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Review

# Moth bean (*Vigna aconitifolia* (Jacq.) Marechal) seeds: A review on nutritional properties and health benefits

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**Abstract**
Ensuing protein malnutrition in developing countries, an affordable protein food source needs to be distinguished. *Fabaceae* family accommodate moth bean (*Vigna aconitifolia* L.) as its one of the important members that ascertains exceptional nutritional composition. Moth bean is a drought-tolerant food legume of the tropics. Seeds of moth bean serve abundant food protein source besides carbohydrate, fatty acids, minerals and vitamins. Additionally, the level of antioxidant and polyphenol contents in moth bean seeds are substantial. Moth bean legume has several health benefits capable of preventing cardiac diseases, diabetes and obesity to humans, if consumed regularly. This review address nutritional bioavailability and associated health benefits in the seeds of moth bean.

**Keywords** Moth bean · Functional food · Food security · Underutilized legume · Nutraceuticals · Lectins

## 1 Introduction

The genus *Vigna* is categorized into seven subgenera and sixteen sections [1]. *Ceratotropis, Haydonia, Lasiocarpa, Macrorhycha, Plectotropis, Sigmoidotropis* and *Vigna* are among the seven [2]. *Ceratotropis, Plectotropis* and *Vigna* are the only three subgenera of *Vigna* that have been domesticated and cultivated [3]. The most well-known subgenera are *Ceratotropis*, also known as Asian *Vigna. And Vigna* is also known as African *Vigna*, which contain popular legumes such as cowpea, black gram and mung bean [2, 3]. *Vigna vexillata* is an intermediate species between Asian and African *Vigna* [2]. Although failed however, a inter-specific hybridization involving members of the Asian and African *Vigna* attributed to post fertilization, successful crossings between members of the three subgenera have been reported [1, 4].

It's worth noting that underutilized species provide enormous potential for combating poverty, hunger and malnutrition [5]. Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the world's most significant grain legume crops, with wider range of occurrence and cultivation in semiarid regions of Africa, Asia, Southern Europe, Southern America, Central and South America [6–8]. Bambara groundnut (*Vigna subterranea* (L.) Verdc) is originated in West Africa and has a wide genetic range [9]. It is a commonly produced food legume in semi-arid Africa that is closely related to cowpea (*Vigna unguiculata*), with which it shares its cultivation region and genetic diversity origin [10]. Moth bean (*Vigna aconitifolia* (Jacq.) Marechal) is among a minor legume crop that is most drought and heat tolerant species of the Asian *Vigna* [11]. It is widely farmed in India and the far East, and it has been identified as a potential future food source [12].

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Moth bean is a food legume belongs to family *Fabaceae*. The genus *Vigna* contains many familiar food species like mung bean, black gram, cowpea and moth bean. *Vigna aconitifolia* is an edible species of moth bean that is underexploited in spite of having nutritional portfolio. Agronomically, it prospers in tropical environment and cultivated on infertile soil too. Consequently, it is grown and consumed in South-East Asia [13]. Rajasthan state of North Central India leads major moth bean producing regions due to crop supporting climatic conditions. Moth bean is predominantly a *Kharif* crop, cultivated and harvested in Indian subcontinent's monsoon season, which last from June to November. Depending upon the region known with different names such as dew bean, haricot mat, Indian moth bean, mat bean, moth gram, matki, or Turkish gram etc. Moth bean seems a versatile pulse crop and provide a source of food, fodder, feed and green manure for animal husbandry. It constitutes an economical source supplement for protein deficiency [14].

Recently, a phytochemical profiling of different accessions of moth bean seeds and their bioactive compounds with in vitro pharmacological studies was carried out by Bhadkaria et al. [15]. Findings recognized moth bean as an alleged source of nutrition both by way of macro and micro micronutrients and certain bioactive components showing antioxidant, anti-diabetic, antihypertensive activities. Seeds of moth bean are appreciated due to high protein contents and carbohydrates associated with an adequate amount of minerals (Ca, Mg, Fe, Zn, and Mn), vitamins (niacin and ascorbic acid), essential amino acids and unsaturated fatty acids [16, 17].

This untapped nutritional source however, can play a vital role in the food security as a protein resource for poor community of developing countries. Very little scientific research has been done on most of the underutilized legumes like moth bean that have become the subject of advanced research now. To recognize the available nutritional opportunities in moth bean so as to integrate it with traditional food system, Indian legume moth bean looks promising. The current status of the food security warrants identifying opportunities related to improved health outcomes. Accordingly, this comprehensive review addresses the possible solutions to food security challenges and available alternatives. Attempt is made herein to address agronomic, nutritional, biochemical potentials of moth bean legume.

## 2 Production

Growing moth bean is easy. It is one of the most drought resistant pulses in India. Rajasthan, state of India contributes almost 85% of crop production. Low yield production of this crop can be attempted in many ways. Moth bean is mainly impacted by Mung bean yellow mosaic virus. Cultivating resistant plant cultivars can overcome low yield matters. The appropriate seed treatment of rhizobium culture can give additional yield advantage. In addition, selection of right cultivar/variety types suitable for available soil types is a key factor for production enhancement. Moth bean crop needs less care when compared to other commercial crops like chickpea and cowpea [18]. Advanced agricultural practices will promote the production and address the challenges of food security and climate change.

Productivity of moth bean seems productive and is estimated more than 1.5 million hectares with an annual production of 0.4 million tons in India [19, 20]. Being a drought-resistant crop, it can be cultivated in arid and semi-arid regions, like arid regions of Rajasthan in India. About 85% of total moth bean cultivation and 0.22 million tons of moth beans produced in Rajasthan [21]. Average seeds yield is estimated in a range of 70–270 kg $ha^{-1}$ which is low but probably due to being grown under dry land conditions without supplementary irrigation and low fertility. Though it yields up to 2600 kg $ha^{-1}$ as recorded in the United States and Australia with experimental seeds [4]. This recommends that it needs to improve breeding efforts towards hot climate adaptive crops with resistance to abiotic and biotic stresses. In addition, the yield of its green matter as animal forage has been estimated to be 37–50 t $ha^{-1}$ and hay at about 7.5–10 t $ha^{-1}$ [22].

