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Review Article

Exploring the Therapeutic Potential of Plant Seeds: Health Benefits, Bioactive Compounds, Applications for Specific Medical Conditions, and Regulatory Challenges

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Abstract

Plant seeds have been used for thousands of years for their nutritional, medicinal, and culinary benefits. Contemporary medical research is investigating plant seeds' therapeutic potential for improving and treating human diseases.

Plant seeds contain bioactive components such as phytochemicals, polyphenols, and lignans, which express antioxidant, anti-inflammatory, antimicrobial, and antibacterial effects. They are being studied for their potential to treat various medical afflictions, including hyperglycemia and diabetes, respiratory and cardiovascular disorders, and eye and skin disorders. Clinical trials are investigating the therapeutic value of various plant seeds-based drugs to act on inflammation, cancer, infectious diseases, and autoimmune disorders. Plant seed extracts have also been found to exhibit antitumor effects.

However, limitations and challenges exist for using plant seeds in medical care. Standardization in seed preparation is crucial to ensure safety and efficacy. The lack of awareness of appropriate dosages for treatment and lack of quality control in production raise concerns about adverse health outcomes with their use. Regulatory challenges remain to incorporate plant seeds-based treatments in medical care and develop practical and comprehensive guidelines for their use. Clinical studies remain limited regarding the therapeutic potential of plant seeds.

Also noted in this paper is plant seeds' potential as an alternative to synthetic pharmaceuticals. Their natural availability makes them a promising source for developing low-cost treatment options and improving quality of life (QoL).

Keywords: *Antioxidant; Bioactive Compounds; Healing; Hyperlipidemia; Micronutrients; Plant-Based Treatments*

Abbreviations

LDL: Low-Density Lipoprotein; TCM: Traditional Chinese Medicine; QoL: Quality of Life; THC: Tetrahydrocannabinol

Introduction

The history of plant seed consumption and its use in human medicine is ancient, going back thousands of years. The earliest use of plant seeds has been traced to the Stone Age period when nuts, seeds, and tubers were found in archaeological digs. The advent of agriculture and the domestication of plants and animals marked the beginning of organized farming in the ancient world, providing a variety of crops from which seeds were collected. Seeds and nuts were staples in ancient diets, having nutritional, culinary, and medicinal properties discovered through trial and error [1].

The value of different plant seeds-based diets in promoting good health has grown over the years, with increasing efforts to understand their usefulness in treating, managing, and preventing human diseases [2,3]. In contemporary settings, nutritionists contend that including seeds in a human diet improves nutrition due to their richness in fiber, minerals, vitamins, and essential fatty acids [2].

Clinical trials are investigating the therapeutic value of nutrients found in plant seeds, such as omega-3 fatty acids derived from flaxseeds, in reducing the risk of cardiovascular diseases. Research studies have observed that including omega-3-rich plant seeds in diets reduces the risk of coronary artery disease, myocardial infarction, and stroke [2]. Other research shows that compounds from plant seeds exhibit antitumor effects, which have sparked interest in their use for cancer treatment [4]. Furthermore, seeds' anti-inflammatory and antioxidant properties have been studied in inflammation-driven chronic illnesses such as arthritis, diabetes, and obesity [3].

Current applications of plant seeds in medicine include extracting bioactive compounds from plant seeds to develop drugs. Researchers are testing plant seeds-based drugs that act on various disease conditions such as inflammation, cancer, infectious diseases, and autoimmune disorders. Notably, a few approved plant seeds-based pharmaceuticals, such as Taxol—derived from the Pacific yew seeds—and paclitaxel, used to treat ovarian, breast, and lung cancer, have been developed from plant seeds [5,6]. Researchers also suggest plant seed extracts could produce functional foods and nutraceuticals [4]. Advances in genetic engineering and biotechnology allow for the enhancement of the medicinal properties of seeds and the development of novel seeds-based products with improved efficacy and safety profiles [4].

