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A Comprehensive Review on Bitter Gourd (*Momordica charantia* L.) As A Gold Mine of Functional Bioactive Components for Therapeutic Food

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Bitter gourd or bitter melon, scientifically known as, is an important cucurbitaceous vegetable widely cultivated in Asia, Africa, and tropical regions for its nutritional and medicinal significance. Despite its characteristic bitter taste, bitter gourd is increasingly recognized as a “gold mine” of functional bioactive compounds with immense therapeutic and nutraceutical potential. The plant contains a wide spectrum of phytochemicals including charantin, polypeptide-P, vicine, momordicosides, cucurbitane-type triterpenoids, flavonoids, phenolic acids, saponins, alkaloids, carotenoids, and dietary antioxidants, which contribute to its diverse pharmacological activities. These bioactive constituents exhibit antidiabetic, antioxidant, anti-inflammatory, anticancer, antimicrobial, antihyperlipidemic, hepatoprotective, immunomodulatory, and anti-obesity properties. Bitter gourd has long been used in traditional medicine systems such as Ayurveda and Chinese medicine for the management of diabetes and other chronic disorders. Bitter gourd is a tropical vine grown mainly in India, China and South East Asia. The plant is cultivated mainly for its fruit part which is edible. Bitter gourd is unaccepted widely due to its bitter taste. Nevertheless, the fruit is a source of several key nutrients. The plant, as a whole contains, more than 60 phyto-medicines that are active against more than 30 diseases, including cancer and diabetes. Currently, the incorporation of the bioactive compounds isolated from bitter gourd into functional foods and beverages finds a new horizon. Nanoencapsulation and novel green extraction methods can be employed to improve the yield and quality of extracted compounds and their stability while incorporation into food products. The present review is an attempt to throw light to nutritional aspects, various bioactive compounds present and important nutraceutical properties of the bitter gourd plant in detail.

Keywords: Bitter gourd, Bioactive, Nutraceutical, Extraction, Encapsulation

Introduction

Momordica charantia L., a prominent tropical and subtropical vine, is increasingly recognized for its vast phytochemical reservoir that holds significant promise for the development of therapeutic food products (Gayathry & John, 2022; Kumar & Pal, 2025). Characterized by its distinct bitter flavor, this member of the Cucurbitaceae family contains a diverse array of bioactive compounds, such as polysaccharides, saponins, and polypeptide-p, which facilitate the management of metabolic disorders and chronic diseases (Bara et al., 2025; Martin, 2024). Beyond its traditional culinary applications, the plant serves as a rich source of over 60 distinct phytochemicals that have demonstrated efficacy against more than 30 clinical conditions, including cardiovascular disease and oncological pathologies (M et al., 2025; Martin, 2024). Recent advancements in molecular research have further elucidated its

capacity to modulate gene expression related to inflammatory responses and apoptosis, positioning the fruit as a potent candidate for nutraceutical intervention (Duarte & Duarte, 2025). Current investigations have also identified emerging components, such as insulin receptor-binding protein-19 and specialized triterpenoids, which appear to play a critical role in regulating glycolipid metabolism and gut microbiota signaling pathways (Xiao et al., 2024).

Furthermore, the integration of these bioactive constituents into functional food matrices requires standardized processing schemes to preserve their pharmacological stability while enhancing bioavailability (Tan et al., 2015). Advanced extraction techniques, such as supercritical fluid extraction, offer a superior, solvent-free approach to obtaining varied chemical profiles while maintaining high selectivity for sensitive phenolic compounds and terpenoids. These technological advancements facilitate the consistent isolation of secondary metabolites, such as Momordica alkaloids and flavonoids, which underpin the plant's diverse antidiabetic, antioxidant, and anti-inflammatory properties (Dandawate et al., 2016; Oliveira et al., 2018; Zhan et al., 2023). Moreover, the exploration of its immunomodulatory potential has revealed that specific polysaccharides and proteins act as potent stimulants of host defense mechanisms, suggesting a broader scope for its application in preventative nutrition. Despite these therapeutic benefits, the prevalence of specific triterpenoid saponins, including momordicine I and momordicoside L, contributes to an intense astringency that challenges.

Bitter gourd: Plant description-

In general, the plant is a monoecious slender, tendril climbing annual vine of almost 2 to 4m high. The plant possesses characteristic leaves with serrate margins which typically giving a look like bites. Each plant has separate yellow coloured male and female flowers. Different varieties of bitter gourd have different shapes of fruits, being discoid or ovoid or ellipsoid to oblong and pointed towards the end (Kole et al. 2020). Usually fruits are 2 to 10cm long. The exterior of the fruits are warty and the cross section is hollow with a thin layer of flesh. Flattened seeds and pith are seen in the central cavity which is surrounded by the thin flesh layer (Gupta et al. 2011). The immature fruits are whitish or pale green in colour whereas the mature ones can be seen in light green, green and dark green depending on the varieties and while ripening the colour turns to orange yellow. The fruit of bitter gourd takes 45 to 80days to gets mature (Sorifa 2018). The seed of bitter gourd is 8 to 15mm long which are straw coloured and they are covered with flesh: white in unripe fruits and red in ripened ones (Poolperm & Jiraungkoorskul 2017).

