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# A critical review on phytochemical profile and health promoting effects of mung bean (*Vigna radiata*)

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**Abstract**

The seeds and sprouts of mung bean are very common cruise in Asia. Evidence showed that bioactive compounds in mung bean have emerged as an increasing scientific interest due to their role in the prevention of degenerative diseases. All data of *in vitro, in vivo* and clinical studies of mung bean and its impact on human health were collected from a library database and electronic search. Botanical, phytochemical and pharmacological information was gathered and orchestrated. Remarkable studies have been demonstrated, showing the enhancement of metabolites in mung bean during the sprouting process, which possesses various health benefiting bioactive compounds. These compounds have been frequently attributed to their antioxidant, anti-diabetic, antimicrobial, anti-hyperlipidemic and antihypertensive effect, anti-inflammatory, and anticancer, anti-tumor and anti-mutagenic properties. In this critical review, we aimed to study the insight of the nutritional compositions, phytochemistry, and health-promoting effects of mung bean and its sprouts. The various curative potential of mung bean provides successive preclinical outcomes in the field of drug discovery and this review strongly recommends that mung bean is an excellent nutritive legume, which modulates or prevents chronic degenerative diseases.


*Keywords:* Mung bean; Nutritional composition; Phytochemistry; Health promoting effects

*Abbreviations:* ABTS, 2, 2′-azinobis 3-ethyl-benzothiazoline-6-sulphonic acid; ACC, acetyl-CoA carboxylase; ALP, alkaline phosphatase; ALT, alanine transaminases; AST, aspartate transaminase; BUN, blood urea nitrogen; C/EBPα, CCAAT/enhancer binding protein alpha; CAT, catalase; COX2, cyclooxygenase; CPK, creatine phosphokinase; CVD, cardiovascular diseases; DAD, diode array detector; DPPH, 2, 2-diphenyl-1-picrylhydrazyl; FFA, free fatty acids; FRAP, ferric reducing antioxidant power; FTICR-MS, Fourier transform ion cyclotron resonance mass spectrometry; GC–MS, gas chromatography/mass spectrometry; GI, glycemic index; GLC, gas liquid chromatography; GLUT4, glucose transporter 4; GPx, glutathione peroxidase; GR, glutathione reductase; GSH, glutathione; GST, : glutathione s-transferase; HbA1c, glycated hemoglobin; HDL, high-density lipoprotein; HO-1, heme oxygenase-1; HPLC, high-performance liquid chromatography; HPLC-DAD, high-performance liquid chromatography with diode-array detection; IFN, interferon; IL, interleukin; kDa, kilo daltans; LDH, lactate dehydrogenase; LDL, low density lipoprotein; LOX, lipoxygenase; LPO, lipid peroxidation; MCHC, mean corpuscular hemoglobin concentration; MCH, mean corpuscular hemoglobin; MDA, malondialdehyde; MTT, 3-(4, 5-dimethyl-thiazol-2-yl)-2, 5-diphenyl tetrazolium bromide; MUFA, monounsaturated fatty acids; NADH, nicotinamide adenine dinucleotide hydrogen; NF&HIPHEN;kB, nuclear factor-kappa B; NMR, nuclear magnetic resonance; ORACL, oxygen radical absorbance capacity-fluorescein; p-AMPK, phosphorylated 5′ adenosine monophosphate-activated protein kinase; PCV, packed cell volume; p-ERK1/2, phosphorylated extracellular signal-regulated protein kinases ½; PGC-1α, proliferator-activated receptor gamma coactivator-1 alpha; PPARγ, peroxisome proliferator-activated receptor gamma; PUFA, polyunsaturated fatty acids; RNS, reactive nitrogen species; ROS, : reactive oxygen species; RT-PCR, reverse transcriptase-polymerase chain reaction; SCFA, short chain fatty acids; SGOT, serum glutamate oxaloacetate transaminase; SGPT, serum glutamate pyruvate transaminase; SOD, superoxide dismutase; STZ, : streptozotocin; TBARS, thiobarbituric acid reactive substances; TC, total cholesterol; TEAC, trolox equivalent antioxidant capacity; TGF-B1, transforming growth factor-b1; TG, triglycerides; TNF α, tumor necrosis factor alpha; UV, ultra violet; VLDL, very low density lipoprotein; WHO, World Health Organization.

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## 1. Introduction

Clinical evidence reported that bioactive food compounds obtained from legumes have potential health benefits and their intakes are annually growing at a rate of 10 percent [1]. WHO has also recommended that the consumption of bioactive compounds has the potential to enhance the healthcare and overcome many chronic degenerative diseases [2]. These compounds appear to the primary function of antioxidants and have become popular nowadays which focuses on the existing nutritional and therapeutic interest [3]. Antioxidants and functional foods are more satisfying to health benefits due to their defense mechanism against various degenerative diseases caused by ROS and RNS [4]. These antioxidants are derived from food legumes and cereals, which provide a diverse multitude and magnitude of activities and they also have the broader scope in managing oxidative stress in biological systems [5]. Epidemiological studies reported that the consumption of antioxidant rich food such as legumes are positively correlated with the lower occurrence of degenerative diseases including diabetes, CVD, cancer, arthritis, and Alzheimer's diseases [6,7]. Currently, more interests have been focused on the potential consumption of food legumes not only in the development of new functional ingredients for food enrichment but also the increasing health and healing potential [8,9].

Mung bean (*Vigna radiata* L.; Family: Fabaceae) is well known as green gram or moong bean. Mung bean has been consumed as a common traditional food worldwide for more than 3500 years. *Vigna radiata* used to be known as *Phaseolus aureus* Roxb. Later, many Phaseolus species were moved to the *Vigna* genus [10]. Taxonomy, vernacular and common names of mung bean are listed in Table 1. Indian farmers have been widely cultivating mung beans since 3500 years ago. As the years passed by, these cultivated mung beans spread rapidly from India to China and various regions of Southeast Asia [11]. At present in China, greater than 5000 mung bean accessions have been documented by the National Crop Gene Bank of China [12]. Mung bean is a creeping annual crop growing up to 90 cm height in warm climate up to 35°. It is a short-duration crop (75–90 days) and has wider adaptability and it extensively grows on all types of soil. It grows greatly under most adverse arid and semi-arid conditions. The leaves are alternate and trifoliate with pale green in color. Besides that, its flowers are greenish yellow to pale yellow in color. Fruits (pods) are pendent, glabrous, linear-cylindric grow up to 12 cm containing 10–15 ellipsoidal green, yellow to brown or black mottled pods [13].

Mung bean and sprouts are widely consumed as a fresh salad, vegetable or even as a common food in India, China, Bangladesh, Philippines, Thailand, South East Asia, and western countries [14]. It is well known for its detoxification properties and is used to alleviate heat stroke and reduce swelling during the summer. In the book *Ben Cao Qiu Zhen*, the Mung bean has recorded to be beneficial in the regulation of gastrointestinal problems due to superficial infections and moisturization of the skin [15]. The paste of Mung bean has been used to treat acne, eczema, dermatitis and relieving itchiness [16]. Mung bean seeds, sprouts and plant with pods are illustared in Fig. 1.

It is also used for the treatment of alcoholism which was one of the first information recorded in the classical book of *Ben-Cao-Gang-Mu* (Compendium of Materia Medica) [17]. In the traditional Chinese medicine, sprouts are said to be a *yin* or a cooling nutritive food. On top of that, it is known to have diuretic, antiscorbutic, antipyretic, antihypertensive, antidote and anticancer properties. It is prescribed by Oriental herbalists for heat, ache, inflammation, and hypertension. In the Philippines, the seeds are used either raw or cooked in matured poultice due to its protective or curative potentials for *Polyneuritis galinarum*. Whereas, in India, the seeds are used for paralysis, fever, cough, rheumatism, and neuro-diseases. They are considered as a hot and tonic, used for piles and liver diseases. Mung beans root are known to be narcotic and are given as a healing property in bone aches [18].

Mung beans are recognized for its high nutritive value, composed of about 20%–25% protein of total dry weight. Among them, globulin (60%) and albumin (25%) are the primary storage proteins. Hence, the intake of mung beans nowadays is significantly increasing together with other cereals [14,19]. The protein in the mung beans contains a greater quantity of essential amino acids, including phenylalanine, leucine, isoleucine, valine, tryptophan, arginine, methionine, and lysine [20]. Hence, it is considered to be a substantive source of dietary proteins (240 g/kg). During sprouting, the proteolytic cleavage of these proteins, amino acids, vitamins, and minerals are significantly high. Studies showed that rodents can grow faster to become mature with protein from this single source [21]. Owing to its palatable taste and nutritional quality, mung bean has been consumed as an iron-rich dietary source for infants and children.

