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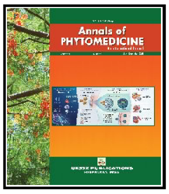

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A review on *Momordica cymbalaria* Hook. Fenzl.: A neglected treasure of phytomedicine

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Abstract

Momordica cymbalaria Hook. Fenzl., a member of the Cucurbitaceae family, is native to the tropical regions of India and Southeast Asia. Locally referred to as kasarakai in Telugu, this plant is not cultivated commercially like other vegetable crops. Instead, it grows naturally during the monsoon season, particularly in areas with black soil found in states such as Tamil Nadu, Karnataka, Madhya Pradesh, Maharashtra, and Andhra Pradesh. This perennial herb develops tuberous roots that enable it to survive unfavorable conditions. While the aerial parts wither at the end of the growing period, the tubers remain dormant in the soil and sprout again when conditions become suitable. Although, it can grow in both the rabi and kharif seasons, its commercial cultivation remains limited due to a lack of public awareness about its nutritional and therapeutic benefits. Recently, interest in *M. cymbalaria* has increased owing to its notable nutritional advantages and diverse medicinal uses. The fruit is recognized for its blood sugar-lowering, kidney-protective, and antidiarrheal properties. Traditionally, it has been employed as a general tonic, digestive aid, mild laxative, stimulant, and remedy for conditions such as gout, rheumatism, and liver and spleen disorders. The juice of the fruit and tea made from its leaves are used to treat intestinal worms, parasites, diabetes, and malaria. Furthermore, the fruit pulp, leaf extracts, and seeds demonstrate significant anthelmintic activity. The root is valued for its astringent, aphrodisiac, abortifacient, and laxative properties and is used to alleviate constipation, diabetes, diarrhea, and rheumatic pain. The increasing recognition of the therapeutic benefits of herbs rich in minerals, essential nutrients, and a wide array of secondary compounds with protective and antioxidant properties is reflected in the growing interest in plants like *M. cymbalaria*.

1. Introduction

India is the second-largest producer of vegetables in the world, surpassed only by China, with an estimated annual production of 205.80 million metric tonnes (Anonymous, 2023-24). Despite this significant production, the average daily per capita vegetable consumption in India remains below the recommended level. According to the Indian Council of Medical Research (ICMR), an adult should ideally consume 300 g of vegetables daily; however, the actual intake is only about 257.7 g per person per day (FAOSTAT, 2016-18). The significant dependence on a limited number of traditional vegetable crops, which puts substantial strain on conventional production systems, is the cause of this consumption disparity. India's diverse climate zones and fertile soils offer excellent potential for cultivating a wide range of vegetables. While more than 60 well-known vegetable crops are grown extensively across the country, there are also around 30 lesser-known or underutilized species that often remain overlooked and underexplored (Jena *et al.*, 2018). Underutilized vegetable crops are generally characterized by their limited commercial cultivation and restricted presence in formal trade channels. Despite their recognized nutritional and medicinal potential, these crops have not received adequate attention in research or extension programs. lack of good-quality planting material, limited public awareness about their nutritional and medicinal benefits, and the scarcity of clear, accessible information on how to grow them successfully are the main reasons for the crops to remain underutilized.

In this context, there is an urgent need to enhance the per capita availability of vegetables, as they remain a key source of essential micronutrients in the human diet. This goal can be achieved either by expanding the production of conventional vegetables or by tapping into alternative, sustainable sources of plant-based foods. One promising approach is the systematic utilization of locally available wild and underutilized plant species as these underutilized vegetable

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species are not only nutritionally rich but also possess valuable medicinal properties (Parvathi and Kumar, 2002). Nevertheless, many of these plants are still mainly utilized as ingredients in Ayurvedic formulations or conventional home treatments, despite their potential (Kulkarni, 2003). Expanding their cultivation and bringing underutilized vegetables into the mainstream could create new job opportunities, boost rural household incomes, and play a meaningful role in strengthening the national economy (Jena *et al*., 2018).