Discussion

Health benefits of plant seeds

Plant seeds have been found to impact human health positively and are widely studied for their potential health benefits. They are a rich source of bioactive components, such as phytochemicals, polyphenols, and lignans. These components have multiple advantages, including antioxidant, anti-inflammatory, antimicrobial, and antibacterial effects [7,8].

Germination has been studied as a process that enhances the nutritional content of some plant seeds and has been associated with increased antioxidant capabilities [9]. In addition, specific micronutrients, such as zinc, have been found to improve the nutritional quality of seeds and exert beneficial effects on human health [10].

Studies have evaluated the role of plant seeds in diets and their effects on different health conditions. Plant seeds are used to address malnutrition and reduce pollution in some areas. Also, they are being studied for their potential use in aquafeeds to support sustainable aquacultural production of various fish species by contributing to the metabolic requirements of fish—thus enhancing the human health benefits of fish consumption [11,12].

Medicinal plant seeds

Numerous plant seeds have been used in traditional healing practices for centuries to treat various ailments. More recently, they have been studied for their potential medicinal properties and health benefits in modern medicine. The following section provides an overview, identifying specific plant seeds, their general characteristics, and their medicinal applications. Although the following list of plant seeds is broad, it is not all-inclusive.

1. Neem *(Azadirachta indica)*

Neem seeds have been found to have anti-inflammatory, antioxidant, and antibacterial properties. Their extracts have been used in treating respiratory disorders, periodontitis, and dermatological conditions [13,14]. Additionally, neem seed oil is effective against bacterial pathogens associated with eye and ear infections [15].

2. Moringa *(Moringa oleifera)*

Moringa seeds contain specific protein fractions effective in skin and hair care. Also, they have been used as natural coagulants [16]. The leaves and seeds of the Moringa tree have been studied for their potential anti-inflammatory, anti-diabetic, and anticancer effects [17,18]. Moringa seed powder consumption has demonstrated hypoglycemic effects in rat studies [19]. Moringa seeds and leaves are considered functional food ingredients due to their health-promoting properties [20,21].

3. Nigella *(Nigella sativa)*

Nigella seeds, also called black seeds, have anti-inflammatory, anticancer, and immunomodulatory properties [22]. These seeds have been studied for their potential application in treating hyperlipidemia and as a natural herbal remedy due to gastroprotective effects [23,24]. Additionally, they stimulate the body's energy and promote overall health [25]. Thymoquinone, an active component of nigella seeds, has been shown to have multiple beneficial effects in treating cancer, chronic diseases, and atherosclerosis and as an effective adjuvant in specific immunotherapy for allergic rhinitis [26–28].

4. Chinaberry *(Melia azedarach)*

Chinaberry seeds have been used for their various biological activities. The extract of Chinaberry seeds has shown significant antibacterial activity against gram-positive and gram-negative bacteria, with potential applications in developing natural antibacterial agents [29]. The oil extracts of Chinaberry seeds have demonstrated repellent and lethal activities against insect vectors that transmit several diseases, including malaria and Chagas disease [30–32]. However, Chinaberry seeds contain toxic compounds. Thus, caution is strongly advised, as poisoning in animals and humans has been reported in cases of overdose [33].

5. Elephant kola (*Buchholzia coriacea)*

Due to its various biological activities, elephant kola seeds have been used in traditional medicine. Elephant kola seed extract has shown significant antibacterial activity against pathogenic gastrointestinal bacteria [34]. It has insecticidal properties. A powder derivative has demonstrated larvicidal effects against mosquito vectors that transmit malaria in Ethiopia [35]. However, like certain other medicinal plants, Elephant kola seeds contain toxic compounds. Their oral intake should be controlled to prevent potential adverse effects.