Mung bean mainly consists of carbohydrate (55%–65% equal to 630 g/kg of dry weight). Starch is the principal carbohydrate, which helps to prepare starchy noodles. Raffinose, stachyose, and verbascose are the remaining carbohydrates, which are associated with flatulence in the diet. However, these oligosaccharides are readily soluble in water and get ridden by sufficient soaking, fermentation, and germination. Mung bean carbohydrates are easily digestible, which causes less flatulence in human compared to other forms of legumes [22]. Mung bean and sprouts produce lower calories compared to other cereals which are advantageous for obesity and diabetic individuals [23]. Furthermore, mung beans are composed of tannins, phytic acid, trypsin inhibitors, hemagglutinin and other antinutrients, which possess various biological activities that help in eliminating toxins [24]. In recent years, many secondary metabolites have been found to possess health-promoting effects on human which includes flavonoids (flavones, isoflavones, and isoflavonoids), phenolic acids (gallic acid, vanillic acid, caffeic acid, cinnamic acid, protocatechuic acid, shikimic acid, and *p*-hydroxybenzoic acid), and many other organic acids [25].

The nutritive value and health-promoting effects of mung beans are significantly elevated during germination [26]. Analytical studies haveshown that a variety of nutrients and metabolites

Table 1
Taxonomy, vernacular and common names of mung bean.

| Taxonomy: | Vernacular name: |
|---|---|
| Kingdom: Plantae | **Bengali:** Mug, Mung |
| Subkingdom: Tracheobionta | **Bissau:** Balatong, |
| Super Division: Spermatophyta | **Brazil**: Feijão-Mungo-Verde |
| Division: Magnoliophyta | **Burmese**: Pe-Di, Pe-Di-Sein |
| Class: Magnoliopsida | **Canada**: Ambérique, Ambérique Jaune |
| Subclass: Rosidae | **Chinese**: Lü Dou, Luhk Dáu,Qing Xiao Dou **Czech**: Fazol zlatý, Mungo fazole, Vigna Zlatá |
| Order: Fabales | **Danish**: Mung-Bønne |
| Family: Fabaceae | **Dutch**: Jerusalembønne, Mungboon |
| Genus: Vigna | **Estonian:** Munguba |
| Species: radiata | **English**- Green Gram, Mung Bean, Mung Dahl |
| Common Name: | **Finnish**: Mungopapu |
| Green Gram, Mung Bean, Golden Gram, Chinese Mung Bean, Golden-Seeded Mung Bean, Indian Mung Bean, Jerusalem Pea, Burmese Mung Bean, Mung Dahl, Moong Bean, Celera Bean | **French**: Haricot Doré, Haricot Mungo |
| | **German**: Jerusalembohne, Lunjabohne, |
| | **Hindi:** Mung, |
| | **Ibanag:** Balataong, |
| | **Ifugao:** Balatong Balatong |
| | **Indonesia**: Arta Ijo, Kacang Djong |
| | **Italian**: Fagiolino Verde, Fagiolo Aureo, |
| | **Japanese**: Bundou, Fundou, Yaenari, Ryokutou |
| | **Kannada:** Pacche Hasiru |
| | **Khmer**: Sândaèk Ba:Y |
| | **Laotian**: Thwàx Khiêw, Thwàx Ngo:K |
| | **Latin America**: Frijo Mungo |
| | **Malayalam:** Cheru Payaru, Cherupayar |
| | **Malaysia**: Kacang Hijau |
| | **Manipuri:** Mung-Hawai |
| | **Marati:** Mung, Udid |
| | **Nepal**: Mas; **Oriya:** Muga |
| | **Peru**: Frijolito Chino, Loctao |
| | **Polish**: Fasolka mung, Fasola Złota, Ola Mung |
| | **Portuguese**: Feijão-da-china |
| | **Punjabi:** Moongi |
| | **Russian**: Mash, Maš, Fasol’ Vidov, Fasol |
| | **Spanish**: Frijol, Fríjol chino, Frijol De Oro |
| | **Sinhalese**: Bu Me, Mun |
| | **Swahili**: Mchooko, Mchoroko |
| | **Swedish**: Mungböna |
| | **Tagalog:** Balatong, Munggo |
| | **Tamil**: Pasipayar, Pasippayaru |
| | **Telugu**: Pacha-Pesalu, Pachha Pesalu |
| | **Thai**: Thuaa Khiaao, Thua Khieo |
| | **Vietnamese**: Dâu Xanh. |

in mung beans are significantly improved during germination [20,27]. For incidence during sprouting, the reduces the content of triacylglycerol, increases the levels of free amino acids and total phenolic acids and alters the metabolites of fatty acid methyl esters, free fatty acids, monosaccharides, and disaccharides. Furthermore, these sprouts contain more potential antioxidant substances such as polyphenols when compared to the raw seeds [28–30]. Hence, germination is thought to enhance the nutritional and medicinal qualities of mung beans. Taking into account, the consumption of mung beans and sprouts in regular basis are not only providing nutrients, but also maintains the microbial flora in the gut, reduces the absorption of toxic compounds, decreases the menace of obesity, hypercholesterolemia, and cardiovascular diseases, and also prevents cancer and diabetes [31,32]. The nutritive compositions of raw, sprouted and cooked mung bean are summarized in Table 2.

## 2. Phytochemistry

Over the last decade, several studies have been focused on isolation and identification of bioactive compounds in mung beans. Flavonoids, phenolic acids, organic acids, sterols and triterpenes, aldehydes and lipids have been found in the seeds and sprouts to recognize its potential pharmacological activities. The structure of bioactive components or secondary metabolites of mung beans are illustrated in Table 3.

Table 2
Nutritive compositions of mung bean in 100 g of edible portion [33].

| Nutrients | Unit | Raw | Sprouted | Cooked |
|---|---|---|---|---|
| Water | g | 9.05 | 90.40 | 72.66 |
| Energy | kcal | 347 | 30 | 105 |
| Energy | kJ | 1452 | 126 | 441 |
| Protein | g | 23.86 | 3.04 | 7.02 |
| Fat | g | 1.15 | 0.18 | 0.38 |
| Ash | g | 3.32 | 0.44 | 0.79 |
| Carbohydrate | g | 62.62 | 5.94 | 19.15 |
| Total dietary fiber | g | 16.3 | 1.8 | 7.6 |
| Total sugars | g | 6.60 | 4.13 | 2.00 |
| Minerals | | | | |
| Calcium | mg | 132 | 13 | 27 |
| Iron | mg | 6.74 | 0.91 | 1.40 |
| Magnesium | mg | 189 | 21 | 48 |
| Phosphorus | mg | 367 | 54 | 99 |
| Potassium | mg | 1246 | 149 | 266 |
| Sodium | mg | 15 | 6 | 2 |
| Zinc | mg | 2.68 | 0.41 | 0.84 |
| Copper | mg | 0.941 | 0.164 | 0.156 |
| Manganese | mg | 1.035 | 0.188 | 0.298 |
| Selenium | μg | 8.2 | 0.6 | 2.5 |
| Vitamins | | | | |
| Ascorbic acid | mg | 4.8 | 13.2 | 1.0 |
| Thiamin | mg | 0.621 | 0.084 | 0.164 |
| Riboflavin | mg | 0.233 | 0.124 | 0.061 |
| Niacin | mg | 2.251 | 0.749 | 0.577 |
| Pantothenic acid | mg | 1.910 | 0.380 | 0.410 |
| Vitamin B-6 | mg | 0.382 | 0.088 | 0.067 |
| Folate | μg | 625 | 61 | 159 |
| Choline | mg | 97.9 | 14.4 | 29.4 |
| Beta Carotene | μg | 68 | 6 | 14 |
| Alpha Carotene | μg | 0 | 6 | 0 |
| Beta cryptoxanthin | μg | 0 | 6 | 0 |
| Vitamin A | IU | 114 | 21 | 24 |
| Vitamin E (alpha-tocopherol) | mg | 0.51 | 0.10 | 0.15 |
| Vitamin K (phylloquinone) | μg | 9.0 | 33.0 | 2.7 |
| Lipids | | | | |
| Total saturated fatty acids | g | 0.348 | 0.046 | 0.116 |
| Total monounsaturated fatty acids | g | 0.161 | 0.022 | 0.054 |
| Total polyunsaturated fatty acids | g | 0.384 | 0.058 | 0.128 |
| Phytosterols | mg | 23 | 15 | 0 |
| Amino Acids | | | | |
| Tryptophan | g | 0.260 | 0.037 | 0.076 |
| Threonine | g | 0.782 | 0.078 | 0.230 |
| Isoleucine | g | 1.008 | 0.132 | 0.297 |
| Leucine | g | 1.847 | 0.175 | 0.544 |
| Lysine | g | 1.664 | 0.166 | 0.490 |
| Methionine | g | 0.286 | 0.034 | 0.084 |
| Cysteine | g | 0.210 | 0.017 | 0.062 |
| Phenylalanine | g | 1.443 | 0.117 | 0.425 |
| Tyrosine | g | 0.714 | 0.052 | 0.210 |
| Valine | g | 1.237 | 0.130 | 0.364 |
| Arginine | g | 1.672 | 0.197 | 0.492 |
| Histidine | g | 0.695 | 0.070 | 0.205 |
| Alanine | g | 1.050 | 0.099 | 0.309 |
| Aspartic acid | g | 2.756 | 0.479 | 0.812 |
| Glutamic acid | g | 4.264 | 0.161 | 1.256 |
| Glycine | g | 0.954 | 0.063 | 0.281 |
| Proline | g | 1.095 | 0.00 | 0.323 |
| Serine | g | 1.176 | 0.033 | 0.346 |
| Isoflavones | | | | |
| Daidzein | mg | 0.00 | 0.06 | 0.01 |