The genus *Momordica* comprises several underutilized and wild-gathered vegetable species valued for their nutritional, medicinal, and ecological significance. Well-known species such as bitter gourd (*M. charantia*), teasel gourd (*M. subangulata* subsp. *renigera*), spine gourd (*M. dioica*), *M. sahyadrica*, and *M. cymbalaria* are recognized for their high content of essential minerals and vitamins, making them some of the most nutrient-dense members of the Cucurbitaceae family. Except for bitter gourd; however, most *Momordica* species remain relatively unknown outside traditional consumer regions in Asia and Africa. One among these, *M. cymbalaria* holds particular significance due to its rich reservoir nutrition, secondary metabolites, its medicinal applications among indigenous forest-dwelling communities and native populations. Despite its widespread traditional use, much of this ethnobotanical knowledge remains unscientifically validated or integrated into mainstream healthcare systems. Traditional medical systems such as Ayurveda, Unani, Siddha, and even Homeopathy (AYUSH) have long incorporated *M. cymbalaria* for various therapeutic purposes (Sivarajan and Balachandran, 1994).

The distribution of *Momordica* species varies considerably across India. *M. dioica* and *M. charantia* are commonly found throughout the country. In contrast, *M. subangulata* subsp. *renigera* is predominantly confined to the northeastern states and the adjacent North Bengal hills.

M. cochinchinensis has a more localized occurrence, primarily in the Andaman Islands and select areas of eastern and northeastern India. *M. balsamina* is adapted to the arid zones of Rajasthan and Gujarat. *M. cymbalaria* is mainly distributed in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra. A recently identified species, *M. sahyadrica*, is endemic to the Western Ghats (Joseph and Antony, 2007).

Momordica cymbalaria Hook. Fenzl., also known by its synonyms *Luffa tuberosa* or *Momordica tuberosa* (Roxb.), is a member of the Cucurbitaceae family, native to the tropical regions of India and Southeast Asia. Commonly called kasarakai in Telugu, aathalakkai in Tamil, karchikai in Kannada, and kadavanchi in Marathi, this plant is traditionally recognized for its medicinal and nutritional value but is not widely cultivated as a conventional crop. Instead of being systematically grown, *M. cymbalaria* typically appears as a wild-growing plant during the monsoon season, thriving particularly in black soil regions often used for crops such as sorghum, Bengal gram, and onions. Its natural distribution is concentrated in the South Indian states of Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, and Tamil Nadu. The species is characterized by its tuberous root system, which supports its perennial growth habit by allowing the plant to regenerate each year. The aerial parts are either pubescent or subglabrous and generally die back at the end of the growing season, while the tubers persist underground until conditions are favorable for regrowth (Aileni *et al*., 2009). Although, it grows well during both the Kharif and Rabi seasons, organized cultivation remains limited. In recent years, *M. cymbalaria* has garnered interest due to its substantial nutritional benefits. Yet, a lack of widespread awareness continues to restrict its cultivation, commercial supply, and broader utilization as a vegetable crop.

2. Morphological description of *Momordica cymbalaria* Hook. Fenzl.

The stems of *M. cymbalaria* are slender, climbing (scandent), branched, and striate with a surface that may be pubescent or nearly glabrous. The roots are woody, tuberous, and perennial, enabling the plant's seasonal regeneration. The tendrils are filiform, simple, and slightly pubescent, supporting the plant's climbing habit. The leaves are orbicular to reniform in shape, measuring 2.5-5.0 cm in length, and are distinctly punctate on both surfaces, with a strongly cordate base. They may be glabrous or bear sparse, scattered hairs. The leaf margins are shallowly lobed into five to seven blunt lobes with short acute or obtuse tips. Petioles are striate and hairy, ranging from 1.25 to 3.80 cm in length. Male flowers occur in racemes bearing two to five flowers. The peduncles are filiform, hairy, and ebracteate, measuring 0.60-2.50 cm long, while individual pedicels are 0.30–1.00 cm long. The calyx is hairy with a short, widely campanulate tube that is slightly constricted at the base. The lobes of the calyx are lanceolate and sharp, about 0.60 cm long. The corolla is pale yellowish-white, with oblong, blunt segments that range from 0.30 to 1.25 cm in length. The androecium consists of two stamens with thick, flattened filaments and a large connective tissue; the anther measures 10.20 cm in length. The female flowers bear slender, ebracteate peduncles that are 1.90-3.80 cm long. The ovary is fusiform with a distinct beak. The fruit is pyriform to broadly fusiform, measuring 1.90-2.50 cm in length, weighing up to 3 g, and tapering into a curved peduncle. Fruits are dark green, fleshy, 8-ribbed, sparsely hairy, and white with a placenta that ranges from spongy to fibrous. Each fruit contains two to three seeds that are broadly ovoid, 0.40-0.60 cm long, slightly compressed, strophiolate, and without a marginal wing. The seed coat is dark brown, glossy, and polished, distinguishing them from seeds of other Asiatic *Momordica* species (Cooke, 1901-1908).

