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Phytochemistry and medicinal uses of the common food of mung bean (*Vigna radiata*)

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Abstract

The seeds and sprouts of green gram (Vigna radiata), a popular food, contain ample nutrients with biological properties. This review offers an understanding of the nutritional worth of green grams and their sprouts, discussing chemical components that have been isolated in recent years, such as flavonoids, phenolic acids, organic acids, amino acids, carbohydrates, and lipids. Additionally, we also summarize fluctuating changes in metabolites during the sprouting process and associated biological properties, including antioxidant, antimicrobial, anti-inflammatory, anti-diabetic, blood pressure-lowering, lipid metabolism regulation, and anti-cancer effects, etc., with the aim of providing scientific proof for improved utilization of this commonly consumed food as a remedy.

Keywords: Antioxidant, Medicinal value, Mung bean, Nutritional value, Phytochemistry, *Vigna radiata*.

Introduction

With increasing clinical evidence suggesting that plant-based foods offer numerous potential health benefits, their consumption has been steadily rising at a rate of 5%–10% annually (Tham *et al*., 1998; Pallavi *et al*., 2022; Sarada Devi *et al*., 2022). Moreover, various global health organizations have recommended an increase in the intake of plant-based foods to improve well-being and prevent chronic diseases (Espin *et al*., 2007).

The mung bean (*Vigna radiata*) has been traditionally consumed as a staple food in China for over 2,000 years. It is widely recognized for its detoxifying properties and is used to refresh the mind, alleviate heatstroke, and reduce swelling during the summer. In the book Ben Cao Qiu Zhen, the mung bean was documented to have beneficial effects on gastrointestinal issues and skin hydration (Min, 2001). The seeds and sprouts of mung beans are also commonly used as a fresh salad vegetable or staple food in India, Bangladesh, Southeast Asia, and Western countries (Fery, 1990). As a dietary choice, mung beans provide a well-rounded nutritional profile, including protein and dietary fiber, as well as significant amounts of bioactive phytochemicals. The high levels of proteins, amino acids, oligosaccharides, and polyphenols in mung beans are believed to be the primary contributors to its antioxidant, antimicrobial, anti-inflammatory, and antitumor properties, as well as its involvement in lipid metabolism regulation (Kanatt *et al*., 2011; Randhir *et al*., 2004; Vanamala *et al*., 2006; Anjum *et al*., 2011).

In recent times, research has indicated that the sprouts of mung beans following germination display more noticeable biological properties and a greater abundance of secondary compounds as the relevant biosynthetic enzymes become active during the initial stages of germination. Consequently, germination is believed to enhance the nutritional and medicinal attributes of mung beans (El-Adawy *et al*., 2003). The proficient utilization of mung beans, as supported by scientific experimentation, will prove advantageous for their utilization as a health food, medication, and beauty product (Golob, 1999). In this current analysis, we summarize the nutritional worth, chemical constituents, and changes in metabolites during the sprouting procedure, as well as the pharmacological effects and clinical uses of mung beans. This will offer a deeper comprehension of the potential applications of this common food.

The nutritional value of mung beans as a common food

Mung beans are a legume crop or pulse used primarily as dried seeds and occasionally as forage, green pods, and seeds for vegetables (Tomooka, 2002). Dried seeds may be eaten whole or split, cooked, fermented, or milled and ground into flour. Mung beans can also be made into products like soups, porridge, confections, curries, and alcoholic beverages. In western cultures, mung bean sprouts are popularly used as a fresh salad vegetable (Lambrides and Mungbean, 2007).

Importantly, mung beans are composed of about 20%–24% protein. Globulin and albumin are the main storage proteins found in mung bean seeds and make up over 60% and 25% of the total mung bean protein, respectively. Therefore, due to its high protein content and digestibility, consumption of mung beans in combination with grains can significantly increase the quality of protein in a meal (Wang *et al*., 2004; Kudre *et al*., 2013). Mung bean protein is rich in essential amino acids, such as total aromatic amino acids, leucine, isoleucine, and valine, as compared with the FAO/WHO (1973) reference. However, compared with the reference pattern, mung bean protein is slightly deficient in threonine, total sulfur amino acids, lysine, and tryptophan (Mubarak, 2005). Moreover, the proteolytic cleavage of proteins during sprouting leads to a significant increase in the levels of amino acids.