Table 2 (*Continued*)

| Nutrients | Unit | Raw | Sprouted | Cooked |
|---|---|---|---|---|
| Genistein | mg | 0.09 | 0.08 | 0.01 |
| Glycitein | mg | 0.00 | 0.00 | 0.00 |
| Total isoflavones | mg | 0.09 | 0.10 | 0.01 |
| Biochanin A | mg | 0.00 | 0.01 | 0.00 |
| Formononetin | mg | 0.21 | 0.01 | 0.00 |
| Coumestrol | mg | 0.00 | 0.93 | 0.00 |
| Flavonols | | | | |
| Kaempferol | mg | 0.1 | 0.3 | 0.00 |
| Myricetin | mg | 0.1 | 0.0 | 0.00 |
| Quercetin | mg | 0.1 | 0.1 | 0.00 |

Twelve phenolic compounds such as catechin, epicatechin, *p*-coumaric acid, ferulic acid, syringic acid, *p*-hydroxy benzoic acid, protocatechuic acid, gallic acid, vitexin, isovitexin, sinapic acid, and quercetin were identified from mung bean sprouts by capillary gas-liquid chromatography [34]. Hot and cold water extracts of mung bean contain six flavonoids namely, robinin, rutin, kaempferol, quercetin, isoquercitrin, and kaempferol-7-*O*-rhamnoside, which were analyzed by HPLC system. These flavonoids content has been increased about 2.5 to 10 fold with the growth of mung bean sprouts [35]. Another study has also revealed that the sprouts of mung bean, contains six phenolic compounds, including four hydroxycinnamic acids (caffeic, 5-*O*-caffeoylquinic, *p*-coumaric and ferulic acids) and two flavonoid glycosides (kaempferol-3-*O*-glucoside and kaempferol-3-*O*-rutinoside),kaempferol-3-*O*-rutinoside), which were determined by HPLC-DAD analysis [36].

Studies in Japan reported that the mature leaves and seeds of mung bean contain 12 groups of flavonoid including three anthocyanins, two leucoanthocyanins, two glycoflavones and five flavonol glycosides [37]. Quercetin, quercetin-3-*O*-glucoside, and myricetin were detected in mung bean seeds and sprouts by HPLC-UV analysis. These compounds were 22 times higher in mung bean sprouts compared to mung bean seeds [38]. Hence, germination of mung bean helps to improve nutritional quality. A new flavonoid *C*-glycoside namely isovitexin-6″-*O*-α-L-glucoside, and another 14 known flavonoids were identified and characterized in mung bean by extensive 1D and 2D NMR and FT-ICR-MS analyses [39]. Vitexin and isovitexin have been investigated to be present in mung bean seeds at about 157.5

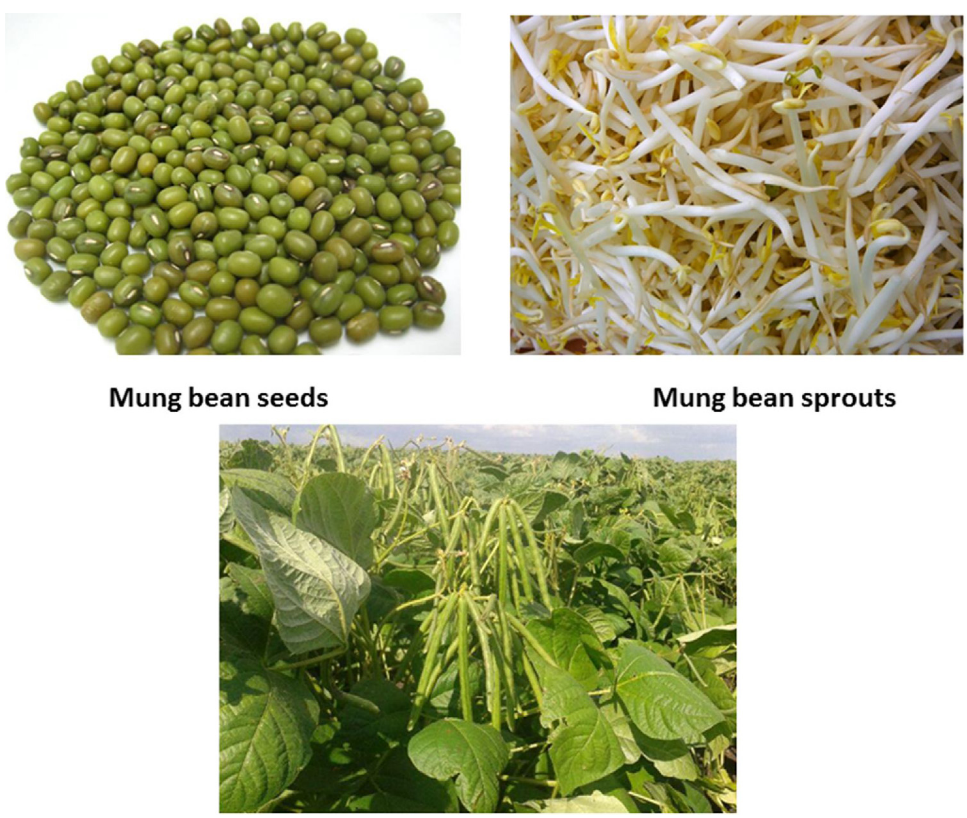



Fig. 1. Mung bean seeds, sprouts and Mung bean plants with pods.

Table 3
List of phytochemicals in mung bean [24,31,34,41,56–59].

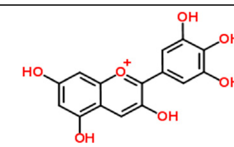
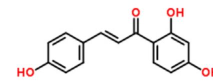
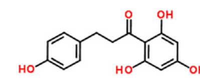
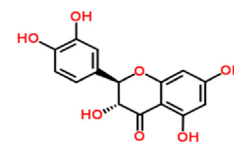
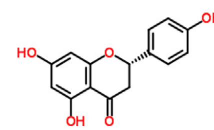
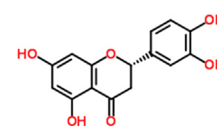
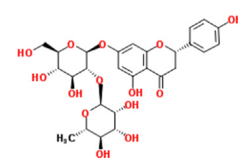
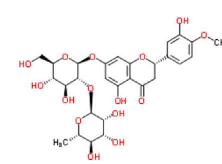
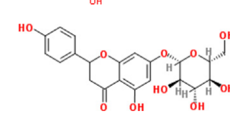
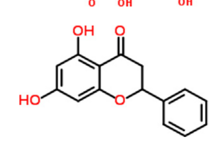
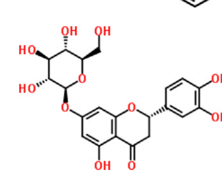
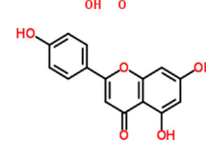
| Polyphenol Class | Polyphenol Sub-Class | Compound Name | Structure |
|---|---|---|---|
| Flavonoids | Anthocyanins | Delphinidin 3-*O*-glucoside |  |
| Flavonoids | Chalcones | 2′,4,4′-Trihydroxychalcone |  |
| Flavonoids | Dihydrochalcones | Phloretin |  |
| Flavonoids | Dihydroflavonols | Dihydroquercetin |  |
| Flavonoids | Flavanones | Naringenin |  |
| Flavonoids | Flavanones | Eriodictyol |  |
| Flavonoids | Flavanones | Naringin |  |
| Flavonoids | Flavanones | Neohesperidin |  |
| Flavonoids | Flavanones | Naringenin 7-*O*-glucoside |  |
| Flavonoids | Flavanones | 5,7-Dihydroxyflavanone |  |
| Flavonoids | Flavanones | Eriodictyol 7-*O*-glucoside |  |
| Flavonoids | Flavones | Apigenin |  |

Table 3 (*Continued*)