Cowpea is likewise other major pulse crop belongs to *Vigna* family. It is widely grown in tropical countries and cultivated under rain fed conditions especially during kharif season. In India, cowpea is grown for its food and fodder. It is cultivated on about 0.5 million ha in small pockets with an average productivity of 750 kg $ha^{-1}$ [23]. Both cowpea and moth bean yields under similar cultivation environments. Cultivation of improved variety along with better crop management practices resulted high yield in cowpea [24]. The yield limiting factor in cowpea is inadequate source, sinks and limiting quality seed production [25, 26]. Therefore, attempts should be made by the breeders to develop nutritionally rich elite cultivars of high yield in these legumes vis-à-vis cowpea and moth bean.

## 3 Chemical composition

Pulses are recommended in diets due to providing nutritional support. Food legumes contain certain bioactive compounds that execute nourishing properties when consumed in the daily diet. Different studies used different methodologies with diverse range of sensitivity. For some analyses, a range of results is found, which may be related to genotype, environment or both. The approximate composition of moth bean seeds include moisture, ash, lipids, fats, proteins and carbohydrates. Reported studies advocate that moth bean seeds are higher in carbohydrates, proteins, minerals and fats but lower in fibre than chickpea, common bean and soybean (Table 1) [4, 27].

### 3.1 Protein

Protein malnutrition is one of the major challenges in developing countries. This occurs due to various pathologies arising because of protein deficiency in the diet. Moth bean seeds accommodate 23–26% protein on dry weight basis [12]. The major categories of protein fractions in seed materials are albumins and globulins as present in different *Vigna* species as major seed storage proteins [28, 29]. The variation in the content of albumin (4.5 to 26 g l00 $g^{-1}$) and globulin (10 to 57 g l00 $g^{-1}$) varies in moth bean seed accessions as studied by Gupta et al. [30]. Protein fractionation data indicated globulin to be the most dominant protein followed by albumin, glutelins and prolamins (Table 1). According to Bennetau-Pelissero [31], the content of protein in moth bean is relatively higher than bambara (19–23%), almost equivalent to cowpea (24–28%) and chickpea (19–27%) while its lower than lentil (21–31%), mung bean (15–33%) and fava bean (26–33%). The relative high protein content implies that these legumes can contribute significantly to daily human protein requirement since 100 g serving can provide about 12–14% of the recommended dietary allowance (RDA) [32, 33]. Amongst various pulses, moth bean seeds have greater protein bioavailability [28, 34, 35].

### 3.2 Amino acids

Seed legumes constitute a great source of plant based amino acids. However, sulfur rich amino acids are limiting in food pulses. Hence, the amount of essential amino acids which cannot be produced in human body must be given through diet. The amino acid profiles of moth bean seeds are presented in Table 2. Moth bean seeds accommodate glutamic (16.12 g l00 $g^{-1}$) and aspartic acid (10.64 g l00 $g^{-1}$) in excess amount and respectively [17]. Leucine is abundant amount in the moth bean seeds as represented (Table 2). Sulfur-rich amino acids are limiting amino acids in albumin and prolamin fractions, whereas isoleucine and lysine are limiting amino acids in total proteins, globulins and glutelins [28]. The concentrations of isoleucine (3.80 g l00$g^{-1}$) and leucine, (6.01 g l00 $g^{-1}$) observed in moth bean were comparably higher to those present in pigeon pea (3.8 g l00 $g^{-1}$; 4.9 g l00 $g^{-1}$), chickpea (2.8 g l00$g^{-1}$; 5.7 g l00 $g^{-1}$), mung bean (3.5 g l00 $g^{-1}$; 5.6 g l00 $g^{-1}$) respectively [36].

Except for soy protein, leguminous proteins are deficient in the sulphur-containing amino acids (SCAA), methionine, cystine and cysteine, as well as tryptophan, and are thus regarded as an inadequate supply of protein [37]. Legumes are commonly consumed with cereals to meet out daily dietary amino acid requirements. In terms of protein, legumes and cereals complement each other because grains are higher in SCAA (poor in legumes) and low in lysine (high in legumes)

**Table 1** Physicochemical parameters of moth bean seeds and some important pulses

| (g l00 $g^{-1}$) | Moth bean [12, 16, 17] | Chickpea [98] | Mung bean [99–101] | Cowpea [98, 102] |
|---|---|---|---|---|
| Water | 9.68 | 7.68 | 10.12 | 11.95 |
| Ash | 4.34 | 2.85 | 2.71 | 3.24 |
| Fat | 1.61 | 6.04 | 2.91 | 1.26 |
| Carbohydrate | 61.5 | 63 | 64.12 | 60.03 |
| Protein | 23–26 | 19–27 | 15- 33 | 24–28 |
| Albumin | 4.5–26 | 8–12 | 16.3 | 4–12 |
| Globulin | 10–57 | 53–60 | 62.0 | 58–80 |
| Prolamin | 1–6.50 | 3–7 | 0.9 | 1–3 |
| Glutelin | 2–11 | 18–24 | 13.3 | 10–15 |