Nutritional profile

Bitter gourd is an often discarded vegetable, due to its bitter taste despite the fact that it is a source of several key nutrients. It has a higher nutritional value than other cucurbits such as squash, pumpkin, cucumber and zucchini owing to its high mineral and vitamin content (Krawinkel & Keding 2006). The fruit is rich in vitamins namely vitamin A, vitamin E, thiamine, riboflavin, niacin, folate and vitamin C. Similarly, it also has high amount of potassium, iron, calcium, magnesium, phosphorous and zinc. It contains a good amount of dietary fibre. Detailed nutritional composition of bitter gourd fruit is given in Table 1. The calorific value for leaf, fruit and seed were 213.26, 241.66 and 176.61kcal / 100g respectively (Joseph & Jini 2013). Vitamin C is one of the abundant compounds in the plant (Goo et al. 2016). It was pointed out that leaf contains an average of 205mg/100g DW and fruits contain an average of 2022mg/100g DW and also noted that the content was higher in young stage fruits. The seeds of bitter gourd also are a rich source of quality proteins and they meet amino acid requirements/standards laid down by FAO/WHO/UNU for preschool children. The detailed amino acid composition of bitter gourd fruit and seed protein is given in Table 2. The bitter gourd seeds contain 35 to 40% of oil with fatty acid profile containing monounsaturated fatty acids (3.33%), saturated fatty acids (36.71%) and poly unsaturated fatty acids (59.96%) (Saeed et al. 2018). Bitter gourd is one of the few edible fruit which contains conjugated α linolenic acid in its seeds. The presence of a long chain PUFA, α

eleostearic acid has been reported in bitter gourd seed oil (Yoshime et al. 2016). They are one of the naturally best sources of chromium (5.65mg / 100 g) and zinc (45.45mg / 100 g) (Saeed et al. 2018).

Constituents	Quantity	Amino acid	<i>M. charantia</i> mature fruit (mg/g protein)	<i>M. charantia</i> mature seed (mg/g protein)
Moisture (g/100 g)	83.20	Cystine	22.3	16.5
Carbohydrates (g/100 g)	10.60	Aspartic acid	93.8	78.0
Proteins (g/100 g)	2.10	Threonine	25.2	17.4
Fiber (g/100 g)	1.70	Serine	55.0	43.5
Calcium (mg/100 g)	23.00	Glutamic acid	96.0	124
Phosphorus (mg/100 g)	38.00	Proline	54.4	49.7
Potassium (mg/100 g)	171.00	Glycine	44.9	39.9
Sodium (mg/100 g)	2.40	Alanine	51.2	46.7
Iron (mg/100 g)	2.00	Valine	42.2	36.7
Copper (mg/100 g)	0.19	Isoleucine	30.8	30.7
Manganese (mg/100 g)	0.08	Leucine	64.9	60.5
Zinc (mg/100 g)	0.46	Tyrosine	59.4	44.7
B carotene	126.00	Phenylalanine	40.2	34.5
Vitamin C	96.00	Methionine	27.6	23.6
		Histidine	72.8	40.9
		Lysine	101	98.7
		Arginine	45.6	80.8

Table -1 Nutritional composition of bitter gourd (Adapted from Behera et al. 2008; Nagarani et al. 2014; Sorifa 2018; Saeed et al. 2018)

Table 2 Amino acid composition of bitter gourd mature fruit and seed (Adapted from Nagarani et al. 2014; Sorifa 2018)