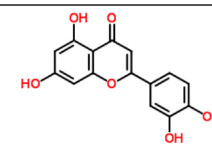
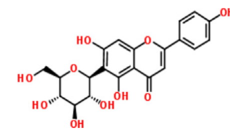
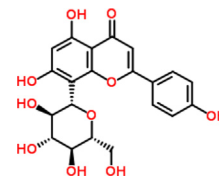
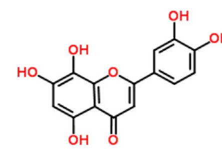
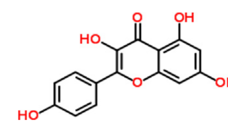
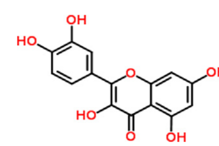
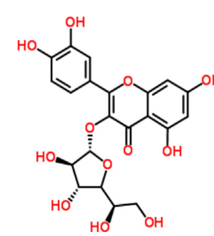
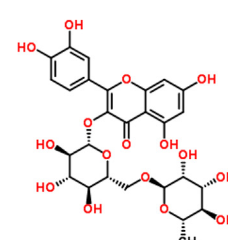
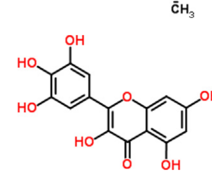
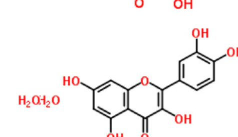
| Polyphenol Class | Polyphenol Sub-Class | Compound Name | Structure |
|---|---|---|---|
| Flavonoids | Flavones | Luteolin |  |
| Flavonoids | Flavones | Apigenin 7-*O*-glucoside |  |
| Flavonoids | Flavones | Apigenin 6-*C*-glucoside |  |
| Flavonoids | Flavones | Hypolaetin |  |
| Flavonoids | Flavonols | Kaempferol |  |
| Flavonoids | Flavonols | Quercetin |  |
| Flavonoids | Flavonols | Quercetin 3-*O*-glucoside |  |
| Flavonoids | Flavonols | Quercetin 3-*O*-rutinoside |  |
| Flavonoids | Flavonols | Myricetin |  |
| Flavonoids | Flavonols | 3,5,7,3′,4′-Pentahydroxyflavonol |  |

Table 3 (*Continued*)

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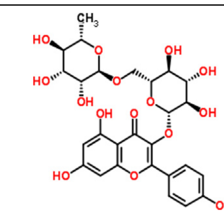
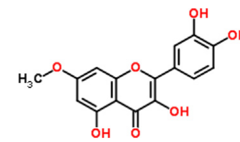
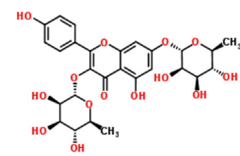
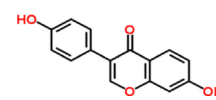
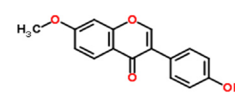
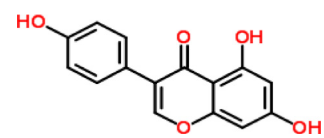
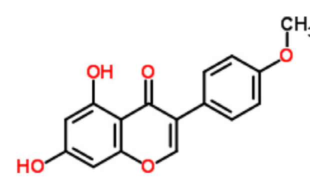
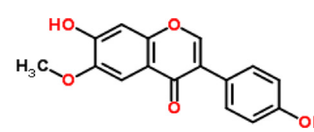
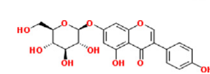
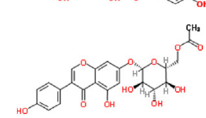
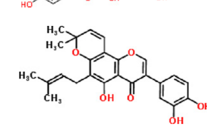
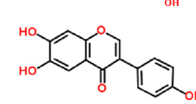
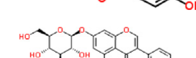
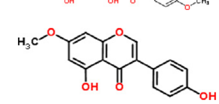
| Flavonoids | Flavonols | Kaempferol 3-*O*-rutinoside |  |
| Flavonoids | Flavonols | Rhamnetin |  |
| Flavonoids | Flavonols | Kaempferitrin |  |
| Flavonoids | Isoflavonoids | Daidzein |  |
| Flavonoids | Isoflavonoids | Formononetin |  |
| Flavonoids | Isoflavonoids | Genistein |  |
| Flavonoids | Isoflavonoids | Biochanin A |  |
| Flavonoids | Isoflavonoids | Glycitein |  |
| Flavonoids | Isoflavonoids | Genistin |  |
| Flavonoids | Isoflavonoids | 6”-*O*-Acetylgenistin |  |
| Flavonoids | Isoflavonoids | Pomiferin |  |
| Flavonoids | Isoflavonoids | 6,7,4’-Trihydroxyisoflavone |  |
| Flavonoids | Isoflavonoids | Dihydrobiochanin A |  |
| Flavonoids | Isoflavonoids | Prunetin |  |

Table 3 (*Continued*)

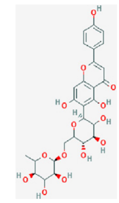
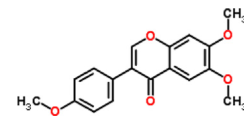
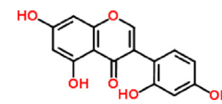
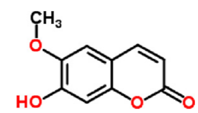
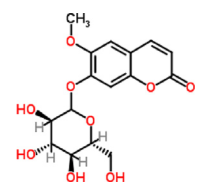
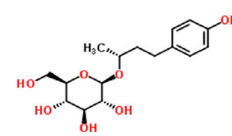
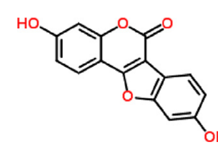
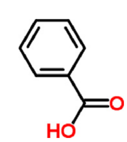
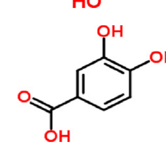
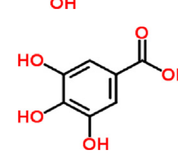
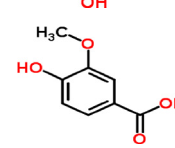
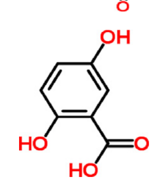
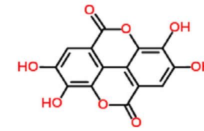
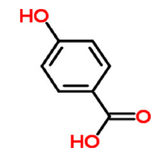
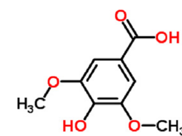
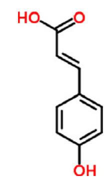
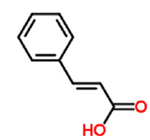
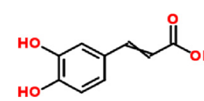
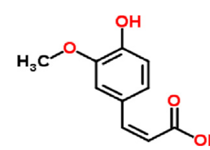
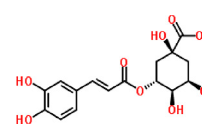
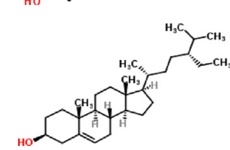
| Polyphenol Class | Polyphenol Sub-Class | Compound Name | Structure |
|---|---|---|---|
| Flavonoids | Isoflavonoids | Dulcinoside |  |
| Flavonoids | Isoflavonoids | 5,7-Dihydroxy-8,4'-dimethoxyisoflavone |  |
| Flavonoids | Isoflavonoids | 2'-Hydroxygenistein |  |
| Other polyphenols | Hydroxycoumarins | Scopoletin |  |
| Other polyphenols | Hydroxycoumarins | Scopolin |  |
| Other polyphenols | Hydroxyphenylpropenes | Rhododendrin |  |
| Other polyphenols | Other polyphenols | Coumestrol |  |
| Phenolic acids | Hydroxybenzoic acids | Ellagic acid glucoside |  |
| Phenolic acids | Hydroxybenzoic acids | Protocatechuic acid |  |
| Phenolic acids | Hydroxybenzoic acids | Gallic acid |  |
| Phenolic acids | Hydroxybenzoic acids | Vanillic acid |  |
| Phenolic acids | Hydroxybenzoic acids | Gentisic acid |  |

Table 3 (*Continued*)

| Polyphenol Class | Polyphenol Sub-Class | Compound Name | Structure |
|---|---|---|---|
| Phenolic acids | Hydroxybenzoic acids | Ellagic acid |  |
| Phenolic acids | Hydroxybenzoic acids | 4-Hydroxybenzoic acid |  |
| Phenolic acids | Hydroxybenzoic acids | Syringic acid |  |
| Phenolic acids | Hydroxycinnamic acids | p-Coumaric acid |  |
| Phenolic acids | Hydroxycinnamic acids | Caffeic acid |  |
| Phenolic acids | Hydroxycinnamic acids | Feruloyl glucose |  |
| Phenolic acids | Hydroxycinnamic acids | Ferulic acid |  |
| Phenolic acids | Hydroxycinnamic acids | Chlorogenic acid |  |
| Phenolic acids | Hydroxycinnamic acids | Sitosterol ferulate |  |

and 198.5 mg/100 g respectively, which were determined using HPLC [40,41]. The seed coat of mung bean mainly contributed to 95.6% of the total vitexin and 96.8% of the total isovitexin [42]. Both of these compounds are functional food ingredients in mung bean, having a wide range of biological activities including antioxidant, anti-inflammatory, antidiabetic, antiviral, anticancer and antitumor activity, hepatoprotective activity, antibacterial and antifungal activity, and other detoxification activities [16,41,43–50].