3. Taxonomic position of *Momordica cymbalaria* Hook. Fenzl.

The classification of *M.cymbalaria* within the genus *Momordica* has long been a subject of debate among botanists and taxonomists (Pandey *et al*., 2006). Historically, two contrasting views have been proposed: one placing the species under the genus *Momordica* and the other under *Luffa*. Initially, Roxburgh (1832) described the species as *Luffa tuberosa*, which Clarke (1879) later reassigned to *Momordica* as *Momordica cymbalaria*. Subsequently, Congiaux (1881) recognized it as *Momordica tuberosa* based on Roxburgh's original classification of *Luffa tuberosa*. Furthermore, complicating its placement, Chakravarty (1959) noted that all *Momordica* species are characterized by the presence of true cystoliths on the lower surface of their leaves, a feature absent in *M. cymbalaria*. Chakravarty (1982) also argued that species within *Momordica* typically bear either muricate or echinate fruits, never angular ones, and therefore questioned the rationale for its transfer from Luffa. However, supporting evidence for its inclusion in *Momordica* was found in seed morphology and chemical studies. Singh and Dathan (2001) reported that the seed coat structure of *M. cymbalaria* aligns with other *Momordica* species. Moreover, Azeemoddin and Rao (1967) demonstrated that the seed fat of *M. tuberosa* contains a conjugated triene acid, a chemical marker typical of *Momordica* seeds but absent in the genus Luffa.

Analyses based on internal transcribed spacer (ITS) sequences of nuclear ribosomal DNA (Ali *et al*., 2010) and multi-genome phylogenetic assessments using plastid, mitochondrial, and nuclear DNA markers (Schaefer and Renner, 2010) strongly support the classification of this species within *Momordica*. Additional studies by Bharathi *et al*. (2011, 2012) highlighted its apparent genetic distinctiveness from other *Momordica* species found in India. Interestingly, phylogenetic data also suggest that *M. cymbalaria* shares closer affinities with certain African species, such as *M. humilis*, *M. kirkii*, *M. boivinii*, and *M. sessilifolia* (Schaefer and Renner, 2010), as well as *M. cabraei* (Ali *et al*., 2010). Together, these morphological, biochemical, and molecular lines of evidence now strongly support the placement of *M. cymbalaria* within the genus Momordica.

4. Cytogenetic characteristics of *M. cymbalaria*

The genus *Momordica* displays a basic chromosome number that varies among species with x = 9, 11, or 14. The commonly cultivated bitter gourd (*M. charantia*) is diploid with a chromosome number of 2n = 22. In general, annual monoecious species within the Cucurbitaceae family tend to have a basic chromosome number of 11, perennial dioecious species have 14, and perennial monoecious species, like *M. cymbalaria*, usually exhibit a basic chromosome number of 9 (Bharathi *et al*., 2011). This pattern indicates a probable shared ancestry among the species within the genus.

Recent cytological studies by Bharathi *et al*. (2011) reported a diploid chromosome number of 2n = 18 for *M. cymbalaria*. This finding contrasts with earlier observations by Mehetre and Thombre (1980), who recorded a meiotic chromosome count of n = 8, and Beevy and Kuriachan (1996), who reported a mitotic count of 2n = 22. Bharathi *et al*. (2011) further confirmed their findings through meiotic analysis, observing nine clear bivalents during diakinesis and metaphase I, supporting a haploid number of n = 9. Comparative studies revealed that the chromosome size in *M. cymbalaria* differs markedly from that of other *Momordica* species. While the average chromosome length and volume were relatively consistent among annual monoecious species (*M. charantia, M. balsamina*) and perennial dioecious species (*M. dioica, M. subangulata, M. sahyadrica*, and *M. cochinchinensis*), *M. cymbalaria* exhibited notably larger chromosomes. Specifically, the average chromosome length and volume in *M. cymbalaria* were 2.62 µm and 1.43 µm³, respectively, compared to minimum values of 0.93 µm and 0.48 µm³ recorded for the tetraploid *M. subangulata* subsp. *renigera* (Bharathi *et al*., 2011).