**Table 2** Amino acid composition of total moth bean seed protein

| Amino acid (g l00 $g^{-1}$ protein) | Moth bean [16, 17, 31, 84] | Common beans [103] | Chickpea [103] | Cowpea [102, 103] |
|---|---|---|---|---|
| Alanine | 3.68–4.25 | 0.84–0.89 | – | 0.94 |
| Arginine | 6.14 | 0.57–1.43 | 1.57 | 1.82 |
| Aspartic acid | 10.64 | 2.59–2.67 | 0.48 | 2.56 |
| Cystine | 0.18–0.64 | 0.14 | 0.23 | 0.14 |
| Glutamine | – | – | – | – |
| Glutamic acid | 16.12 | 3.13–3.55 | | 4.14 |
| Glycine | 3.08 | 0.78–0.93 | 0.55 | 1.03 |
| Histidine | 0.77–3.84 | 0.58–0.77 | 0.44 | 0.85 |
| Isoleucine | 1.14–5.14 | 0.89–1.04 | 0.85 | 0.87 |
| Leucine | 1.54–8.11 | 1.62–1.70 | 1.60 | 1.70 |
| Lysine | 1.25–6.34 | 1.24–2.57 | 1.27 | 1.26 |
| Methionine | 0.22–1.62 | 0.24–0.27 | 0.09 | 0.37 |
| Phenylalanine | 1.03–5.48 | 1.21–1.36 | 0.97 | 1.46 |
| Proline | 3.33 | 0.80–0.87 | 0.05 | 0.94 |
| Serine | 4.36 | 1.16–1.36 | 1.22 | 1.22 |
| Threonine | 3.96 | 0.79–0.95 | 0.60 | 0.88 |
| Tryptophan | 0.15–1.24 | 0.18–0.20 | 1.32 | 0.22 |
| Tryosine | 3.14 | 0.70–0.90 | 0.49 | 0.87 |
| Valine | 0.73–5.16 | 1.00–1.05 | 0.84 | 1.01 |

[38]. For nutritional balance, legumes and grains should be consumed in the 1:3 ratios [39]. Dhal with rice in India, beans with corn tortillas in Mexico, tofu with rice in Asia, peanut butter with bread in the United States and Australia [40], samp (dried maize kernels) and beans (South Africa), bambara groundnut and maize kernels (Zimbabwe), maize meal pap with beans (Southern Africa), rice and beans (Southern Africa, Latin America) are just a few examples of such combinations [41].

## 3.3 Lipids and fatty acids

Legume seed lipids are the key source of dietary fat. In legume taxa, generally lima bean, faba bean, common bean, cowpeas, pea, which are economically important dietary legumes, have higher levels of common essential fatty acids [42]. Lipids do supply nutritionally necessary fats viz. linoleic and linolenic acids. The fatty acid profiles of moth bean seeds are provided in Table 3. The most common fatty acid present in it was linoleic acid (22%), followed by linolenic acid (20%), oleic acid (18%) and palmitic acid (16%). The linoleic acid content in moth bean (22%) is higher than chickpea (2%) and pigeon pea (5%) and lower than mung bean (36%). Further, linoleic acid in moth bean (22%) is greater than black gram

**Table 3** Fatty acid profile of lipids of moth bean seed

| Fatty acid (%) | Tresina et al. [5] | Kamani et al. [47] |
|---|---|---|
| Myristic acid (C14:0) | 02 | 0.21 |
| Palmitic acid (C16:0) | 16 | 23 |
| Palmitoleic acid (C16:1) | 09 | – |
| Stearic acid (C18:0) | 07 | – |
| Oleic acid (C18:1) | 18 | – |
| Linoleic acid (C18:2) | 22 | 31 |
| Linolenic acid (C18:3) | 20 | 19 |
| Eicosenoic acid (C20:1) | 04 | – |
| Saturated fatty acid | 26 | 27 |
| Polyunsaturated fatty acid | 74 | 50 |

**Table 4** Mineral constituent in moth bean seeds

| Element (mg 100 $g^{-1}$) | USDA [27] | Tresina et al. [17] | Chinazum et al. [57] | Bhadkaria et al. [15] |
|---|---|---|---|---|
| Phosphorus | 489 | 174.26 | 31.13 | – |
| Magnesium | 381 | 214.04 | 18.44 | 43 |
| Calcium | 150 | 244.10 | 16.30 | 47 |
| Sodium | 30 | 34.06 | 37.20 | – |
| Potassium | 1190 | 2256.68 | 51.57 | – |
| Iron | 10.8 | 7.46 | 1.49 | 40.63 |
| Zinc | 1.92 | 1.41 | 2.48 | 8.7 |
| Manganese | 1.82 | 1.61 | – | – |
| Copper | 0.688 | 0.76 | – | – |

**Table 5** Vitamin constituent in moth bean seeds

| Vitamins (mg 100 $g^{-1}$) | USDA [27] | Chinazum et al. [57] | Tresina et al. [17] |
|---|---|---|---|
| Vitamin A | 32 (IU) | 14.65 (IU) | – |
| Thiamin | 0.562 | 0.23 | – |
| Riboflavin | 0.091 | 0.45 | – |
| Niacin | 2.8 | 0.47 | 28.08 |
| Ascorbic | 4 | 42.25 | 59.10 |
| Vitamin E | – | 0.25 | – |
| Pantothenic acid | 1.54 | – | – |

(12%) and mung bean (16%) and lower than chickpea (43%) and pigeon pea (56%) [17, 43]. Linoleic acid metabolism produces hormones like prostaglandin which reduces blood pressure and do participate in smooth muscle constriction. The most significant fatty acids responsible for growth, physiology and maintenance are linoleic and linolenic acids [44]. Unsaturated fatty acids are equally essential in reducing the risk of cardiovascular diseases. Moth bean thus accounts nutritional benefits due to its balanced fatty acid composition including large amounts of unsaturated fatty acid [45].

### 3.4 Minerals

When compared to different *Vigna* species, the moth bean was found rich source of minerals that includes Zn, Fe, and Mn, indicating nutritional food resource. Moth bean seeds present various micro elements with average value such as zinc (3.63 mg 100 $g^{-1}$), calcium (114.35 mg 100 $g^{-1}$), phosphorus (231.46 mg 100 $g^{-1}$), magnesium (164.12 mg 100 $g^{-1}$), and iron (15.10 mg 100 $g^{-1}$) [15, 17, 27] as given in Table 4. When compared to Fe content of other pulses such as chickpea (5.45 mg 100 $g^{-1}$), lentils (8.60 mg 100 $g^{-1}$), and beans (7.48 mg 100 $g^{-1}$), moth hold higher total iron content [46]. The amount of information available on the other minerals found in moth bean is minimal [47].