Bioactive compounds present in bitter gourd

The primary metabolites in bitter gourd are common sugars, proteins and chlorophyll while secondary metabolites are phenolics, carotenoids, curcubitan triterpenoids, alkaloids, saponins etc. Secondary metabolites are responsible for the nutraceuticals properties of bitter gourd which scarcely contribute to the nutritional value but produce beneficial physiological effects in the body (Daniel et al. 2014). Around 228 different compounds were identified from different parts of *M. charantia*. (Nagarani et al. 2014) Aqueous extract of bitter gourd contained carbohydrates, proteins, amino acids, sterols, flavonoids, phlobatannins, terpenoids, cardiac glycosides and saponins. Qualitative tests found out the presence of carbohydrates, proteins, amino acids, phenolics, saponins, sterols, alkaloids, cardiac glycosides, cholesterol and phlobatannins in the ethanolic extract of bitter gourd. Hexane extract showed the presence of alkaloids, cardiac glycosides, saponins and cholesterol. Methanolic extract was found to contain alkaloids, glycosides, cholesterol, saponins, flavonoids and terpenoids (Supraja et al. 2015). Barua et al. (2020) extracted bioactive compounds from fruits of two varieties of *M. charantia* with petroleum ether, ethyl acetate and ethanol. Phytochemical screening of the obtained extracts revealed the presence of alkaloids, flavonoids, saponins and tannins while the ethanolic extract showed higher phenolic content which may have the potential for food application. The essential oil obtained from the seeds of *M. charantia* was analysed by GC/MS and 25 constituents representing 90.9% of the oil were identified; the main constituents being trans- nerolidol, apiole and cis – dihydrovarveol (Braca et al. 2008). Kumari et al. (2017) concluded that the phytochemical composition of bitter gourd genotypes exhibited genetic diversity in phytochemical composition in flesh of bitter gourd and this variation may be due to genotype, level of phytochemicals present in genotypes, agro climatic condition and other agricultural practices.

Anti- diabetic activity

Diabetes mellitus is a metabolic disease characterised by hyperglycaemia resulting from defects in insulin secretion, insulin action or both. *M. charantia* is a traditional remedy used since ages for management of diabetes in alternative and complementary medicine. Extensive research has been conducted to identify the compounds and the mechanism of anti-diabetic activity attributed to the bitter gourd.

Anticancer property

In last few decades, a number of preliminary trials have been conducted to reveal and establish the anti-cancer property of *Momordica charantia*. Studies suggest the role of bioactives in *M. charantia* in the regulation of cervical cancer, breast cancer, liver cancer, nasopharyngeal carcinoma, leukemia, colon cancer etc. Although several trials have been

conducted in vitro and in vivo to explore the activity against carcinoma, systematic clinical trials are needed in cancer patients to establish the anti-cancer effects of *M. charantia*. In vitro anticancer activity of ethanolic extract of *M. charantia* whole fruit on cell lines representing breast and cervical carcinomas was established by Shobha et al. (2015). Cytotoxicity assay on HeLa (cervical cancer) and MCF 7 (breast cancer) cell lines showed 50% ethanolic extract is more potent based on IC₅₀ value. The effect was directly attributed to the higher content of phenolic acids in the ethanolic extract. Güneş et al. (2019) also reported that the ethanolic whole fruit extract exhibited a higher anti-cancer activity. They investigated and compared the anti-carcinogenic effect of *M. charantia* fruits and seed extracts on human cancer cell lines which included lung cancer (A 549), breast cancer (MCF 7), chronic myeloid leukemia (K 562) and T cell leukemia (Jurkat cells). These were incubated with ethanol and acetone extracts of fruits and seeds of bitter gourd. Among the acetone and ethanolic seed and fruit extracts, ethanolic fruit extract showed the highest anti-tumour activity (90, 92, 85, and 87% against K562, A549, MCF 7 and Jurkat cell lines respectively) and they suggested the ethanolic extract as a potential source for development of anti-cancer compounds. Fang et al. (2012) studied the activity of *Momordica charantia* lectin, a type of ribosome inactivating protein from bitter gourd on two nasopharyngeal carcinoma cell lines, NPC CNE 1 and CNE 2 using in vivo assay in nude mice. Lectin was purified from bitter gourd seeds. The protein showed potent cytotoxicity towards both the cell lines CNE 1 and CNE 2 at the half maximal inhibitory concentration (IC₅₀) of 6.9 and 7.4 respectively. An intraperitoneal injection of lectin (1mg/kg/d) led to an average remission of NPC xenograft tumours subcutaneously inoculated in mice. A similar study was also reported in which MAP 30 protein, isolated from bitter gourd seeds, promoted the apoptosis in liver cancer cells in vitro and in vivo. Inhibition in cell viability with an IC₅₀ value of 28.6µM for 24hrs and 7.8µM for 48hrs was obtained in Hep G2 cells and the anti-tumour potential was also effective in Hep G2 bearing mice (Fang et al. 2012). Dia and Krishnan (2016) reported a novel anticancer peptide, BG-4 isolated from *M. charantia* seeds showed a trypsin inhibitory activity 8.6 times higher than soybean trypsin inhibitor, which can be a possible reason for BG-4 to cause cytotoxicity to human colon cancer cells HCT116 and HT-29 with median effective dose (ED₅₀) values of 134.4 and 217µg/ml respectively. The report was first to establish and anti-cancer potential of a novel bioactive peptide isolated from *M. charantia*. However, in vivo models were not conducted to address the results. Similarly Bai et al. (2016) pointed out the potential of a triterpenoid from bitter gourd in inhibiting the growth of breast cancer cells by conducting an in vitro assay in MCF 7 and MDA-MB- 231 breast cancer cell lines. The triterpenoid 3β, 7β, 25 - trihydroxycucurbita 5,23 (E)- dien-19- al (TCD) was isolated from whole *M. charantia* plant. Suppression in proliferation of MCF-7 and MDAMB-231 breast cancer cell lines with IC₅₀ values at 72h of 19 and 23µM respectively via a PPAR γ independent manner was established. Yung et al. (2016) suggested the use of crude bitter melon extract as a supplement to improve the efficacy of cisplatin based chemotherapy in ovarian cancer.