Mung legumes contain a higher amount of carbohydrates (50%–60%) compared to soybeans, and the main type of carbohydrate present is starch. Because of their abundance in starch, mung beans have traditionally been used for making starchy noodles, known as muk in Korea. Oligosaccharides, which include raffinose, stachyose, and verbascose, found in raw or poorly processed legumes, can cause flatulence when consumed. Although these oligosaccharides are also present in mung beans, they can be dissolved in water and eliminated through proper soaking, sprouting, or fermenting. The energy provided by mung beans and sprouts is lower than that of other grains, which is advantageous for individuals with obesity and diabetes (Zheng, 1999). Furthermore, trypsin inhibitors, hemagglutinin, tannins, and phytic acid present in mung beans have been reported to possess biological functions that aid digestion and detoxification (Lin and Li, 1997).

In addition to a high amount of protein and low-calorie content, mung beans also contain different enzymes and abundant trace elements. For instance, superoxide dismutase (SOD) obtained from the mung bean can be chemically altered and transformed into an SOD oral solution. This chemically modified SOD can evade destruction by stomach acid and pepsin, thereby prolonging its lifespan and making it suitable for human oral uptake (Lin and Li, 1997).

Overall, regular consumption of mung beans could regulate the microbiota of enterobacteria, decrease the absorption of harmful substances, decrease the risk of high cholesterol levels and heart disease, and prevent cancer (Kruawan *et al*., 2012).

Chemical constituents

In recent years, flavonoids, phenolic acids, organic acids, and lipids have been discovered in the seeds and sprouts of mung beans. These compounds have been found to play a role in the medicinal properties of the beans.

Flavonoids

Flavone, isoflavone, flavonoid compounds, and isoflavonoid compounds (compounds 1–44) are the significant metabolites found in the mung bean (Prokudina *et al*., 2012; Wang *et al*., 2008). Most flavonoids have multiple hydroxyl substitutions and can be classified as polyphenols with evident antioxidant activity. Vitexin (apigenin-8-C-β-glucopyranoside) and isovitexin (apigenin-6-C-β-glucopyranoside) have been reported to be present in mung bean seeds at approximately 51.1 and 51.7 mg g^{-1}, respectively (Li *et al*., 2012; DongKwan *et al*., 2008). Flavonoids are involved in stress protection (i.e., oxidative and temperature stress), early plant growth, signaling (i.e., legume nodulation), and defense against insect and mammalian herbivores (Koes *et al*., 1994).

Phenolic acids

Phenolic compounds are secondary compounds primarily produced through the PPP, shikimate, and phenylpropanoid pathways (Randhir *et al*., 2004). These compounds are important bioactive phytochemicals, and their presence in wild plants has led to an increase in the use of wild plants as food sources (Estomba *et al*., 2006; Singh *et al*., 2009).

A total of twelve phenolic compounds have been identified in mung bean seeds and sprouts (Sosulski and Dabrowski, 1984; Sawa *et al*., 1999). Mung beans have high levels of total phenolics and total flavonoids, which contribute to their ability to scavenge the DPPH radical, inhibit tyrosinase, and exhibit antiproliferative and alcohol dehydrogenase activities. These properties make mung beans a potential substitute for prescription drugs and a preventive or therapeutic agent for human diseases (Kim *et al*., 2012).

Others

Mung beans and sprouts have also been discovered to contain natural acids and fats. Twenty-one natural acids, such as phosphoric and citric acid, and 16 fats, including γ-tocopherol, were identified as the main constituents of mung beans using gas chromatography/mass spectrometry (GC/MS) (Bowles, 1990).

Dynamic changes in metabolites

Under both biotic and abiotic stress, the physiology of plants undergoes significant alterations. The activation of defense mechanisms, including those involving proteinase inhibitors, results in a response that shields the plant from these types of pressures (Jom *et al*., 2011). As part of this response, the production of secondary metabolites with diverse health advantages has been observed (Bowles, 1990; Kessler and Baldwin, 2002). However, even in the absence of stress, healthy plants can also be prompted by stress stimulators to artificially generate secondary metabolites. Focused examinations have revealed that the sprouting of mung beans is accompanied by a range of noteworthy changes in the contents of metabolites, such as reduced concentrations of antinutrients (Kataria *et al*., 1989) and increased levels of free amino acids (Mubarak, 2005; Kataria *et al*., 1989; Kavas and Sedef, 1991; Abdel-Rahman *et al*., 2007; Kirchhoff, 2002).