### 3.5 Vitamins

Vitamins required in trace amounts are obtained through a well-balanced diet. Beans are rich in both water and fat-soluble vitamins. Fat-soluble vitamins in diet are vitamins A, D, E and K. Each one has its important function and can be found in a variety of food. The water-soluble vitamins don't last long in the body; they need to be replenished frequently. The important water-soluble vitamins are vitamin C and the group of B vitamins. Moth bean contains a variety of water-soluble vitamins as shown in Table 5. The common vitamins found in this bean include vitamin B, thiamine, riboflavin, and niacin. This legume has a smaller amount of thiamine, riboflavin, and niacin than other legumes such as soybean and mung bean. Provitamin A (14.65–32 IU), vitamin B1 thiamine (0.23–0.562 mg 100 $g^{-1}$), vitamin B2 riboflavin (0.091–0.45 mg 100 $g^{-1}$), vitamin B3 niacin (0.47–28.08 mg 100 $g^{-1}$), vitamin B5 pantothenic acid (1.54 mg 100 $g^{-1}$), folate (649 µg 100 $g^{-1}$) and vitamin C ascorbic acid (4–59.10 mg 100 $g^{-1}$) are present in the moth bean seeds [28]. A minor amount of vitamin E is also present. Vitamin levels are comparable to/or higher than those found in other legumes like chickpea (thiamine 0.116 mg, riboflavin 0.063 mg, niacin 0.526 mg, pantothenic acid 0.286 mg, folate 172 µg) and mung bean (thiamine 0.621 mg, riboflavin 0.233 mg, niacin 2.251 mg, pantothenic acid 1.91 mg, folate 625 µg).

### 3.6 Polyphenol

The average total phenolics and flavonoids in the moth bean seeds were found to be 0.88 g 100 $g^{-1}$ and 0.13 g 100 $g^{-1}$ (Table 6). Vanillic acid, caffeic acid, ferulic acid, gallic acid, kaempferol, quercetin, tannic acid, cinnamic acid and k-3-rutnoside are the most common phenolic compounds present in different *Vigna* species [15, 43, 48–51]. The process of sprouting enhances addition of various phenolic compounds. Key phenolic compounds found in moth bean sprouts include caffeic acid, ferulic acid, cinnamic acid and kaempferol [49]. A study identified thirteen distinct phenolic compounds in various moth bean accessions, with eight being identified as phenolics viz. caffeic acid, gallic acid, syringic acid, vanillin, cinnamic acid, chlorogenic acid, ferulic acid and tannic acid and five as flavonoids viz. catechin, epicatechin, myricetin, naringenin and quercetin [15]. Analysis revealed catechin to be most abundant phenolic compound available in moth bean seeds, followed by gallic acid, tannic acid and chlorogenic acid [15]. The concentration of these display variations viz. catechin (1471.05 µg $g^{-1}$), gallic acid (736.58 µg $g^{-1}$), vanillin (39.04 µg $g^{-1}$), cinnamic acid (31.12 µg $g^{-1}$) and quercetin (5.54 µg $g^{-1}$), chlorogenic acid (354.89 µg $g^{-1}$), ferulic acid (485.22 µg $g^{-1}$) and epicatechin (343.96 µg $g^{-1}$) contents were present in the moth bean seeds. The content of vallinin, syringic acid, caffeic acid and epicatechin were found proportionate to each other. Myricetin was reported in very small amount. Earlier results showed that moth bean seeds have adequate levels of bioactive phenolic compounds.

### 3.7 Antioxidants

Flavonoids and other phenolic compounds are commonly known as plant secondary metabolites that hold an aromatic ring bearing at least one hydroxyl groups. More than 8000 phenolic compounds as naturally occurring substances from plants have been reported. Phenolic compounds as well as flavonoids are well-known as antioxidant due to their benefits for human health, curing and preventing many diseases [49]. The dark-colored seed coats of various legumes such as moth bean, lentils, lablab bean and pigeon pea contained low to medium amounts of total phenolic compounds [18]. High phenolic content corroborate with high antioxidant activity in moth bean and other *Vigna* species [22]. Tannins and phenolic compounds are widely distributed secondary metabolites in plants, and play a prominent role in general defense strategies of plant, as well as contributing to food quality. The term 'hydrolyzable' and 'condensed' tannins are used to distinguish between the two important classes of vegetable tannins, namely gallic acid-derived and flavan-3,4-diol-derived tannins, respectively [52]. The antioxidant capabilities of moth bean could be attributed due to the

**Table 6** Antinutritional factors of moth bean seeds

| Component | Tresina et al. [17] | Chinazum et al. [57] | Bhadkaria et al. [15] |
|---|---|---|---|
| Saponin (mg100 $g^{-1}$) | – | 0.65 | – |
| Total free phenolics (g100 $g^{-1}$) | 1.46 | 0.15 | 0.05–1.03 |
| Flavonoid (g 100 $g^{-1}$) | – | 0.13 | 0.25 |
| Tannins (g 100 $g^{-1}$) | 0.65 | 2.89 | 0.13–0.30 |
| Phytic acid (g 100 $g^{-1}$) | 0.42 | – | 1.74 |
| Trypsin inhibitor activity (TIU $mg^{-1}$ protein) | 28.30 | – | – |
| Oligosaccharides (g 100 $g^{-1}$) | | | – |
| Raffinose | 0.54 | – | – |
| Stachyose | 1.68 | – | – |
| Verbascose | 1.26 | – | – |
| Phytohaemagglutinating activity*(HU $mg^{-1}$ protein) | | | 1.60–18.48 |
| Blood group (A) | 32 | – | – |
| Blood group (B) | 133 | – | – |
| Blood group (O) | 18 | – | – |

tannin's direct interaction with the hydroxyl radical [53]. Within tissues and membranes, naturally occurring antioxidants suppress both free radicals and oxidative chain reactions [54].