Methods of extraction of bioactive components from bitter gourd

Owing to the above said nutraceutical properties of bioactive compounds from *M. charantia*, recently much attention is being paid to the extraction techniques of those compounds. It is very much important that the extraction should not affect quality of the compounds and the extract should not be toxic, as it has to be incorporated ultimately to a food. Similarly, the technique must provide maximum yield along with maximum bioactive content. Solid liquid extraction is the most used method for the extraction from fruits and vegetables in which plant material is mixed with the extraction solvent and let the soluble phytochemicals diffuse out of the plant cell walls (Sutanto et al. 2015). A wide range of studies are being conducted using different solvents namely water, ethanol, methanol, acetone, hexane and butanol to find out the suitable method which gives highest bioactive content in the bitter gourd extract as depicted in Table 6. Extraction using water is the safest and easiest procedure even though the yield of phytonutrients is a matter of questioned. Jain and De (2016) suggested an optimum condition for water extraction of proteins and polyphenols with an optimum

temperature and fruit water ratio. However, even after optimization the yield was found to be lower when compared to alcohol based extraction. In contrast, another report suggested that the aqueous method could be optimised to give an extraction yield of phenolic compounds equivalent to that obtained with the best organic solvent tested (80%) alcohol and less solvent and less time was required with water than with 80% alcohol (Tan et al. 2014). However, in the case of extraction of flavonoids particularly, acetone was the best solvent among water, n - butanol, methanol and ethanol even though after trying with optimised conditions for water extraction (Tan et al. 2014). Studies have also investigated alternate extraction procedures, such as ultrasound assisted extraction of bioactive compounds from bitter gourd fruit. This method reduces both extraction time and temperature (Sutanto et al. 2015). Another study compared two sonication modes namely normal and pulsed mode and optimised the variables. Among them pulsed mode sonication showed better performance than that of normal mode sonication with marginally lower vegetable to solvent ratio but higher bio active content and it was suggested as a promising method with respect to conventional methods for production of bitter gourd aqueous extract for medicinal and functional applications (Chakraborty et al. 2020). An attempt was also made to extract β -carotene from enzyme treated ripe bitter melon pericarp using supercritical fluid extraction using carbon dioxide as a solvent and ethanol as a modifier to enhance the yield (Patel et al. 2019). Further, another study also put forward the use of super critical carbon dioxide extraction in extracting charantin from dried bitter gourd fruit promising a better yield of charantin with ethanol as a modifier. However, the highest yield of charantin was obtained by soxhlet extraction with water as solvent and lowest yield with supercritical extraction using pure carbon dioxide when a comparative study was done. When supercritical carbon dioxide extraction method was modified with ethanol, the extraction was more effective than conventional method. Thus it was proposed as a 'green extraction method' than a conventional method (Zaini et al. 2018). Microwave assisted ethanol extraction of saponins were also tried from *Momordica cochinchinensis* seeds and use of full fat seed powder was recommended for better yield (Le et al. 2018).

Conclusion

Bitter gourd is a wonder fruit which has nutritional and functional properties but due to its bitter taste, usage among population is limited. Not only the fruit but other parts of the plant also have proven functional attributes. Numerous researches had identified the bioactive compounds present in the bitter gourd and different parts of the plant. In vitro and in vivo studies have also extensively investigated bioactive properties such as anti-diabetic, anti-cancer, hypocholesterolemic, anti-dementia activities among others. Various novel technologies and concepts like nanoencapsulation and green extraction methods enhance the possibilities of bitter gourd as a functional food thereby adding the need of value addition. However, researches are still at its infancy. The applications of bitter gourd and the identified phytochemicals in food and pharmaceutical industries are yet to be explored widely. The long term effects of consumption of bitter gourd have not been studied and moreover the bioactivities are proven mostly in vitro and in vivo trials. Proper clinical trials are required to know the efficient and effective positive effects of these properties on human systems.

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