critical elements responsible for their cytotoxic effects on cancer cell lines, including those of colon and breast cancer. These chemicals stimulate pro-apoptotic pathways, including p53-mediated

signalling, resulting in programmed cell death in malignant cells (Bortolotti et al., 2019). Bitter gourd seed oil also includes flavonoids and phenolic substances that possess potent antioxidant capabilities, mitigating oxidative stress, a significant factor in carcinogenesis. Research has emphasized the oil's capacity to control inflammatory pathways, namely NF- κ B and MAPK signalling, which are often disrupted in cancer development. Bitter gourd seed essential oil mitigates chronic inflammation, a recognized risk factor for tumorigenesis, by blocking these pathways. Moreover, phytosterols like β -sitosterol found in the oil are associated with anti-proliferative properties that inhibit cancer cell proliferation and metastasis (Yoshime et al., 2016). Due to its diverse pharmacological attributes, bitter gourd seed essential oil is being investigated for its possible use in integrative oncology, especially as a supplementary therapy to standard cancer therapies.

4.4. Antimicrobial activity: The essential oil of bitter gourd (*Momordica charantia*) has considerable antibacterial efficacy, mostly attributable to its abundant bioactive constituents, including flavonoids, alkaloids, and phenolic acids. Research has shown that the oil has extensive antibacterial and antifungal characteristics, making it useful against several harmful microbes. Studies demonstrate that bitter gourd seed oil suppresses the proliferation of Gram-positive bacteria, including *Staphylococcus aureus* and *Bacillus subtilis*, as well as Gram-negative bacteria such as *Escherichia coli* and *Pseudomonas aeruginosa*. The antibacterial action is ascribed to momordicine, a bioactive alkaloid that compromises bacterial cell membranes and obstructs microbial multiplication. Bitter gourd seed essential oil has antifungal properties against *Candida albicans* and *Aspergillus niger*, indicating its potential use in the treatment of fungal infections. The oil's elevated phenolic content enhances its capacity to neutralize microbial toxins and inhibit biofilm formation, which is essential in addressing antibiotic-resistant bacteria. Bitter gourd seed essential oil, due to its inherent antibacterial qualities, is being investigated for use in food preservation, medicinal formulations, and dermatological therapies (Torre et al., 2020).

V. FOLKLORE USE OF BITTER GOURD

Bitter gourd has been extensively used in several traditional medicinal systems, including Ayurveda, Traditional Chinese Medicine (TCM), African herbal medicine, and South American folk cures. Bitter gourd seeds were traditionally used in Ayurvedic medicine for skin infections, fever alleviation, and digestive ailments, often processed into pastes or infused in therapeutic oils (Sharma et al., 2020). In Traditional Chinese Medicine, extracts from bitter gourd seeds are said to cleanse the blood, regulate Qi energy, and are recommended for liver cleansing and diabetes management (Li & Wang, 2021). In Southeast Asian societies, bitter gourd seed oil was used topically to promote wound healing, address inflammatory disorders, and relieve joint pain, owing to its cooling and detoxifying properties (Ramachandran et al., 2019). Indigenous populations in India and Africa have historically used bitter gourd seed formulations as anthelmintics to eliminate intestinal parasites and to enhance immune function (Adebola & Yusuf, 2022). Bitter gourd was often used in herbal teas in South and Central America for its hypoglycemic properties, noted in native remedies for diabetes and metabolic illnesses (Fernández et al., 2023). Numerous folkloric uses are now undergoing scientific investigation, with contemporary research substantiating the pharmacological foundations of bitter gourd's therapeutic attributes. Traditional medical procedures depended on empirical application; however, current research has shown that phytochemicals in bitter gourd, including momordicine, flavonoids, and phenolic acids, have a role in its therapeutic efficacy (Sharma et al., 2020; Li & Wang, 2021). The ongoing investigation of traditional knowledge may facilitate the development of plant-derived medications and functional foods that amalgamate old wisdom with contemporary science.

VI. CURRENT RESEARCH TRENDS

Current studies are concentrating on nanoencapsulation methods to enhance the absorption and stability of bitter gourd seed essential oil, namely its α -eleostearic acid and flavonoids, which are responsible for its antioxidant and anti-inflammatory effects (Saha et al., 2024). Nanoformulations are being investigated to enhance therapeutic efficacy in diabetes control, antimicrobial applications, and cancer treatment, hence

improving drug delivery methods. Furthermore, innovative green extraction techniques, like supercritical fluid extraction and ultrasound-assisted extraction, are being advanced to enhance yield and purity while maintaining the oil's therapeutic characteristics (Khan et al., 2023). An intriguing research avenue is the incorporation of bitter gourd seed oil into functional meals and nutraceuticals, with scientists investigating its ability to regulate glucose metabolism and mitigate oxidative stress. This has resulted in heightened investigation of the synergistic effects between bitter gourd seed oil and traditional medications, with the objective of enhancing treatment effectiveness while minimizing negative effects (Gupta & Sharma, 2023). Furthermore, the essential oil derived from bitter gourd seeds is under investigation for its mechanisms of antimicrobial resistance, namely its efficacy against multi-drug-resistant bacteria and fungi. This is essential for the development of natural antibiotic alternatives, as researchers explore its use in dermatological therapies, wound healing, and microbial infections (Patil et al., 2019). Although preclinical investigations have shown substantial pharmacological advantages, experts underscore the need for human clinical trials to confirm its efficacy and safety for prolonged usage. These developments emphasize the increasing scientific focus on botanical medication discovery, highlighting the potential of bitter gourd seed essential oil in contemporary medicine.

VII. CONCLUSION

Essential oil derived from bitter gourd (*Momordica charantia*) seeds has significant pharmacological potential, with several research underscoring its anti-diabetic, antioxidant, anti-inflammatory, antibacterial, and anticancer qualities. The bioactive substances, such as α -eleostearic acid, flavonoids, alkaloids, and phytosterols, have shown potential therapeutic benefits in several animal paradigms. Recent research advances, including nanoencapsulation and environmentally friendly extraction techniques, are enhancing its bioavailability and effectiveness in pharmaceutical formulations. Moreover, its incorporation into functional foods and nutraceuticals offers promising opportunities for illness prevention and control. Notwithstanding significant scientific progress, several research gaps remain unresolved. A significant restriction is the absence of extensive clinical trials, since the majority of research has been performed in vitro or with animal models. Extensive human studies are crucial to determine safety, appropriate doses, and long-term health impacts. Moreover, there is little investigation into standardized extraction and formulation methods, which are essential for guaranteeing consistency in therapeutic effectiveness. Moreover, while synergistic benefits with traditional medications have been proposed, further research into possible interactions and harmful consequences is necessary. A further study gap exists in the mechanistic comprehension of its pharmacological effects. Although research underscores its anti-diabetic, antibacterial, and anticancer properties, the specific molecular routes are yet inadequately investigated. Advanced methodologies, including proteomics, metabolomics, and gene expression studies, may provide profound insights into its therapeutic processes. Future research must concentrate on addressing these deficiencies, namely via the execution of rigorously designed clinical trials, the formulation of standardized pharmacological procedures, and the assessment of long-term safety to promote its wider integration into medical practice. By overcoming these obstacles, bitter gourd seed essential oil may evolve from an experimentally endorsed natural cure to a clinically substantiated pharmaceutical and nutraceutical component.

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