The chromosome length in *M. cymbalaria* ranged from 1.68 to 3.59 ìm, with an average length of 2.62 µm, whereas other species showed chromosome lengths varying from 0.52 to 2.17 µm. This difference suggests that the greater chromosome length in *M. cymbalaria* is unlikely to be due solely to technical factors such as preparation artifacts or differences in condensation. Notably, the total chromosome length for *M. cymbalaria* is about 50 µm, which is higher than that of other diploid Momordica species with haploid numbers of n = 11 or n = 14 despite having the lowest haploid chromosome number of n = 9 (Bharathi *et al*., 2011).

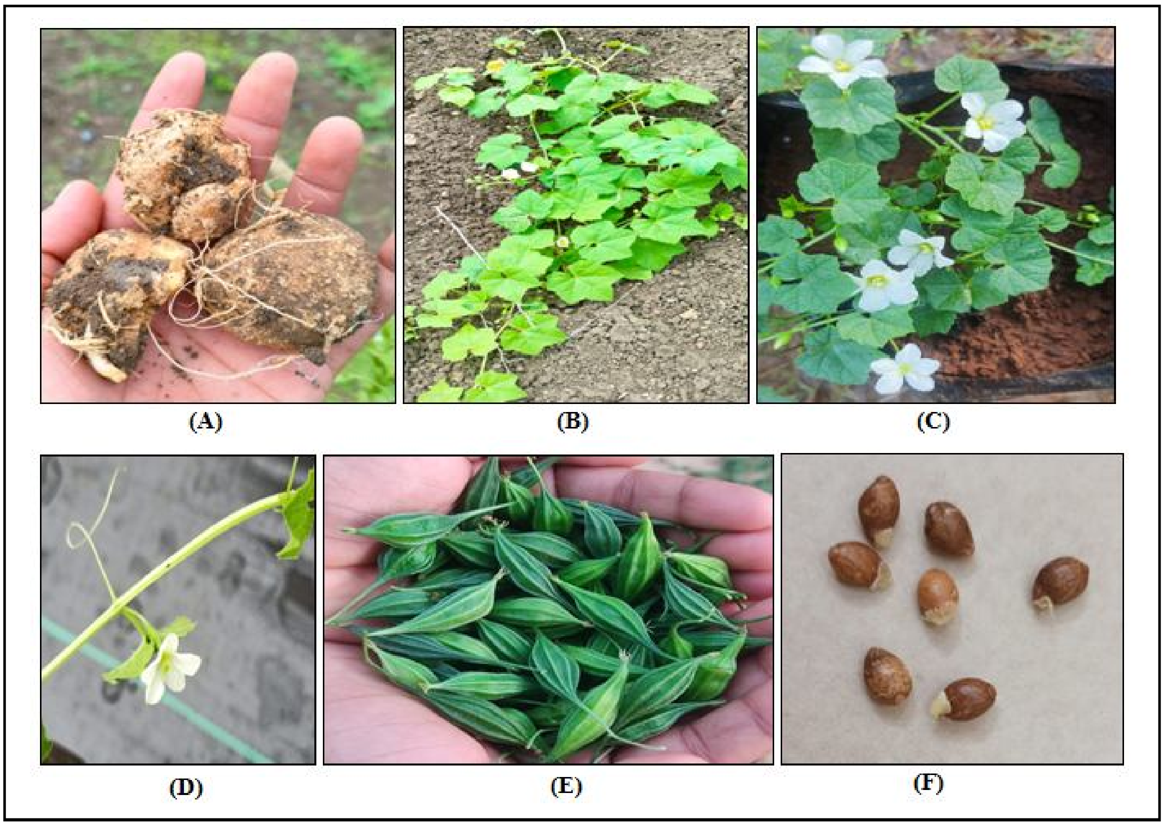

Figure 1: Morphological features of the plant: (A) Tuber (B) Plant (C) Male flower (D) Female flower (E) Fruits (F) Seeds.