Sprouting significantly decreases the levels of reducing sugars and starches by 36.1% and 8.78%, respectively (Mubarak, 2005). Interestingly, until 60 h of incubation, levels of the monosaccharides fructose and glucose increase dramatically in the sprouting material. However, significant decreases in the levels of both sugars have been observed during the final sprouting stage from 60 to 75 h. The concentration of the disaccharide sucrose increases within the first 24 hours but rapidly declines after the initial sprouting phase (El-Adawy *et al*., 2003; Mubarak, 2005; Bowles, 1990). Moreover, raffinose and stachyose are completely eliminated during sprouting. The decrease of sucrose in the latter stages of sprouting may be due to the absence of raffinose, resulting in the breakdown of sucrose for energy supply (Mubarak, 2005).

In comparison to grains, mung beans have higher levels of protein (Kirchhoff, 2002). As previously explained, the breakdown of proteins during sprouting results in a notable rise in the quantities of most amino acids. Furthermore, targeted analysis has revealed elevated levels of free amino acids in sprouted mung beans and lentils (Kavas and Sedef, 1991; Chau and Cheung, 1997).

Gentistic acid, cinnamic acid, and p-hydroxybenzoic acid are the main phenolic acids of metabolites that are present throughout the sprouting process (Amarowicz *et al*., 2009). Within the first day of incubation, the concentrations of caffeic acid, ferulic acid, and shikimic acid are relatively low in mung bean seeds. However, after the initial soaking and early germination phases, mung bean samples show significantly increasing amounts of these compounds (Singh *et al*., 2009). Furthermore, the concentrations of gallic acid, chlorogenic acid, and coumarin increase dramatically in the germination material until day 3 or 4, and catechin concentrations increase during the final stage of mung bean sprout development (i.e., on the eighth day of incubation) (Sosulski and Dabrowski, 1984).

The overall concentrations of natural acids also increase during sprouting. Phosphoric acid and citric acid are two of the main natural acid byproducts. A clear and continuous rise in lactic acid is observed, while malic acid and citric acid reach their highest points after only 24 hours of incubation (Bowles, 1990).

Fatty acid methyl esters (FAMEs) are primarily formed through the transesterification of the raw lipid extract and indicate the presence of mung bean triglycerides. Within the initial 24 hours of incubation, changes in the levels of most FAMEs are relatively minimal. However, after the initial soaking and early germination phases, mung bean samples show significant decreases in the levels of FAMEs. In contrast, the levels of γ-aminobutyric acid in mung bean sprouts are increased throughout sprout development and may be particularly important for human nutrition due to its health-enhancing effects (Bowles, 1990; Moumita *et al*., 2010).

Proteinase blockers are proteins or peptides capable of impeding the catalytic activities of proteolytic enzymes that play crucial roles in biological systems, controlling proteolytic processes, and participating in defense mechanisms against a wide range of insects, fungi, and other disease-causing microorganisms (Lawrence and Koundal, 2002). During the initial 5 days of sprouting, there is a gradual decline in the levels of extractable trypsin blockers in mung bean seeds (Lorensen *et al*., 1981). The hemagglutinin activity of mung bean seeds has also been documented to decrease by approximately 84.4% after 3 days of sprouting (Messina, 1999).

Biological activities

In ancient texts, mung beans were widely recognized for their ability to remove toxins from the body. Mung bean protein, tannin, and other compounds called polyphenols are believed to bind with organophosphorus pesticides, mercury, arsenic, and other heavy metals, aiding in the elimination of waste from the body (Zhang, 1988). Mung beans have also been found to possess antioxidant, antimicrobial, and anti-inflammatory properties. Additionally, mung beans have been shown to have benefits for diabetes, hypertension, lipid metabolism, blood pressure regulation, and cancer prevention, among other effects. These different characteristics of this functional legume are explained further below.