Mung beans and sprouts are rich in organic acids and fatty acids. About 21 organic acids, including oxalic, malic, quinic, succinic, citric, aconitic and fumaric, phosphoric, were demonstrated in mung beans [29]. Malic and quinic acids were the primary organic acids in mung bean sprouts, representing 55%–86% of the total organic acids [36]. The quantification of organic acids was determined by HPLC-UV [14,36]. About 15 fatty acids, including lauric, myristic, pentadecanoic, palmitic, palmitoleic, heptadecanoic, stearic, oleic, elaidic, linoleic, arachidic, heneicosanoic, behenic, tricosanoic and lignoceric acids were demonstrated as fatty acids in mung bean sprouts. Palmitic and stearic acids were reported as the primary fatty acids in mung bean sprouts, representing 26% of total fatty acids [29]. Further, the study revealed that mung bean seeds possess an enormous quantity of fatty acids such as myristic, oleic, linoleic and arachidonic acids [25]. In addition, mung bean sprouts are essentially composed of saturated fatty acids (71%) monounsaturated fatty acids (18%) and polyunsaturated fatty acids (11%). Oleic acid and linoleic acid were the most abundant MUFA (24%) and PUFA (14%) of the total fatty acids found in mung bean sprouts. The separation and quantification of lipids and fatty acids were determined by GC–MS [14,36].

Four isoflavones including two aglycones (daidzein and genistein) and their glycosides (daidzin and genistin, respectively), were identified by HPLC-DAD method in mung bean sprouts. Among them, glycosides were the primary components, representing 85% of the total isoflavones. Daidzin was the primary glycosides in the sprouts composed of 67%–89% in the determined isoflavones [36]. About 30 volatile compounds belonging to different classes which include (*E*)-2-hexenal, hexanol, benzaldehyde, benzyl alcohol, phenylacetaldehyde, (*E*)-2-nonenal, (*Z*)-2-heptanal, and β-cyclocitral were determined in mung bean sprouts using headspace-solid phase micro extraction [36]. The analysis of sterols and triterpenes in the alkaline hydrolyzed extracts of mung bean sprouts were determined by HPLC-DAD analysis. Based on the analysis, sprouts contain betulin, stigmasterol, campesterol, and β-sitosterol, which were the range of 141 to 227 mg/kg [36]. Among sterols and triterpenes, campesterol was the main metabolite (56%) in all matrices. Mung beans and sprouts are rich in aldehydes and phenylacetaldehyde which are the primary aldehyde in the sprouts [36]. Considering the information on the phytochemistry of the mung bean sprouts reveals that it contains health-promoting bioactive compounds, which are therapeutic agents for the treatment of various human ailments.

## 3. Health promoting effects of mung bean

Based on the high constituents and efficacy of the bioactive compounds, mung beans are playing a greater role in radical scavenging activities, detoxification, and also exhibits chemo-preventive effects. These compounds have the potential health benefit as a complementary and alternative medicine which is exerted for its antioxidant, hepatoprotective, antibacterial, antifungal, antiviral, cardioprotective, anti-inflammatory, antidiabetic, anticancer, anti-obesity, hypolipidemic, and potent chemopreventive properties. Detailed information on dose range, route of administration, the model used, negative controls, and other pharmacological results are based on the experimental research of *in vivo*, *in vitro*, and clinical study which is in accordance with the appropriate title depicted, that is presented in Tables 4–9.

### *3.1. Antioxidant activity*

The seeds, sprouts, and hulls of mung beans contain an enormous amount of macro (protein, polypeptides, oligo, and polysaccharides) and micronutrients (flavonoids, phenolic acids, organic acids, sterols, triterpenes, aldehydes), which exerts potent antioxidant properties. Germination generally causes an increase in micronutrients, including secondary metabolites (phenolics, flavonoids, α-tocopherol, and vitamin C), through aerobic respiration and biochemical metabolism [51,52]. These phenolic compounds and vitamins are notably beneficial as antioxidants. Both of the compounds have the ability to restrain the generation of free radicals by chelating metal ions or inhibiting key enzymes (protein kinase, xanthine oxidase, GSH, lipoxygenase, cyclooxygenase, NADH oxidase and GST) that are involved in the radical generating mechanism [53–55]. Mung bean sprouts have higher antioxidant potential than raw seeds. It possesses a higher quantity of secondary metabolites [40]. The total antioxidant activity of mung bean sprouts on the 8 th day has significantly elevated six times more than that of dried mung bean seeds as determined by radical scavenging activities of DPPH, ABST, and FRAP [38,47].

Additionally, mung bean containing quercetins and kaempferol 3-*O*-neohesperidoside gets glycosylated, which have also widely reduce the metal chelating potential determined by DPPH assay [60,61]. Wongekalak et al. [62] have reported that the mung bean protein hydrolysate has potent antioxidant properties that were evaluated by ORACFL (0.67 μmol Trolox equivalent/mg protein) and TEAC (0.46 μmol Trolox equivalent/mg protein) assays. A Water-soluble polysaccharide (uronic acid) is extracted from mung bean hull, possesses mannose, rhamnose, and galactose, which exhibits higher radical-scavenging activities by DPPH, hydroxyl, and stronger scavenging potentials of superoxide [63]. Based on these results, it can be concluded that the presence of high contents of protein, polysaccharides, phenolics, and flavonoids, which makes mung sprouts as functional food ingredients and excellent dietary source of antioxidants. *In vitro, in vivo* studies of mung bean in terms of antioxidant potentials are summarized in Table 4.

### *3.2. Antidiabetic activity*

The consumption of mung bean has been reported as a potential antidiabetic agent. An experimental animal study showed that the effect of fermented and non-fermented mung bean extracts on normoglycemic, glucose-induced hyperglycemic and alloxan-induced hyperglycemic effects, caused no significant hypoglycemic effect and significantly lowered the blood sugar levels in glucose and alloxan-induced hyperglycemic mice [64]. Another experimental study also revealed that mung bean sprout (2 g/kg) and seed coat extracts (3 g/kg) possessed potent antidiabetic effects and significantly lowered blood glucose, plasma C-peptide, glucagon, TC, TG, and BUN levels [65]. Epidemiological studies have also demonstrated that the use of whole-grain foods and beans reduce the menace of type II diabetes by 25%–30% when compared with low consumption of it [66]. This one fourth reduction effect may be caused due to the decrease digestibility of bean's carbohydrates, more amylose, and resistant starch composition, high dense dietary fibers and generation of SCFAs in the gut, which inhibit high blood sugar levels and prevent high glycemic and insulinemic effects [66,67]. Effects of possible mechanisms of mung bean consumption on diabetes are illustrated in Fig. 2.

Based on the bean's slow digestibility and release of carbohydrates, they are recognized as low glycemic index (GI) foods [68]. Experimental studies also stated that the intake