Raw seeds of moth bean contained greater quantities of total phenolics (0.05–1.46 g 100 $g^{-1}$) and tannins (0.13–2.89 g 100 $g^{-1}$). On cooking, inactivates some, but not all, as they soften the cell wall and facilitate the extraction of bioactives such as polyphenols. Antioxidant activity in the moth bean seed extract could be assessed by alpha, alpha-diphenyl-beta-picrylhydrazyl (DPPH), 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) ABTS, Ferric reducing/antioxidant power (FRAP), and Metal chelating activity in crude extracts of moth bean. Kestwal et al. [49] observed sprouting of moth bean seeds yielded 28% increase in the phenolic content. Oxidative stress is an important parameter of stress. Moth bean sprouts play a crucial role in declining such stress in cell lines. The ethanolic extract of moth bean sprouts reduced intracellular oxidative stress in HepG2 cells. Its potential as a natural antioxidant to medical researchers warrants more investigation.

## 3.8 Antinutrients

In addition to nutritional composition, several antinutritional elements reported in moth bean. This includes saponins, phytic acid, tannins, lectins and protease inhibitors are shown in Table 6. These antinutrients interfere with the assimilation of nutrients when consumed raw, so are processed (soaking, heating, germination etc.) to inactivate them before consumption.

### 3.8.1 Saponin

Saponins also known as triterpene glycosides, are bitter-tasting usually toxic plant-derived organic chemicals that causes haemolysis of red blood cells (RBC's) and form persistent froth if shaken with water. Primarily, saponins protect healthy plants from insects. For this reason, ingesting foods that contain saponins can cause toxicity in the human body. Chemical and physical properties of saponins available in different legumes exhibit diversity. Further, some of the saponin-containing plants are toxic for ruminants leading to dysfunction of body system. Saponins are bioactive compounds found in legumes. They are made up of a triterpenoid aglycone (sapogenin) linked to one or more oligosaccharide moieties. They display a variety of biological activities of interest to pharma and food sectors. They are capable of absorbing free radicals and activating antioxidant cascade of enzymes. It has been evaluated that moth bean has fairly lower content of saponin (0.65 mg 100 $g^{-1}$) when compared with chickpea (2.97 g 100 $g^{-1}$), soybean (4.08 g 100 $g^{-1}$), lupin (4.55 g 100 $g^{-1}$), lentil (10.63 g 100 $g^{-1}$), fenugreek (12.90 g 100 $g^{-1}$) and various other beans [55]. It is observed that sprouting can reduce the saponin content of the bean (56–66%). The loss of saponin from seeds during soaking may be attributed to leaching of saponin into the soaking medium through simple diffusion. Soaking in a mixed mineral salt solution was equally effective in removing up to 30–36%, while water soaking reduces 9–18% of the saponin content. The normal cooking processes can reduce the saponin content 12–15% [56]. Loss during cooking may indicate the thermolabile nature of saponins. On contrary, saponin known to exert beneficial effects *vis-a-vis* lowers plasma cholesterol in humans [57].

### 3.8.2 Tannins

Foods rich in tannins are considered to be of low nutritional value. Tannins are complex chemical substances derived from phenolic acids. In legume, tannins are naturally present showing pigmented seed coat [58]. These are water-soluble phenol derivatives synthesized by plants naturally and accumulate as secondary metabolites. Tannins are classified into two major groups viz. hydrolysable tannins and condensed tannins. Hydrolysable tannins include gallotannines, ellagitannines, and complex tannins mainly glucose, gallic acid and ellagic derivatives [59]. Condensed tannins are more resistant to microbial degradation than hydrolysable tannins. Further, they have higher antibacterial, antiviral and antifungal activity. Tannin content in the moth bean seeds range from 0.13–0.30 g 100 $g^{-1}$ [15, 57] which is higher than chickpea (0.01 g catechin equivalent (CAE) 100 $g^{-1}$) and cowpea (0.10 g CAE 100 $g^{-1}$). In the case of common beans varieties, the tannin content of black beans ranged from 0.41 to 0.60 g CAE 100 $g^{-1}$and lentil contained 0.40 to 1.02 g CAE 100 $g^{-1}$ [58]. The low level of tannins in moth bean seeds reflect in higher nutritive value than other edible pulses, which affect carbohydrate and fat digestibility, as well as mineral bioavailability [60].

#### 3.8.3 Phytic acid

Phytic acid impairs the absorption of iron, zinc and calcium, therefore it is often referred as anti-nutrient. Moth bean phytic acid ranges from 0.42 to 1.74 g 100 $g^{-1}$ [5]. These levels observed to be lesser than reported for chickpea (0.75–0.80 g 100 $g^{-1}$), black gram (0.65–0.67 g 100 $g^{-1}$) and pigeon pea (0.01–1.66 g 100 $g^{-1}$), suggesting nutritive value of raw moth bean seeds to comparatively higher extent. Food processing methods like soaking, germination and fermentation reduce phytic acid content in the moth bean seeds [61]. On comparing with other common legumes, moth bean contained significantly lower antinutritional factors.

#### 3.8.4 Trypsin inhibitor

A trypsin inhibitor is a protein and a type of serine protease predominantly present in legume seeds. The presence of trypsin inhibitor(s) adversely affects the digestibility of dietary proteins by inhibition of proteolytic enzymes in the intestinal tract. Trypsin inhibitors have been found in a variety of legumes including common beans, cowpea, mung beans, lima beans, winged beans, chickpeas and rice beans [62]. Trypsin Inhibitor activity (TIA) reported significantly low in processed moth bean seeds, however higher trypsin activity in raw seeds was noted [17]. Moth bean trypsin inhibitor features to seed storage proteins which contains globulin, vicilin α-phaseolin, β-conglycinin, cupin and convicilin [63]. Traditional cooking, pressure cooking and sprouting can completely eliminate the TIA from the seeds [62].