5. Phylogenetic placement and genetic distinctness of *M. cymbalaria*

The genus *Momordica* is considered monophyletic and can be divided into eleven distinct clades, as established by Schaefer and Renner (2010). These molecular clades largely align with the morphological groupings previously proposed by Jeffrey and de Wilde (2006). Among the Asiatic species, three primary sections are recognized: dioecious species such as *M. cochinchinensis*, *M. dioica*, *M. sahyadrica*, *M. denticulata*, *M. denudata*, *M. clarkeana,* and *M. subangulata* are grouped under section Cochinchinensis; monoecious species like *M. charantia* and *M. balsamina* fall under section *Momordica*; while *M. cymbalaria* is classified within section raphanocarpus (Schaefer and Renner, 2010).

Within India, *M. cymbalaria* is the sole representative of the section Raphanocarpus, giving it an isolated taxonomic status within the genus attempts to create interspecific hybrids between *M. cymbalaria* and related species, such as spine gourd (*M. dioica*), bitter gourd (*M. charantia*), and sweet gourd (*M. cochinchinensis*), have consistently failed to produce viable seeds. Despite conducting approximately 50 interspecific crosses, researchers found no successful seed set in *M. cymbalaria*, demonstrating clear reproductive barriers. Bharathi *et al*. (2012) further reinforced its genetic distinctiveness from other Indian *Momordica* species through molecular and karyomorphological analyses.

Table 1: Nutrient composition of *M.cymbalaria* and *M.charantia* Behera *et al.* (2011) and Jeyadevi *et al.* (2012)

Composition	*M. cymbalaria*	*M. charantia*
Moisture %	84.30	83.20
Fibre %	6.42	1.70
Beta Carotene %	0.01	126.00
Protein %	2.15	2.10
Carbohydrate %	12.60	10.60
Energy k cal/100 g	3.00	60.00
Calcium mg/100 g	72.00	23.00
Sodium mg/100 g	40.00	2.40
Potassium mg/100 g	500.00	171.00
Iron mg/100 g	1.70	2.00
Zinc mg/100 g	2.82	0.46
Manganese mg/100 g	0.32	0.08
Copper mg/100 g	0.18	0.19
Phosphorus mg/100 g	0.46	38.00
Vitamin C mg/100	290.0	96.00

6. Nutritional value

Kasarkai is valued for its edible fruits and leaves, which are used as vegetables, and its tubers, which are primarily utilized for medicinal purposes. The nutritional profile of kasarakai includes significant amounts of carbohydrates (3.72%), protein (3.26%), fat (1.61%), fibre (5.63%) and ash (1.25%). Kasarakai is particularly rich in beta-carotene, containing 224.9 IU per 100 g, compared to sponge gourd (200 IU per 100 g) and ridge gourd (55 IU per 100 g). It also has a high content of ascorbic acid, with 160.77 mg per 100 g. Additionally, kasarakai contains higher levels of iron (130 mg per 100 grams) and phosphorus (5.50 mg per 100 g) compared to other species.

When comparing the nutrient content of kasarakai to that of bitter gourd, earlier has three times more calcium and twice the amount of ascorbic acid, making it a significant source of vitamin C. Calcium plays a vital role in the development and maintenance of healthy bones and teeth as well as in regulating normal heart rhythm, blood clotting, muscle contraction, and nerve function. The notably high calcium content presents an opportunity for its use as a valuable dietary source to help meet daily calcium requirements (Jha *et al*., 2018). In addition to its calcium richness it has been reported to contain potassium levels that are approximately double those found in the widely consumed bitter gourd (Bharathi *et al*., 2011). Given these higher concentrations of essential minerals, this underutilized species holds promise for addressing micronutrient deficiencies and contributing to improved nutritional security, particularly in rural and nutritionally vulnerable communities.

7. Medicinal value/ therapeutic uses

Plants with medicinal properties have long been used in traditional healthcare systems to manage a wide range of ailments and infectious diseases. In recent years, scientific investigations have provided evidence supporting the therapeutic potential of various vegetable extracts that have been traditionally used for medicinal purposes (Jha *et al*., 2018). In this context, numerous pharmacological studies have highlighted the medicinal significance of its fruits, leaves, tubers are valued for their bioactive compounds and possess therapeutic properties that may aid in the treatment of multiple health conditions.