Table 4
Summary of *in vivo, in vitro* and clinical studies of antioxidant potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Mung bean sprouts | *In vitro* | 104 g | – | Assay of vitamin C, total phenolic compounds, total flavonoids, Quercetin-3-*O*-glucoside | Antioxidants activity | [38,100] |
| Mung bean seeds | *In vitro* | 100 mg/mL | – | Assay of DPPH, ABTS and FRAP, α-amylase, α-glucosidase inhibition | Antioxidant and antidiabetic activities | [59,101] |
| Mung bean sprouts, vitexin, isovitexin, | Male Sprague–Dawley rats | 100 μl, 6 mg/kg/p.o; 750 mg/kg/p.o for 7 days | Isoproterenol (6 mg/kg/s.c) | Assay of ABTS, DPPH, LDH, CK, and AST as well as the tissue level of MDA and SOD | Antioxidant and myocardial protective activities | [59] |
| Mung bean sprouts | *In vitro* | 100 g | – | Assay of DPPH, ABSA, ORAC, free phenolic acid and bound phenolic acid, total anthocyanin, cyanidin-3-glucoside, α-glucosidase and advanced glycation end products | Antioxidant and antidiabetic activities | [65,69] |
| methanolic extract of mung bean hulls | *In vitro* | 100 mg/mL | – | Assay of lipids, liposome, carbohydrate, protein and 2'-deoxyguanosine, deoxyribose | Antioxidant activity | [99] |
| Flavanoid fraction of Vigna species | Rabbit | 150 mg/kg/p.o | Cholesterol (400 mg/kg | Assay of LDH, CPK, atherogenic index, SGOT, SGPT, COX2 and LOX15 in peripheral blood monocytes, genotoxicity study using a Comet assay and gene expression by RT-PCR of TGF&HIPHEN;b1 and HO-1 | Antioxidants and the antihyperlipidemic activities | [102–105] |
| Methanol extract of mung bean | Wistar rats | 250 mg/kg/p.o. | Starch (2 g/kg/p.o) | Assay of DPPH, ABTS, Hydrogen peroxide, nitro blue tetrazolium, glycated hemoglobin, intestinal α-glucosidase | Free radicals scavenging potentials, antioxidant and antidiabetic activities | [108] |
| Mung bean sprouts | Male Sprague–Dawley rats | 100, 500 and 1000 mg/kg/p.o | Acetaminophen (3 g/kg/p.o) | Assay of SGOT, SGPT | Antioxidant and hepatoprotective activity | [109] |
| Lyophilized mung bean sprouts | F344/DuCrj rats | 5% for 4 weeks | Acetaminophen 5% | Assay of AST, GSH, GR, CAT, hepatic phosphatidylcholine hydroperoxide and phosphatidylethanolamine hydroperoxide | Antioxidant and hepatoprotective activity | [110] |
| Fermented mung bean | Male Balb/c mice | 200 mg/kg/p.o and 1000 mg/kg/p.o for 7 days | 100 μL of 50% (v / v) of ethanol for 7 days | Assay of AST, ALT, TG, TC, SOD, MDA, FRAP, and NO levels and histopathological analysis | Antioxidant and hepatoprotective activity | [114] |
| Fermented mung bean | Male Balb/c mice | 200 mg/kg/p.o and 1000 mg/kg/p.o for 8 weeks | Cholesterol (1 g/kg body weight) | Assay of TC, TG, LDL, HDL, AST, ALT, and ALP levels, SOD, MDA, FRAP, and NO levels | Antioxidant and hypolipidemic activity | [115] |
| Mung bean sprouts | Male Balb/c mice | 250 mg/kg/p.o and 1000 mg/kg/p.o for 7 days | 0.2% sodium carboxymethyl cellulose and 2 mg/kg of diazepam | Assay of TC, TG, total protein, ALT, ALP, and glucose, adrenal gland weight, brain 5-hydroxytryptamine, and MDA. | Antioxidant activity | [117] |

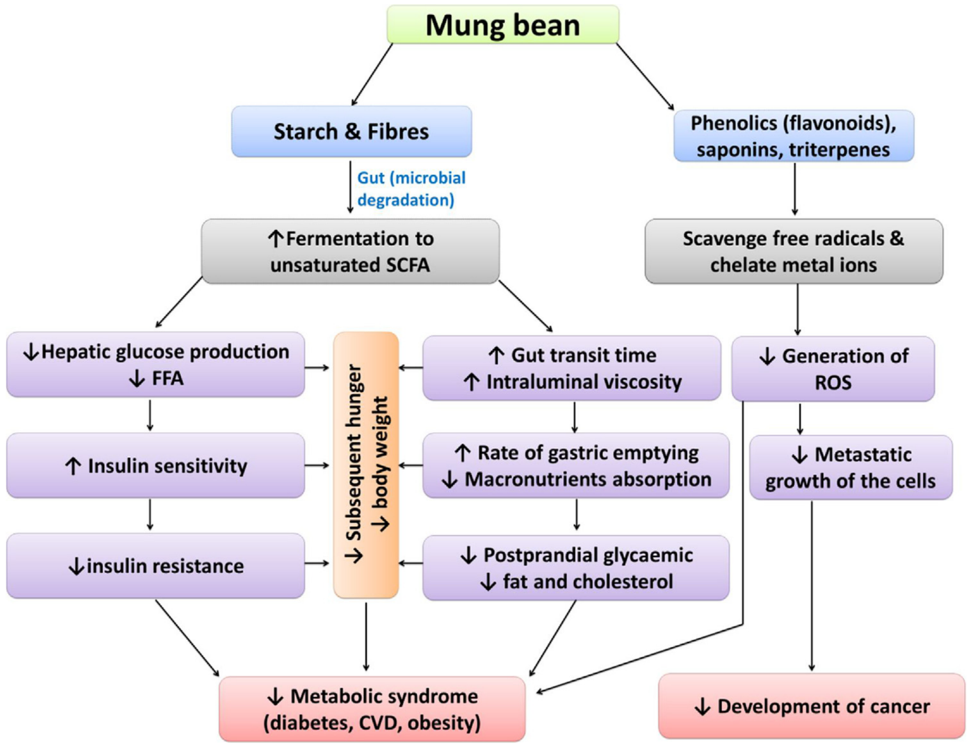



Fig. 2. Effect of possible mechanisms of mung bean consumption on diabetes, CVD, obesity, and cancer. SCFA&HIPHEN;short chain fatty acids, FFA- free fatty acids, ROS&HIPHEN;reactive oxygen species, and CVD&HIPHEN;cardiovascular diseases.

of low GI foods helps to reduce the complications and incidence of diabetes and obesity [69–71]. Furthermore, it is noted that the consumption of 10% low GI food provokes almost 30% to elevate insulin sensitivity in the body [72]. These low GI diets are potential in maintaining the diet-induced insulin responses of insulin resistant or type II diabetes subjects by enhancing glucose uptake mediated by adipocyte-insulin signals [73]. In addition, these low glycemic index diets provoke glucose oxidation suggesting an increase of peripheral insulin action and thereby more utilization of glucose [74]. Epidemiological studies among the Chinese population also reported that the consumption of beans, vegetables, and other food legumes are inversely connected with the risk of type II diabetes [75,76]. Based on these results, it is concluded that these slow digestibility, rich amylose, and fiber content enhance insulin sensitivity resulting in decrease the prevalence rate of type II diabetes. *In vitro, in vivo* studies of mung bean in anti-diabetic potentials are summarized in Table 5.

### 3.3. Antihyperlipidemic and antihypertensive effect

Metabolic syndrome is the name of a group of disorders that is connected with the risk of high levels of blood glucose, TG, LDL, low levels of HDL, which leads to high possibilities of threats to diabetes, hypertension, obesity, and CVD [77–79]. The regular intake of beans in the food is known to be beneficial for healthy and hypercholesterolemic which subjects by decreasing in the serum TC, TG, and LDL and increase HDL [80]. The effect of mung bean consumption on CVD is depicted in Fig. 2. Mung beans containing dietary fibers and its resistant to starch are well-known for satiety inducing properties. They are the primary compounds accountable for the management of metabolic syndrome by slow downing the fuel production by glucose and fat and suppressing appetite through enhanced satiety, and thereby reduce the risk of CVD [81]. Microbial flora in the gut facilitates the breakdown of dietary fibers and resistant starch yield enormous quantity of short-chain fatty acids (propionate), which regulates the metabolic pathways and maintains a postprandial sugar level which then reduces the levels of TG and TC in the blood [82,83]. Thus, the gut fermentation of beans containing dietary fibers and its resistant to starch produces an enormous amount of SCFA, which is a protective function to lower the cholesterol and promote human health in regards of CVD [84].

Experimental studies associated with modulation of lipid metabolism by mung bean have been well established. In this study, hyperlipidemic rats fed with the hydro alcoholic extract of mung bean seeds significantly reduced TC, TG, VLDL and LDL levels and alleviated the symptoms of atherosclerosis and CVD [85]. Another experimental study in rodents also showed that the administration of mung bean extracts significantly lowered TC within 7 days, which was due to phytosterol content of mung beans that facilitated the prevention of biosynthesis and absorption of cholesterol in the rodents [84,85]. Similarly, Reverri et al. [81] also observed a significant decline in serum TC, TG, VLDL and LDL in healthy rats who were given resistant starch of beans (25 g/100 g diet for 4 weeks), the resistant starch reduced the risk of heart diseases by 20%.