Antioxidant effects

The proteins, polypeptides, polysaccharides, and polyphenols from the seeds, sprouts, and hulls of mung beans all display potential antioxidant activity. The antioxidant abilities of mung bean protein hydrolysate (MPH) have been documented as 0.67 and 0.46 μmol Trolox equivalent (TE)/mg protein, as measured by oxygen radical absorbance capacity-fluorescein (ORACFL) and Trolox equivalent antioxidant capacity (TEAC) assays, respectively. Freeze-drying in lactose excipient decreases the antioxidant capacity of MPH to 0.48 μmol TE/mg protein in the ORACFL assay but does not modify the results of the TEAC assay (Wongekalak *et al*., 2011).

MP_1 and MP_2, derived from the aqueous extract of mung beans, are two acid heteropolysaccharides with 9.9% and 36.4% uronic acid content, respectively. The primary composition of MP_1 (molecular weight: 83 kDa) is mannose, while MP_2 (molecular weight: 45 kDa) consists of rhamnose and galactose. MP_2 demonstrates higher activity in scavenging hydroxyl radicals, whereas MP1 exhibits greater reducing power and stronger scavenging capacity for superoxide and DPPH radicals, as well as more significant inhibition of the self-oxidation of 1,2,3-phentriol than MP_2 (Lai *et al*., 2010).

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During the germination process, sprout extracts display higher levels of total phenolics, total flavonoids, and DPPH radical scavenging activity compared to seed extracts (Kim *et al*., 2012). Furthermore, the antioxidant activity of mung bean sprouts reaches its peak on either the first or second day, depending on the method of analysis used (i.e., β-carotene assay or DPPH assay, respectively) (Randhir *et al*., 2004).

The DPPH scavenging activity (SA) of mung bean broth (MBS; 20 mg/mL) is roughly 145% of that of tea broth (5 mg/mL) and 195% of that of vitamin C solution (0.15 mg/mL), indicating that the DPPH-SA of 100 g mung bean is comparable to that of 36.3 g dried green tea and 1462 mg vitamin C. Vitexin and isovitexin are the primary antioxidant components in mung beans (Cao 2011). Vitexin inhibits DPPH radicals by approximately 60% at 100 μg/mL and effectively prevents UV-induced skin cell death (Kim *et al*., 2005).

Antimicrobial activity

The utilization of phytochemicals as natural biocides, which are known as antimicrobial agents, is gaining popularity. Enzymes, peptides, and polyphenols derived from mung beans have demonstrated both antimicrobial and antifungal properties. Tests for antifungal activity are typically conducted using the inhibition crescents method, while tests for antimicrobial activity are carried out using either the deferred plate method or the agar-diffusion method (Wang *et al*., 2009; Wang 2009).

A non-specific lipid transfer peptide (nsLTP; molecular weight: 9.03 kDa) with antimicrobial and antifungal properties was isolated from mung bean seeds. Interestingly, nsLTP exhibits antifungal effects on *Fusarium solani*, *F. oxysporum*, *Pythium aphanidermatum*, and *Sclerotium rolfsii*, and antibacterial effects on *Staphylococcus aureus* but not Salmonella typhimurium (Wang *et al*., 2004).

Mungin, a novel cyclophilin-like antifungal protein isolated from mung bean seeds, has activity against the fungi *Rhizoctonia solani*, Coprinus comatus, Mycosphaerella arachidicola, *Botrytis cinerea*, and *F. oxysporum*. Mungin also has inhibitory activity against α- and β-glucosidases, suppressing [3H] thymidine incorporation by mouse splenocytes (Ye, 2000).

In 2005, a chitinase (30.8 kDa) with antifungal activity was isolated from mung bean seeds. The protein has a pI of 6.3, as determined by isoelectric focusing, and an estimated specific activity of 3.81 U/mg. The enzyme shows optimal activity at pH 5.4 and is stable from 40 to 50°C. Importantly, chitinase shows antifungal activity on *R. solani*, *F. oxysporum*, *M. arachidicola*, *P. aphanidermatum*, and *S. rolfsii* (Wang *et al*., 2005).

Furthermore, aside from the aforementioned antimicrobial and antifungal properties, polyphenolic extracts derived from mung bean sprouts have also been demonstrated to exhibit efficacy against Helicobacter pylori, a prevalent bacterial infection in the human population that leads to gastroduodenal ailments (Randhir *et al*., 2004).