#### 3.8.5 Oligosaccharides

α-Galactosides, characterized by the presence of α (1 → 6) links between the galactose moieties, may induce flatulence. α -Galactosides are the most widely distributed soluble carbohydrates in the plant kingdom [64]. One group of α-galactosides is the raffinose family of oligosaccharides (RFO) including raffinose [O-α-D-galacto- pyranosyl-(1 → 6)-α-D-glucopyranosyl-(1 → 2)-β-D-fructofuranoside], stachyose and verbascose [64]. Total oligosaccharide content in legumes ranged diversely 70.7 mg $g^{-1}$ in yellow peas to 144.9 mg $g^{-1}$ in chickpeas [65]. In moth bean, the content of raffinose (5.40 mg $g^{-1}$), stachyose (16.80 mg $g^{-1}$), verbascose (12.60 mg $g^{-1}$) is lower which can be eradicated by traditional cooking methods like soaking, sprouting, soaking with ultrasound (47 MHz), soaking with high hydrostatic pressure (HHP, 621 MPa) and gamma irradiation [64, 66].

#### 3.8.6 Lectins

Lectins are glycoproteins that are prevalent in edible legumes. They possess an affinity for sugar molecules and are known by their ability to bind with receptors that are present on cell membrane [67, 68]. They bind directly on the intestinal mucosa and interfere with the absorption and transportation of nutrients during digestion [69–71]. Lectins in moth bean are poorly characterized and reported absent in the raw seeds of moth bean cultivars [70]. According to Sathe and Venkatachalam [28], there was no detectable haemagglutination activity (HA) in moth bean seed protein, when tested using human blood erythrocytes. The lack of HA in moth bean may composite nutritionally advantageous [71]. Recent studies reported low level of hemaagglutinating activity in moth bean seeds too i.e. 1.60 to 18.48 HU $mg^{-1}$ protein using rabbit erythrocytes [15].

## 4 Nutritional processing of moth bean seeds

The nutritional quality of any edible legume can be improved through traditional processing methods to reduce antinutrients. Dehulling, soaking, germination, fermentation, and enzyme treatment are some of the main processing procedures employed to lowering anti-nutritive components and thus boosting organoleptic quality. Dehusked splits of moth bean seeds are milled and used in human diets (Fig. 1).

In legumes, during germination the raffinose family oligosaccharides are metabolized both in the endosperm and in the cotyledons of the seed a galactomannan get localized in the endosperm. After the development of radicle the endosperm, galactomannan begins to be mobilized. The polysaccharide is degraded to produce galactose and mannose, absorbed by the cotyledons in which sucrose increases and starch is formed. Mobilization of the galactomannan is supplemented by the formation in the endosperm of a dissolution zone the form of which implies that the