Table 5
Summary of *in vivo*, *in vitro* and clinical studies of antidiabetic potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Fermented and non-fermented mung bean | Balb/c mice | 200 mg/kg/p.o and 1000 mg/kg/p.o for 7 days | Alloxan (100 mg/kg/i.p, 0.1 mL) | Assay of blood glucose, TC, TG, HDL, LDL and MDA | Antidiabetic activity | [64] |
| Mung bean sprout extracts and Mung bean seed coat extracts | Diabetic KK-$A^y$ mice and C57BL/6 mice | 1, 2, 3 g/kg/p.o | – | Assay of blood glucose, plasma C&HIPHEN;peptide, glucagon, TC, TG, BUN and immunohistochemical staining of pancreas | Antidiabetic activity | [65] |
| Mung bean sprouts | Female Wistar rats | 200, 400 mg/kg/p.o for 28 days | STZ (55 mg/kg b.w i.p) | Assay of serum Protein, lipids TC, TG, HDL, VLDL, LDL, SGOT, SGPT, Creatinine, urea and histopathology studies of liver, kidney, and pancreas | Antidiabetic activity | [92] |

The consumption of resistant starch of beans elevated the production of cecal SCFA (butyrate), and enhanced fecal neutral sterol excretion, and thereby reduced the serum TC level. In addition, administration of hot water bean extracts to high cholesterol diet fed animals resulted in decreased TG and TC levels and thus prevents hypercholesterolemia [120]. Various epidemiological and clinical studies have also demonstrated that the regular consumption of bean is positively associated with lowering the risk of CVD, coronary artery diseases, and myocardial infarction up to 22%, 11%, and 38%, respectively [121–125]. Based on these results, it is concluded that fiber rich content of mung bean consumption lowers the incidence of CVD. Intragastric administration of raw sprout extract, dried sprout extracts and enzyme-digested sprout extracts at a dose of 600 mg mung bean peptide/kg b.w reduced significantly systolic blood pressure in short term (3–6 h) and long term (30 days) studies in rats. It might be utilized for physiologically functional food with antihypertensive activity [126]. These results indicate that the concentrated mung bean sprout juice has the potential in the prevention and management of hypertension. *In vitro, in vivo* studies of mung bean in antihyperlipidemic and antihypertensive potentials are summarized in Table 6.

### 3.4. Antimicrobial activity

The utility of bioactive compounds from food legumes as natural antimicrobial agents are commonly known as biocides. Mung bean sprouts have potent antiviral and prophylactic activities against respiratory syncytial virus and Herpes Simplex virus −1, and these activities were comparable with Acyclovir. The underlying mechanism was attributed to active components of mung bean sprouts potentially induce antiviral cytokines in human cells and thereby nullify the actions on viral proliferation [106]. Similarly, antifungal and antiviral potency of two beans proteins, designated alpha (28 kDa) and beta (28 kDa) proteins were isolated and were capable of inhibiting human immunodeficiency virus reverse transcriptase and glycohydrolases associated with HIV infection [127]. Further, antifungal peptides (7.3 kDa, 9.03 kDa) were isolated from beans, which exerted an antifungal effects and inhibited mycelial growth in *Fusarium oxysporum, F. solani, Pythium aphanidermatum, Sclerotium rolfsii, Mycosphaerella arachidicola,* and antibacterial effects on *Staphylococcus aureus* [128,129]. In addition, two proteins, Mungin (18-kDa) and chitinase (30.8 kDa) isolated from mung bean seeds possess antifungal activity against *Rhizoctonia solani, Coprinus comatus, Mycosphaerella arachidicola, Botrytis cinerea,* and Fusarium oxysporum [90]. Mungin and chitinase exert an inhibitory activity against α- and β-glucosidases, suppressing [3H] thymidine in the corporation by mouse splenocytes [127]. In 2004, polyphenols were isolated from mung bean sprouts, which exert antibacterial activity against *Helicobacter pylori*, one of the most common causative organisms in gastrointestinal disorders [53]. Furthermore, several *in vitro* and *in vivo* studies have also been reported that mung bean seeds are protective against sepsis [112,119,130]. *In vitro* antimicrobial studies on mung bean are summarized in Table 7.

Table 6
Summary of *in vivo*, *in vitro* and clinical studies of anti-hyperlipidemic and antihypertensive potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Mung bean | Female SHRs | 30% W/W for 45 days | Fructose solution | Assay of blood pressures and heart rate, glucose, insulin, TC, TG | Antihypertensive, antihyperlipidemic, and antidiabetic activities | [32] |
| Vitexin and isovitexin | 3T3-L1 pre adipocytes, KK-Ay diabetic mice | 10, 100, and 500 μM; 1 g/kg.p.o | 60% high-fat diet for 3 weeks/p.o | Assay of Plasma insulin, TC, TG, glucose, HbA1c, MTT, TNF-α, IL-6, and monocyte chemoattractant protein-1, ACC, PPARγ, C/EBPα, *p*-AMPK, AMPK, (PGC-1α), GLUT4, *p*-p38, p38, *p*-ERK1/2, ERK1/2 | Antiobesity activity | [71] |
| Hydroalcoholic extract of the seeds of *V. mungo* | SD strain of albino rats | 500 mg/kg, p.o. for 7 days | Poloxamer 407 (1 mL of 30% w/v solution, i.p.) | Assay of TC, TG, LDL, VLDL, HDL, HMG COA reductase, fecal cholesterol, SOD, CAT, GSH, myeloperoxidase, NO, ascorbic acid | Antihyperlipidemic activity | [85] |
| Mung bean protein isolate | Wistar strain male albino rats | 200, 400 mg/kg/p.o for 28 days | Casein 88.1% crude protein | Assay of body weight, TC, TG, HDL, glucose, total protein, albumin, BUN, AST, ALT, adiponectin | Antihyperlipidemic activity | [97] |

### 3.5. Anti-inflammatory effects

Mung beans have been consumed in several cuisines and in traditional medicine to treat heat stroke connected with thirst, irritation, and high body temperature, detoxification, and these health promoting effects of mung bean seeds and sprouts are believed to be associated with the inflammatory response in Asian countries [98]. Experimental studies associated with modulation of inflammatory effects by mung bean have been well established. In one of the study, high-fat diet induced obesity mice with the extract of mung bean seeds significantly reduced lipopolysaccharide-stimulated peritoneal macrophages and inflammation-related parameters (TNF-α, IL-1β, IL-6, nitric oxide synthase, COX-2, and NF-κB), and alleviated the symptoms of obesity, colitis, and colon inflammation [131]. Mung beans possess various bioactive compounds including polyphenols, gallic acid, vitexin, and isovitexin, which significantly reduced the activity of murine macrophages through the inhibition of proinflammatory gene expression without cytotoxicity [132,133]. Similarly, hydro alcoholic extract of mung beans also improved the arthritic condition by significantly reducing pain and inflammation in the murine model [134]. The immunomodulatory effects of aqueous extracts of mung bean on human peripheral blood mononuclear cells have also been evaluated. The results demonstrated that mung bean containing bioactive compounds including genistein, phytic acid, syringic acid, vitexin, and isovitexin provoke a prominent immune response. The study concluded that several non-nutritional compositions of mung beans including flavonoids, organic acids, and plant hormones are believed to be most significant components in the modulation of human immunity [135]. *In vitro, in vivo* studies of mung bean in anti-inflammatory potentials are summarized in Table 8.

### 3.6. Anticancer effects

Mung beans proteins (48 kDa) have been isolated and exert anticancer properties through various underlying mechanisms. The novel anticancer and immunomodulatory effects of methanolic extracts of mung bean sprout were evaluated in cervix adenocarcinoma (HeLa) and hepatocellular carcinoma (HepG2) cell lines by testing anticancer cytokines (TNF-α and IFN-β), immunological cytokines (IL-4, IFN-γ, and IL-10), cell cycle regulatory genes (cyclin D, E, and A), apoptotic gene expression (Bax, BCL-2, caspases 7–9), tumor suppressor genes (p27, p21, and p53) and percentage of apoptotic cells. These results strongly recommend that mung bean sprout is a potent anticancer and immunomodulatory agent granting new prospects of anticancer therapy [91,136]. *In vitro* studies have also reported that mung bean exerted dose-dependent antiproliferative effects against various cancer cell lines such as digestive system (CAL27, AGS, HepG2, SW480, and Caco-2), ovary (SK-OV-3) and breast (MCF-7) [137]. Similarly, the study evaluated the effects of trypsin inhibitors from mung beans possess anticancer activities on the metastasis and proliferation of human colon cancer cells SW480 cells [138].