Extracts derived from *M. cymbalaria* are rich not only in minerals and primary metabolites but also in a diverse range of secondary metabolites, many of which exhibit antioxidant activity (Jeyadevi *et al*., 2012). These properties contribute to its traditional use in indigenous medical systems and underscore its potential as a source of natural therapeutic agents for future pharmaceutical applications.

7.1 Fruits

The fruits are the primary economically vital part of the plant and have long been valued in traditional medicine for their wide range of therapeutic properties. Traditionally, the fruits have been regarded as tonic, stomachic, stimulant, laxative, and alterative agents with applications in the management of conditions such as gout, rheumatism, and specific spleen and liver disorders. Modern studies have substantiated several of these traditional uses through scientific evidence. Research has demonstrated that the fruits exhibit notable hypoglycemic effects in animal models (Jha *et al*., 2018). Various studies have further revealed that *M. cymbalaria* fruits possess hypoglycemic, hypolipidemic, cardioprotective, hepatoprotective (Koneri *et al*., 2008), nephroprotective (Kumar *et al*., 2011), and antidiarrheal (Swamy *et al*., 2008) properties. These effects are attributed to the presence of bioactive compounds such as saponins, which are linked to its hepatoprotective activity.

Additional investigations have identified significant antioxidant and anticancer properties (Patel *et al*., 2014) as well as antimicrobial effects (Kulkarni *et al*., 1992). The fruit juice is traditionally used to treat ailments such as malaria, wounds, parasitic infestations, and intestinal worms. Moreover, *M. cymbalaria* fruits have been shown to help manage diabetes; for example, Rao *et al*. (2001) and Kumar *et al*. (2010) demonstrated that the alcoholic extract of the fruits significantly reduced serum glucose levels in both normal and type II diabetic rats. Of particular interest is the identification of a 17 kDa protein with an isoelectric point of 5.0 named *M.cy* protein, which has been isolated as the active antidiabetic principle in the fruit extract.

The seeds of *M. cymbalaria* are also noteworthy, as they contain conjugated fatty acids such as punicic acid, which may contribute to the plant's health benefits (Jha *et al*., 2018). Furthermore, *M. cymbalaria* has demonstrated cardioprotective potential. Koneri *et al*. (2008) reported that administering *M. cymbalaria* powder at a dose of 500 mg/kg body weight effectively prevented alterations in cardiac myofilamentous structures, such as myocytosis and myofibrillar degeneration in experimental rat models. Together, these findings highlight the diverse medicinal potential of *M. cymbalaria* fruits and support their further exploration as a source of natural therapeutic agents.

7.2 Leaves

In addition to its fruits, the leaves of *M. cymbalaria* can be consumed as a leafy vegetable, although their pronounced bitterness due to the presence of phytochemicals, specifically bitter-tasting cucurbitane-type triterpenoids often limits their culinary use. Despite this, the leaves have significant medicinal value, particularly for managing diabetes. Traditional practices recommend consuming one teaspoon of dried leaf powder with water each morning, which has been reported to help reduce blood sugar levels in diabetic patients within approximately 15 days of use (Osinubi *et al*., 2008). Beyond their hypoglycemic effect, the leaves are traditionally prepared as herbal tea to address ailments such as malaria, wounds, intestinal worms, parasitic infections, and fevers (Fernandes *et al*., 2007; Osinubi *et al*., 2008). Phytochemical and antimicrobial investigations by Ramanath and Kour (2012) confirmed that leaf extracts exhibit potent antimicrobial activity against a range of pathogens, supporting their traditional use in treating minor infections, wounds, and fevers.

Furthermore, the aerial parts have demonstrated notable anticancer potential. A study by Jeevanatham (2011) demonstrated that administering a methanol extract of the aerial parts at a dose of 200 mg/kg body weight significantly inhibited cancer growth in mice with Ehrlich ascites carcinoma, comparable to the standard chemotherapeutic agent cyclophosphamide.