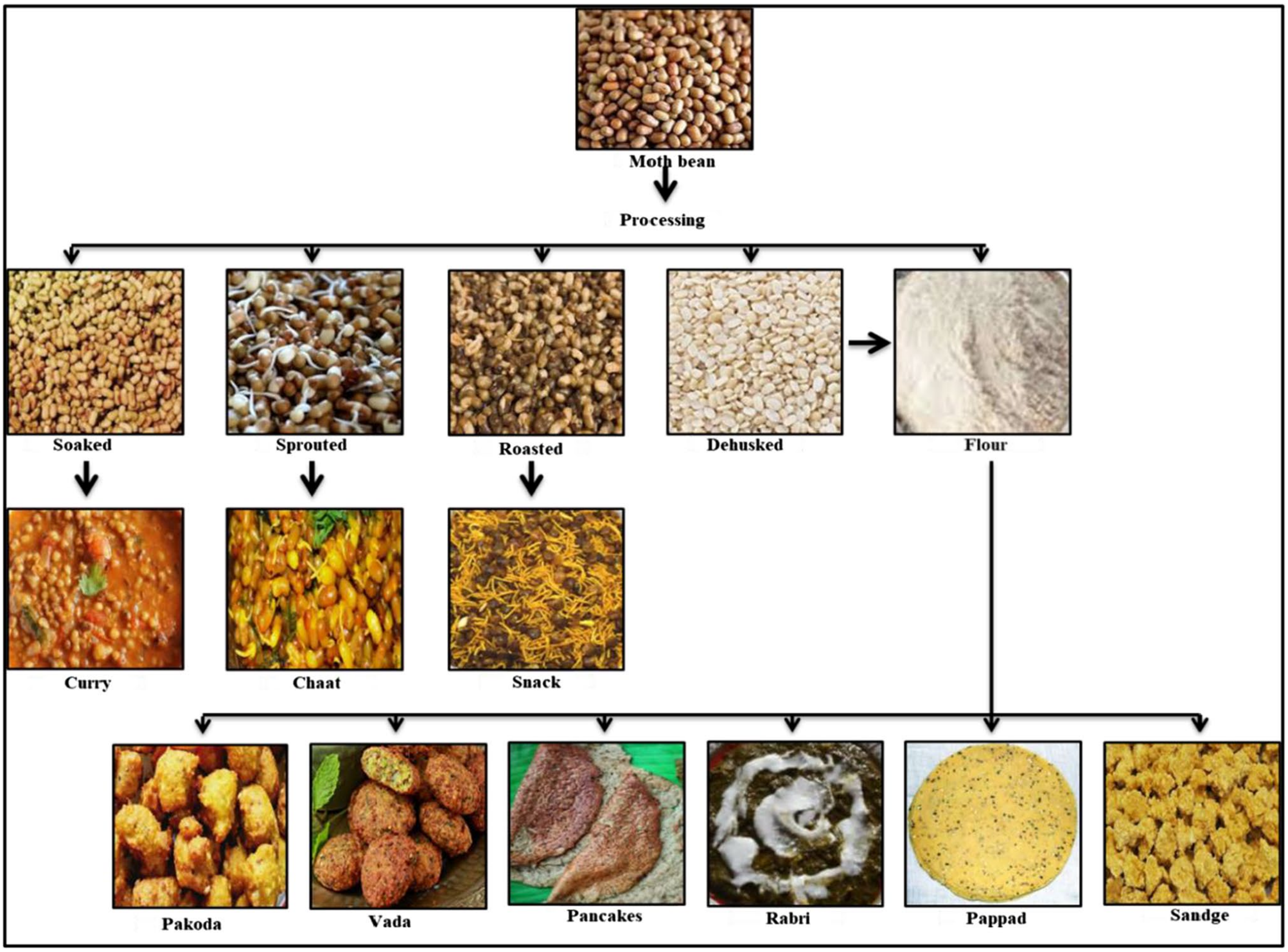


**Fig. 1** Processing of moth bean seeds for human consumption by soaking, sprouting, roasting, dehusked and grinded into flour to prepare different products like curry, chaat, snacks (pakoda, vada, pancakes, rabri), papad and sandge [14, 36, 72, 73, 77, 78, 87]

aleurone layer is involved in the degradation process [72]. In case of beans, the endosperm is completely absorbed at maturity and the fleshy cotyledon is formed after germination. In germinating grains, amylases catalyze the hydrolysis of starch, stored as amylose and amylopectin, to simple sugars, i.e., the reducing sugars glucose and maltose and, to a lesser extent, the non-reducing sugar sucrose resulting in a higher digestibility [73]. Soaking seeds in water for 12 h with mineral salt reduces the amount of phytic acid to the maximum level of 46–50% [74]. Furthermore, in vitro carbohydrate and protein digestibility were enhanced by 19–36% and 1–8%, respectively. Equally, it lowers the seeds' total sugar content [75]. The tannin level of moth bean was dramatically lowered after soaking [76]. The whole seed germinated sprouts boost riboflavin, niacin and thiamine content [77]. The sprouted seeds reported to enhance the protein and starch digestibility, as well as the phenolic content and antioxidant activity [78, 79]. Fermentation at various temperatures and time periods results in considerable improvement in protein and starch digestibility by reducing the quantity of antinutrients in the moth bean seeds. Chavan et al. [79] created fermented probiotic drinks with sugar, cardamom, and *L. acidophilus* using germinated and ungerminated moth bean seeds. Fermentation also enhanced acidity, pH, probiotic count, antioxidant and polyphenol levels.

Cooking moth bean seeds can improve the levels of starch, total soluble sugar and protein digestibility. It further lowers the carbohydrate content due to hydrolysis of total sugar [74, 77]. Antinutrients such as total free phenols, tannins, and phytic acid get reduced in the seeds [80–82]. Roasting boosts iron bioavailability while lowering phytic acid in moth bean seeds. There occurs no reduction in amino acids due to roasting. It also improves the protein efficiency ratio of digestibility, as well as the rate of growth [35]. Radiation is equally important to eliminate anti-nutritional factors improving self-life of the food material. Gamma radiation increased the crude protein content, polyphenols, IVPD, linoleic acid, palmitoleic acid and eicosenoic acid in moth bean seeds. Crude fat, crude fibre and antinutrients such as L-DOPA, hydrogen cyanide, trypsin inhibitors, oligosaccharides and phyto-haemagglutinins have all been reduced [17, 83].

## 5 Product development from moth bean

In developing countries, moth bean is a preferred poor man's diet. Humans consume the seeds and young pods of the moth bean, while animals consume the leaves and stalks. Moth bean can be used to make a variety of nutrient-rich products as shown in Fig. 1. Whole seeds, dehusked seeds, and sprouts are the most common forms of consumption. Because of their vitamin and mineral richness, moth bean seed sprouts are eaten as a vegetable/curry. Moth bean flour is used to make traditional Indian cuisines such as papad, bhujia, mangori, vada, kheech, roti, rabri, and sandge [12]. The addition of whole seeds to a thick soup of whole seed meal aids in the reduction of the effects of cough and bronchitis in the rural population [84].

Moth bean starch accounts as a natural source of starch that may be used in a variety of food applications. The shelf life of fresh lemon was extended up to 12 days using modified moth bean starch films with potential functional features [85]. The hydrophobic inert matrix of acetylated moth bean starch is capitalized in the formulation of controlled release tablets of lamivudine, which is prescribed in the treatment of hepatitis B (HBV) and acquired immunodeficiency Syndrome (AIDS) [86].

Moth bean seed sprouts are widely consumed raw and as a vegetable rich in vitamin and mineral. Protein bioavailability is increased by 30% when sprouted [14] and improves health by scavenging free radicals. Sprouting alters physiochemical and functional food properties, which is important in the development of gluten-free food products thus attracting large market potential. The moth bean flour has the potential to be used in the development of gluten-free products, which have a considerable commercial potential [87]. The functional qualities of composite flours were improved by adding moth bean seed powder to wheat flour at various concentrations. In addition, except for lysine, bread samples enriched with moth bean seed powder had higher levels of essential amino acids than the dietary recommended value by FAO/WHO/UNU [33, 88].

## 6 Health benefits of moth bean

The therapeutic benefits of moth bean seeds are depicted in Fig. 2. In rural areas, it is used to treat fever [85]. The roots are narcotic in nature [22]. Cough and bronchitis are treated with moth bean soup. It is used to treat irregular menstruation cycles in women. It is also good for renal diseases due to the property as astringent, diuretic and tonic [12]. By enhancing bile acid binding at active sites, moth bean protein efficiently causes hypocholesterolemia by lowering low density cholesterol and prominently boosting high density cholesterol levels [89–91]. Moth bean trypsin inhibitor has antiproliferative activity for lymphoma MBL2 cells [92]. The seeds of moth bean have anti-Parkinson activity [93]. Antioxidants and phytochemicals are bioactive molecules found in plants that can be used to cure or prevent variety of diseases [94].