Table 7
Summary of *in vivo, in vitro* and clinical studies of antimicrobial potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Mung bean sprouts | *Fusarium solani, Fusarium oxysporum, Pythium aphanidermatum and Sclerotium rolfsii, Staphylococcus aureus* and *Salmonella typhimurium* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antibacterial and antifungal activity | [88] |
| Mung bean sprouts | *Physalospora piricola, Mycosphaerella arachidicola, Botrytis cinerea, Pythium aphanidermatum, Sclerotium rolfsii and Fusarium oxysporum,* and *Staphylococcus aureus.* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antibacterial and antifungal activity | [89] |
| Mung bean sprouts | *Fusarium oxysporum, Fusarium solani, Pythium aphanidermatum, Sclerotium rolfsii, Botrytis cinerea,* and *Staphylococcus aureus.* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antibacterial and antifungal activity | [90] |
| Mung bean sprouts | *Fusarium verticillioides, F. proliferatum, Aspergillus flavus* and *A. parasiticus* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antifungal activity | [93] |
| Mung bean sprouts | *Fusarium solani, F. oxysporum, Mycosphaerella arachidicola, Pythium aphanidermatum,* and *Sclerotium rolfsii.* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antifungal activity | [94] |
| Mung bean sprouts | *Botrytis cinerea, Physalospora piricola, Fusarium oxysporum,* and *Pythium aphanidermatum* | 0.5 mg/mL | – | Assay of minimum inhibitory concentration | Antifungal activity | [95] |
| Mungin | *Rhizoctonia solani, Coprinus comatus, Mycosphaerella arachidicola, Botrytis cinerea,* and *Fusarium oxysporum* | 100 mg/mL | – | Assay of minimum inhibitory concentration and alpha- and beta-glucosidases analysis | Antifungal activity | [96] |
| Methanol extract of mung bean sprouts | Respiratory syncytial virus and Herpes Simplex virus −1, African green monkey kidney cells (Vero) and human embryonic lung fibroblast cell lines | 600 mg/mL | – | Assay of cytotoxicity, virus yield reduction, virucidal activity, and prophylactic activity assays, level of antiviral cytokines, IFNβ, TNFα, IL-1, and IL-6 measured | Antiviral activity | [106] |
| Mung bean sprouts | Human immunodeficiency virus type I | 0.5 mg/mL | – | Assay of minimum inhibitory concentration and reverse transcriptase, protease and integrase | Antiviral activity | [107] |

Table 8
Summary of *in vivo*, *in vitro* and clinical studies of anti-inflammatory potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Mung bean sprouts | Wistar strain male albino rats | 600 mg/kg per day for 13 days. | Phenyl hydrazine (40 mg/kg per day for 2 days | Assay of PCV, MCH, MCHC, MDA | Anti-anemic and Anti-inflammatory activity | [86] |
| Ethanolic extract of mung bean sprouts | Male Wistar rats | 100, 500, 1000 μg/mL for 3 weeks | 0.1 mL of complete Freund's adjuvant into the sub planer region of the left hind paw | Assay of membrane stabilization and protein denaturation, body weights, paw volume, LPO, total GSH, myeloperoxidase, cathepsin-D, N&HIPHEN;acetyl β-D-glucosaminidase and β-D-glucuronidase | Anti-inflammatory and antiarthritic activity | [87] |
| Mung bean sprouts | In vitro | 100 mg/mL | – | DPPH scavenging activity and ferric reducing antioxidant power assay, protease and aldose reductase inhibitory assays | Anti-inflammatory and anti-diabetic activities | [98] |
| Mung bean sprouts | In vitro | 250 mg/kg/p.o and 1000 mg/kg/p.o for 7 days | – | Assay of angiotensin converting enzyme, calmodulin dependent enzymes; and copper-chelating activity | Hypoallergenic activity | [111] |
| Vitexin, or vitexin 2-O&HIPHEN;rhamnoside | Murine macrophage-like RAW 264.7 cells | 400 ng/mL | – | Assay of inflammatory cytokine production by RT-PCR, proteomic and metabolomics analysis, | Immunomodulatory activity | [112] |

Epidemiological studies have also suggested that the intake of beans reduces the prevalence of cancers including colon, breast, prostate, and adenocarcinoma [139–141]. The data obtained from 41 countries and documented that the higher consumption of beans reduced the mortality rate by breast, colon, and prostate cancer [139]. The consumption of beans more than twice a week was linked with markedly decreased (47%) the risk of colon cancer [140] and prostate cancer [141]. It was found that regular intake of beans in rats decreased azomethane-induced tumor morphology by almost 50% [142]. The feeding of cooked bean powder in rats markedly reduced (67%) incidence of breast cancer [143]. Similarly, the diets fed with beans reduce the total tumor incidence and adenocarcinoma incidence by 54% and 75%, respectively [144]. Mung beans contain resistant starch, dietary fibers, phenolic compounds, and micro constituents such as phytic acid, vitexin, isovitexin, protease inhibitors and saponins, which are highly associated with antioxidant and anticarcinogenic properties [144,145]. The antioxidant properties of polyphenols in mung beans decrease metastatic proliferation of the cell and thereby inhibit the development of cancer [146]. The effect of possible mechanisms of mung bean consumption on cancer is illustrated in Fig. 2.

Microbial flora facilitates fermentation of dietary fibers and resistant starch in the gut results in the production of SCFA (butyrate), which has the potential effects on colon cancer. Butyrate has known to be microbial metabolites inducing apoptosis, inhibit cell proliferation in colon cancer [147,148]. These microbial metabolites serve as messengers to the host by acting through selective receptors in the host colon and help the host in energy and nutritional homeostasis, development and maturation of the mucosal immune system, and protection against inflammation and carcinogenesis [149]. Beans contain phenolic compounds and flavonoids, which has a potential properties of antimutagenic, anticarcinogenic and antioxidant activities [146,150]. These compounds have the ability to prevent mutagenic agents (viz., nitrosamines, hydrocarbons, mycotoxins and polycyclic aromatic hydrocarbons) and anticarcinogenic by inhibiting activation of enzymes, scavenging free radicals and inducing detoxification [151,152]. In addition, dry beans contain an adequate amount of saponins and phytic acid, which has the ability of anti-mutagenic and anti-carcinogenic activities to prevent of colon cancer [153,154]. Similarly, protease inhibitors in beans, especially chymotrypsin inhibitors have the ability to restrain cancer-based on the mechanism of inhibiting protein degradation and thereby suppression of uncontrolled proliferation of cancer cells [155]. *In vitro, in vivo* studies of mung bean in anticancer, antitumor, and anti-mutagenic potentials are summarized in Table 9.

## 4. Conclusion and future directions

Mung beans have been consumed in the diet worldwide and play an important function in human nutrition, especially as source rich in protein, and micro nutrients. Besides these nutrients, mung beans possess certain bioactive food components, which contain enormous quantities of polyphenols and other metabolites, have antioxidant potential and major role in

Table 9
Summary of *in vivo, in vitro* and clinical studies of anticancer potentials of mung bean (*Vigna radiata* L.).

| Mung bean | Model | Dose and route of administration | Negative control | Investigation | Results | Reference |
|---|---|---|---|---|---|---|
| Mung bean sprouts | Human cervical (HeLa) and hepatocarcinoma cancer cell line (HepG2) | 300 to 9.37 mg/mL | – | Assay of MTT, cytokines, TNF-α and IFN-β from cancer cells, and immunological cytokines, IL-4, IFN-γ, and IL-10 from peripheral mononuclear cells, apoptotic genes (Bax, BCL-2, Caspases 7–9) and cell cycle regulatory genes (cyclin D, E, and A) and tumor suppressor proteins (p27, p21, and p53) | Anticancer and immunomodulatory activity | [91] |
| Vitexin and isovitexin | Mouse melanoma cell line B16F1 | 6.25, 12.5, 25, and 50 μM | – | Assay of MTT, melanin, tyrosinase, | Inhibitory effects against melanogenesis | [113] |
| Fermented mung bean | Breast cancer MCF-7 cells | 40 mg/L | – | Assay of antioxidant, cytotoxicity and immunomodulatory effects | Anticancer, antioxidant, cytotoxicity and immunomodulation activities | [116] |
| Fermented mung bean | Yac-1 and 4T1 breast cancer cells and female Balb/C mice | 40 mg/L; 200 mg/kg/p.o | Tamoxifen (1 mg/kg body weight) | Assay of tumor development, spleen immunity, serum cytokine (interleukin 2 and interferon gamma) levels, spleen/tumor antioxidant levels, spleen T cell populations, splenocyte cytotoxicity, and histopathological analysis | Potential cancer chemoprevention activity | [118] |
| Mung bean coat containing vitexin, or isovitexin | Recombinant HMGB1 rats, Balb/C mice and Murine macrophage-like RAW 264.7 cells and human monocyte U-937 cells | 40 mg/L | – | Assay of nucleosomal protein, autophagy and several chemokines in macrophage cultures | Protective against lethal sepsis | [119] |

health promoting effect and protect against various degenerative diseases. Although the exact mechanism by which mung bean prevents the expression of cellular molecules remains to be elucidated, they can be used as excellent components to modulate or prevent such chronic degenerative diseases. In any case, more support for such properties/dynamic constituents has been acquired from cellular and molecular studies, while clinical studies are as yet inadequate. Since animal research does not generally interpret human circumstances, additional clinical studies are justified for comprehending the full interpretation of the effects of polyphenol rich mung bean in human disease prevention. Subsequently, futures far-reaching clinical studies are required to warrant the therapeutic convenience of bioactive rich mung bean. Furthermore, highlighting the synergistic multi-component effects of mung beans on biological functions would be a recommendation for further studies, as well as studies of the mechanism of action and new biomarkers to prove the effectiveness of mung bean bioactive compounds in preventing and treating several symptoms and/or pathologies.

## Conflicts of interest

The authors declared that no conflicts of interest.

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