7.3 Tubers

The tubers of *M. cymbalaria* have been traditionally used for centuries to treat a variety of ailments, including wounds, diarrhea, stomach aches, and mouth ulcers. Modern research has confirmed that these tubers are a valuable source of bioactive compounds, including sterols, triterpenes, saponins, and carbohydrates, which are essential secondary metabolites with therapeutic potential (Kumar *et al*., 2010; Fernandes *et al*., 2007). Experimental studies have demonstrated significant nephroprotective and hepatoprotective effects of ethanolic extracts of *M. cymbalaria* tubers in animal models (Kumar *et al*., 2011; Koneri *et al*., 2011). Additionally, the tubers exhibit anti-implantation (Koneri *et al*., 2007) and anti-ovulatory properties, as well as abortifacient activity when tested in rats (Koneri *et al*., 2006). Research has also highlighted their potential as an antidiarrheal agent (Swamy *et al*., 2008). Phytochemical analyses have revealed that the tubers contain bitter glycosides, beta-sitosterol, steroidal saponins, and starch (Jha *et al*., 2018), which contribute to their medicinal value. Notably, Kolluru *et al*. (2016) demonstrated that topical application of methanoliof *M. cymbalaria* tubers significantly accelerated wound healing in albino Wistar rats using an excision wound model. The wound closure and contraction were found to be faster and more effective than with the standard nitrofurazone ointment.

7.4 Roots

Diabetes mellitus remains a major global health challenge, creating substantial economic and social burdens and driving renewed interest in traditional plant-based remedies for its management. The roots have shown promising antidiabetic activity due to the presence of an oleanane-type triterpenoid saponin, which has been studied *in vitro* using a rat insulinoma cell line (RIN-5F) (Koneri *et al*., 2014). In traditional medicine, the roots are valued for their diverse therapeutic properties. They are used to treat ailments such as constipation, indigestion, diabetes, diarrhea, and rheumatism, and are also known for their astringent, abortifacient, and aphrodisiac effects (Fernandes *et al*., 2007).

Koneri *et al*. (2014) demonstrated that the saponin extract from *M. cymbalaria* roots (at 1 mg/ml) significantly enhanced insulin secretion in the RIN-5F cell line. Their findings indicated a quantitative increase of about 75% in beta-cell numbers, suggesting that the saponin may support beta-cell rejuvenation and modulate calcium channels, thereby contributing to its hypoglycemic effect. These results highlight the roots of *M. cymbalaria* as a promising natural resource for developing alternative treatments for diabetes and related metabolic disorders.

8. Propagation of *M. cymbalaria*

M. cymbalaria primarily propagates through a sexual means, relying on its tuberous roots for regeneration. After the onset of the monsoon season, the dormant tubers sprout and produce new growth, while during the dry summer months, they enter a period of dormancy. Typically, each tuber can give rise to one or, occasionally, up to two to four new plants. Although, the plant produces shiny, black, hard seeds, they are rarely used for propagation due to their extremely low or negligible germination rates. To improve germination, both fresh and old seeds were subjected to different pre-sowing methods such as mechanical scarification (sandpaper rubbing and nicking), chemical treatments (sulfuric acid for 10 min and gibberellic acid at 200 ppm), hot water soaking (5 min), overnight soaking, and untreated control by (Chittapur *et al*., 2015). Among these, mechanical scarification gave the best results, though the germination percentage was still very low. Treatments with acid, GA*f* , hot water, or soaking failed to support seed germination. This clearly shows that the hard seed coat is the main barrier, and mechanical scarification is the most effective approach for breaking dormancy and improving germination in this species.

As an alternative, tissue culture techniques have shown promise for large-scale multiplication. Several studies have successfully established protocols for *in vitro* propagation using various explants, offering a viable approach for conserving and expanding the cultivation of this underutilized species (Nikam *et al*., 2009).

9. Tissue culture and *in vitro* regeneration of *M. cymbalaria*

Tissue culture techniques have been successfully applied to various *Momordica* species, including *M. charantia*, *M. balsamina*, *M. dioica*, *M. subangulata* subsp. *renigera,* and *M. cymbalaria*, using explants such as shoot tips, nodal segments, cotyledons, and root sections for regeneration. Specifically for *M. cymbalaria,* multiple shoot regeneration has been effectively achieved using nodal segments and leaf explants (Nikam *et al*., 2009; Ailinea *et al*., 2009; Jeyadevi *et al*., 2012).