Moth bean seed extracts exhibit multiple antioxidant and inhibitory activities against α-glucosidase ($IC_{50}$ = 50.42 mg/mL) and pancreatic lipase ($IC_{50}$ = 7.32 to 9.85 mg $mL^{-1}$) [52]. The presence of excess phenolics and flavonoids in the ethanolic extract of moth bean confer antioxidant, anti-diabetic and anti-hypertensive properties. Moth bean sprouts contain caffeic, ferulic, and cinnamic acids, as well as kaempferol, which help to reduce oxidative stress. The antibacterial activity of silver nanoparticles made from moth bean sprouts was tested against gram positive and gram negative microorganisms and reported to offers inhibition [95]. Moth bean seeds are high in phenolic compounds, antioxidants and enzyme inhibitors linked in the management of various chronic health conditions such as diabetes, anti-inflammatory and anti-hypertensive effects. As a result, consuming moth bean contains influential nutraceuticals that are beneficial to human health. Thus, incorporating moth bean legumes protein into the development of functional meals with improved therapeutic potential would be a significant step towards improving health well-being [15].

Natural antioxidants and phytochemicals are bioactive compounds present in plants used to treat and prevent various diseases. Phytochemicals from these medicinal and functional food species represent a wide array of biochemicals for possible use in the medicinal industries [96, 97]. Many of the phytochemicals discussed related to moth bean requires further research insights.

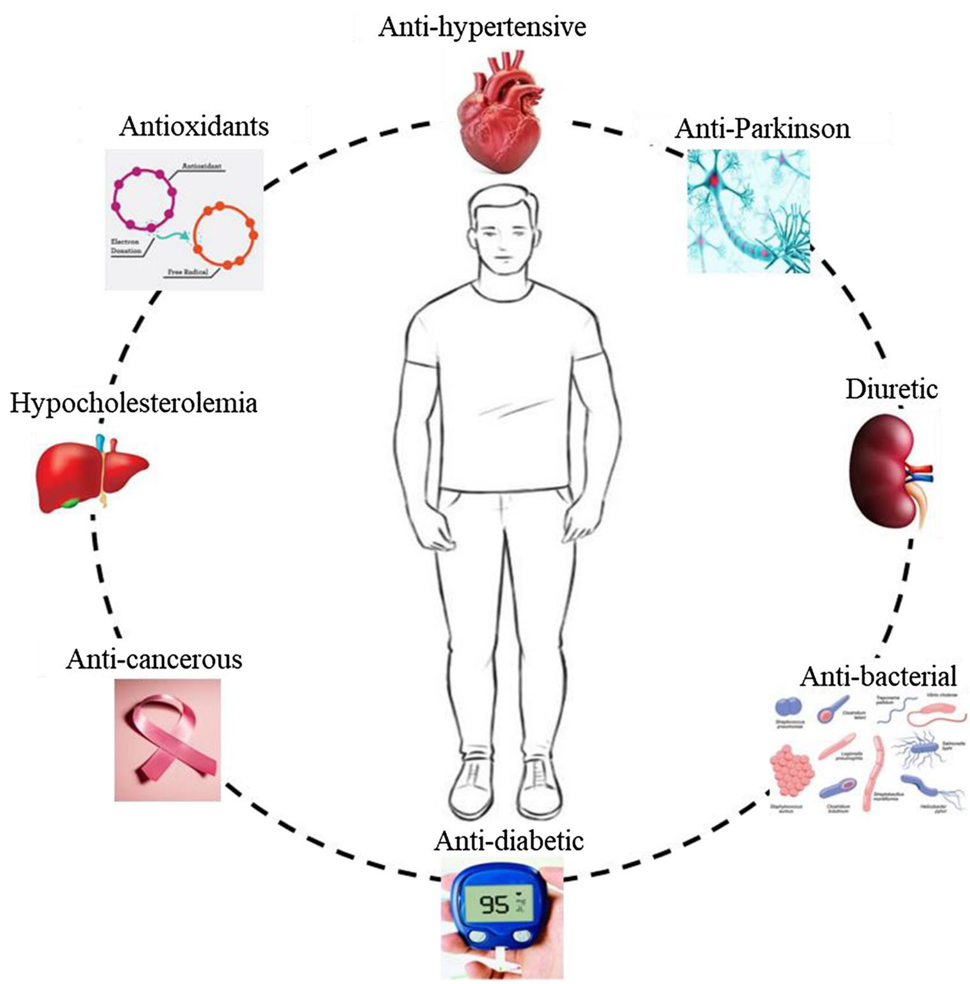


**Fig. 2** Pharmacological effects of consumption of moth bean on human health [12, 89–95]

## 7 Conclusion

Moth bean being underutilized food legume constitutes potential nutraceutical properties rich in dietary fibre having low glycemic index. Moth bean potentially address the food security concerns and provide a good source of plant-based proteins. It has the potential to aid malnutrition in *toto*. Celiac patients may get benefit from the usage of moth bean in manufacturing gluten-free products. Moth bean deliver balanced nutrition when added to cereal-based foods. Food-bioactives of moth bean seeds can influence direct health benefits on its consumption. The seeds of this legume are nutritive, draws the attention of plant breeders for quality cultivar production meeting dietary protein requirements for human consumption in developing world.

**Author contributions** AB and SSB conceived the study, conducted literature screening and wrote the manuscript. DTN, NG and AK conducted literature screening and wrote the manuscript. SSB edited and reviewed the manuscript. All the authors read and approved the final manuscript.

**Declarations**

**Competing interests** The authors declare no conflicts of interest.

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