Anti-inflammatory activity

In Asia, mung beans have been utilized in various cuisines and in traditional remedies to address poisonous intoxication, heat stroke linked to thirst, irritability, and fever; these advantageous effects of mung beans are believed to be connected to the inflammatory response (Lee *et al*., 2011).

Scientists have examined the anti-inflammatory impacts of mung bean ethanol extracts on lipopolysaccharide (LPS)-stimulated macrophages. The extract predominantly contained polyphenols, gallic acid, vitexin, and isovitexin and significantly reduced the activity of murine macrophages by inhibiting pro-inflammatory gene expression without causing harm to cells (Yeap *et al*., 2012). Additionally, a study demonstrated that all pro-inflammatory cytokines, including interleukin (IL)-1β, IL-6, IL-12β, tumor necrosis factor (TNF)-α, and inducible NO synthase (iNOS), were significantly decreased in cells treated with 3.7 mg/mL polyphenols. These findings suggested that the ethanol extract had immense potential to alleviate the clinical symptoms of diseases associated with inflammation, such as allergies and diabetes (Bellik *et al*., 2012).

The immunomodulatory effects of mung bean aqueous extracts and individual compounds on PBMCs have also been assessed using BrdU immunoassay, secretion of IFN-γ and IL-10, and identification of responding cells using flow cytometry. The findings revealed that 20 µg/mL genistein, phytic acid, and syringic acid stimulate a Th1-biased immune response by significantly reducing IL-10 secretion and enhancing IFN-γ secretion. The research concluded that various non-nutritive components of mung beans, including flavonoids, acids, and plant hormones, likely play a crucial role in modulating human immune function (Cherng *et al*., 2007).

Antidiabetic effects

Research has also explored the antidiabetic properties of extracts from mung beans. In a 2008 study, the antidiabetic effects of extracts from mung bean sprouts and mung bean seed coats were examined in male KK-Ay mice and C57BL/6 mice with type 2 diabetes. These extracts were given orally to the KK-Ay mice for a period of 5 weeks, and the mung bean sprout extracts (2 g/kg) and mung bean seed coat extracts (3 g/kg) reduced levels of blood glucose, plasma C-peptide, glucagon, total cholesterol, triglycerides, and blood urea nitrogen (BUN). Additionally, both treatments significantly improved glucose tolerance and increased levels of insulin immunoreactivity (Yao *et al*., 2008).

Phenolic antioxidants and L-DOPA can be increased in mung bean extracts through solid-state bioconversion (SSB) by R. oligosporus, with the aim of enhancing health-related functionality. α-Amylase is responsible for breaking down starch during digestion, which is important for regulating postprandial blood sugar levels. A study in 2007 by Randir and Shetty examined the inhibition of α-amylase and H. pylori in bioprocessed extracts and connected these effects to the management of diabetes and peptic ulcers, respectively. The potential inhibition of α-amylase in the tested sprout extract was moderately high in the early stages (days 0–2) and increased during days 4–10, which was linked to a higher phenolic content (Randhir and Shetty, 2007).

Lipid metabolism accommodation

The regulation of lipid metabolism by mung beans has been extensively established. In a preliminary investigation, rabbits with hyperlipidemia were given a 70% combination of mung bean meal and mung bean sprout powder. The combinations influenced the overall cholesterol and β-lipoprotein levels, relieving the symptoms of coronary artery diseases (Li, 1981). Furthermore, in more recent research, normal mice and rats were administered mung bean extracts for 7 days, and total cholesterol was significantly reduced in both types of rodents. This impact was believed to stem from the phytosterol content of mung beans, which was comparable to blood cholesterol, facilitating the prevention of cholesterol biosynthesis and absorption (Zhang and Cai, 1995).

Antihypertensive effects

Large doses (600 mg peptide/kg body weight) of unprocessed sprout extracts, dehydrated sprout extracts, and enzyme-digested sprout extracts have been demonstrated to significantly decrease systolic blood pressure (SBP) in rats after being administered for 6–9, 3–6, or 3–9 hours, respectively. Similar alterations were observed in the plasma angiotensin I-converting enzyme (ACE) activity of these mung bean extracts. A prolonged (1-month) intervention study was conducted, which included treatment with freshly ground sprout powder, dehydrated sprout powder, and concentrated extracts of the sprouts. The findings indicated that the sprout powders were not as effective as concentrated sprout extracts. The SBPs of rats treated with concentrated extracts of fresh and dehydrated sprouts were significantly reduced during the intervention period from weeks 1–4 and weeks 2–4, respectively (Hsu *et al*., 2011).