Devi *et al*. (2017) demonstrated that direct organogenesis through axillary buds is a promising approach for the micropropagation of *M. cymbalaria*. Their study showed that when the Murashige and Skoog (MS) medium was supplemented with 2.0 mg l^{-1} BAP, shoot regeneration was successfully induced. Subsequent shoot multiplication reached an average of 7.48 shoots in MS medium fortified with 3.0 mg l^{-1} BAP, with optimal rooting obtained in half-strength MS medium containing 1.0 mg l^{-1} IBA and 0.1 mg l^{-1} NAA. The regenerated plantlets were then acclimated in a coco-peat potting mixture, demonstrating the potential for efficient mass multiplication.

In another study, Nikam *et al*. (2009) reported that indirect regeneration *via* callus formation produced a maximum of 9.0 ± 0.5 shoots per explant from leaf explants when cultured on MS medium supplemented with 2.5 µM BA. Further enhancement of large-scale shoot formation was achieved through repeated subculturing of the leaf-derived callus, yielding up to 35 ± 3.4 shoots per culture on the same shoot induction medium (MS + 2.5 ìM BA). These advances in tissue culture protocols highlight the practical potential of *in vitro* propagation for conserving, multiplying, and utilizing *M. cymbalaria,* particularly given its poor seed germination and underutilized status in conventional cultivation.

10. Future prospects

The sustainable utilization and broader adoption of *M. cymbalaria* face several significant challenges. One of the primary constraints is the lack of adequate, high-quality planting material and the absence of a well-defined package of agro management practices tailored to this species. Standardized methods for propagation remain underdeveloped, and natural propagation through perennial tubers is inherently limited, as only a small number of tubers persist in the soil, and each produces just a single plant in the subsequent season (Nikam *et al*., 2009). Additionally, the species faces mounting threats from habitat loss due to human activities, overharvesting without systematic conservation, and insufficient scientific understanding of its propagation, breeding, and cultivation requirements. These factors place *M. cymbalaria* at risk of becoming endangered in its native regions (Jeyadevi *et al*., 2012).

Propagation through seeds is further hindered by the small number of seeds per fruit, their dormancy, and very low germination rates, which severely restrict natural population expansion and hinder large-scale cultivation efforts. Consequently, much of the genetic potential of *M. cymbalaria* remains unexplored and underutilized. To harness the full horticultural, nutritional, and medicinal value of this underexploited species, future research should prioritize the characterization of local genotypes to support pre-breeding activities. Identifying and developing genotypes with desirable traits could help expand their use in both local markets and global trade. Furthermore, advanced breeding techniques such as protoplast fusion, embryo rescue, and embryo culture offer promising tools to overcome post-fertilization barriers and develop improved planting material. Focused research in these areas, combined with sustainable conservation practices, will be vital to safeguard and realize the significant potential of *M. cymbalaria*.

11. Conclusion

M. cymbalaria has a long history of use in traditional Asian medicine, owing to its rich array of bioactive compounds, including flavonoids, carotenoids, cucurbitane triterpenoids, phenolic acids, and phytosterols. These constituents contribute to its broad pharmacological potential, playing vital roles in the management of various conditions, including diabetes mellitus, cardiovascular disorders, ulcers, cancer, and diabetic neuropathy. The tuber has been traditionally used in ancient folk medicine for its abortifacient properties.

In addition to its ethnomedicinal uses, modern research has confirmed that *M. cymbalaria* has diverse therapeutic properties, including hypoglycemic, wound-healing, fertility-regulating, hypolipidemic, hepatoprotective, nephroprotective, and antioxidant effects. Like other species within the Momordica genus, this plant holds significant potential as a nutritious and underutilized vegetable crop. Its nutritional composition suggests that it could be included in the human diet to improve dietary diversity and nutritional security. Due to its valuable medicinal, nutritional, and genetic traits, *M. cymbalaria* germplasm is a vital resource for crop improvement initiatives. There is an urgent need to systematically collect, characterize, evaluate, and conserve germplasm from wild populations and indigenous tribal regions of southern India to ensure its sustainable use and protection for future generations.

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Authentication of plant species

The plant species, *Momordica cymbalaria* Hook. Fenzl. is authenticated by Professor K. Madhava Setty, Plant Taxonomist, Department of Botany, Sri Venkateswara University, Tirupathi, Andhra Pradesh, India. Herbarium No. is 4211.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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