Antitumor effects

Mung beans have been demonstrated to display antitumor effects through various distinct mechanisms. The genetically engineered plant nucleases R-TBN1 and R-HBN1, akin to nucleases derived from pine pollen and mung beans, were discovered to be efficacious against melanoma tumors and were approximately 10-fold more powerful than bovine seminal ribonuclease (RNase). Because of their comparatively low cytotoxicity and elevated effectiveness, these genetically engineered plant nucleases seem to be stable biochemical agents that can be focused on as potential antitumor cytostatics (Matousek *et al*., 2009).

Furthermore, mung beans have been demonstrated to display antiproliferative properties, as evaluated by the MTT assay using a cell culture system in vitro. Mung beans demonstrate antiproliferative effects that vary according to the dosage, as observed against CAL27, a cell line of tongue squamous cell carcinoma, as well as various other cancer cell lines such as DU145, SK-OV-3, MCF-7, and HL-60 cells (Xu and Chang, 2012).

Another study analyzed the impacts of trypsin inhibitors derived from mung beans (known as LysGP33) on the spread and growth of human colon cancer cells (SW480 cells). In this investigation, the consequences of the purified GST-LysGP33 active portion on the movement of SW480 cells were assessed using wound healing experiments. The findings indicated that at the 24-hour mark, the GST-LysGP33 active fragment at a concentration of 10 μmol/L influenced cell migration. By the 72-hour mark, cells treated with GST-LysGP33 displayed a roughly 50% reduction in wound healing compared to the control group (Zhao *et al*., 2012).

Antisepsis effects

The aqueous extract from the outer layer of mung beans (MBC) has demonstrated protective effects against sepsis both in laboratory settings and in living organisms. This effect was achieved by inhibiting the activity of high mobility group box 1 (HMGB1), a protein found in the nucleus of cells that has recently been identified as a late mediator of life-threatening systemic inflammation. This discovery has led to the development of a wider range of potential treatments for sepsis. It was observed that the MBC extract reduced the release of HMGB1 and various chemokines in cultures of immune cells in a dose-dependent manner. When administered orally to animals, MBC significantly increased the survival rate from 29.4% in the control group (mice given a saline solution) to 70% in the experimental group that received the MBC extract (Zhu *et al*., 2012). Chlorogenic acid (56) has also been found to have protective effects against sepsis by inhibiting late mediators of the condition. In murine peritoneal macrophages, chlorogenic acid suppressed the release of HMGB1 induced by endotoxins in a concentration-dependent manner. Furthermore, administration of chlorogenic acid reduced the accumulation of HMGB1 in the body and prevented mortality caused by endotoxemia and polymicrobial sepsis (Lee *et al*., 2012).

Conclusion

The mung bean [*Vigna radiata* (L.) Wilczek] is one of the most significant short-term, summer-growing legumes and is cultivated widely throughout tropical and subtropical regions. As we have discussed in this overview, mung beans have extensive applications in the agriculture, health food, pharmaceutical, and cosmetics industries. Mung bean seeds and sprouts are excellent examples of functional foods that reduce the risk of various diseases. Moreover, the seeds and sprouts have health-enhancing effects in addition to their nutritional value.

During the germination process of the mung bean, its chemical constituents undergo a series of biochemical reactions. One such reaction is the production of small active compounds from large molecules, promoting absorption and utilization. Another change observed during germination is the formation and accumulation of many categories of active substances, such as polyphenols, saponins, vitamin C, etc. Therefore, we believe that these alterations in the chemical composition of mung beans during germination will result in significant and important modifications in the pharmacological activities of mung beans as well.

Investigation into the chemical components and biological effects of mung bean seeds and sprouts has furnished a strong theoretical foundation for the progress and utilization of mung beans. Coupled with the examination of the metabolites of these chemical components, exploration of the physiological roles of these compounds is essential for the further development of this area. Consequently, forthcoming research can concentrate on the isolation and refinement of novel substances with physiological activity in agriculture, nutritional supplements, beauty products, and medical applications.

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