6. Rosary pea *(Abrus precatorius)*

The rosary pea plant has been used in traditional medicine for its various therapeutic properties. Rosary pea seed extract has antioxidant, anti-inflammatory, antimicrobial, and antifungal effects against phytopathogenic fungi [36]. The extract is for topical use only. Rosary pea seeds contain abrin, a highly toxic compound that can cause severe poisoning if ingested. While rosary pea seed extract may have potential in medicinal care, its use must be strictly controlled due to the toxicity of abrin [37].

7. Balsam apple *(Momordica balsamina)*

Balsam apple seeds are known to have potential medicinal properties. Balsamin, a ribosome-inactivating protein (RIP) with antiviral, antifungal, and antitumor activity, has been purified from the seeds [38]. The seeds also contain phenolic compounds with potential health-promoting properties, including gallic and ellagic acids [39]. Moreover, the antibacterial activity of balsam apple leaf extract against Enterobacteriaceae has been studied with promising results [40]. However, the plant contains toxic compounds that can cause adverse reactions if ingested [41].

8. Safflower *(Carthamus tinctorius)*

In traditional Chinese medicine (TCM), safflower seeds improve blood circulation, osteoporosis, and diabetes and alleviate pain. In conventional medicine, they have been investigated as a natural treatment for metabolic disorders, liver injury, hepatomegaly, and pain reduction [42]. Safflower seed extract has shown potential as a functional food [43].

9. Coriander *(Coriandrum sativum)*

Coriander seeds alleviate digestive issues like gas and bloating and act as a diuretic [44]. Current research has identified potential health benefits of coriander seeds, including their antioxidant and antibacterial properties. A coriander seed extract has shown potential as an alternative antibiotic treatment against pathogenic bacteria, such as *Staphylococcus aureus* and *Escherichia coli* [45]. Coriander seeds have been studied for their potential to lower blood glucose levels and improve lipid profile in patients with diabetes mellitus [44].

10. Papaya *(Carica papaya)*

Papaya seeds have been used as a vermifuge, anti-fertility agent, and to treat liver cirrhosis and parasitic infections [46]. Studies have identified potential health benefits of papaya seeds, including its antioxidant and anti-diabetic activities [47]. Papaya seed extract has shown promise as a treatment for amoebiasis [46]. Also, papaya seeds are rich in phytochemicals and nutrients, making them a helpful addition to the diet and useful as a nutraceutical [48].

11. Job's tears *(Coix lacryma-jobi)*

Job's tears seeds have been used to treat edema and diarrhea [49]. It has been studied for its antiproliferative and antioxidative activities and potential as an anticancer agent [50]. Job's tears seeds are a staple food crop and supplement in traditional diets. Moreover, Job's tears seeds are known for their nutritional content and potential use as a functional food [51].

12. Tamarind *(Tamarindus indica)*

Tamarind seeds are a source of protein, containing essential amino acids. Tamarind seed extract has antioxidant properties and strong scavenging activity. Tamarind seeds could be an alternative protein source to alleviate protein malnutrition [52].

13. Betel palm *(Areca catechu)*

Betel nut palm seeds have been traditionally used in Ayurvedic medicine to treat various conditions, including inflammation, diabetes, and headaches [53]. However, betel nut usage has been associated with several adverse health effects, including oral cancer and cardiovascular diseases, due to the presence of arecoline and other alkaloids in the nut [54]. Medical use of betel nut is limited and should be approached with caution due to its association with adverse effects.

14. Lotus *(Nelumbo nucifera)*

The embryo of lotus seeds, known as Lian Zi Xin, treats restlessness, palpitations, and insomnia. The seeds contain health-promoting nutrients and bioactive compounds that have potential as functional foods or nutraceuticals. Lotus seed extract shows antioxidant activity, which may have potential therapeutic applications [55].

15. Bitter apricot *(Prunus armeniaca)*

Bitter apricot seeds have been traditionally used to address respiratory and digestive ailments. Apricot kernel extract has antioxidant and antimicrobial properties and potential anticancer and neuroprotective activities [56]. However, the kernels contain amygdalin, which can release cyanide when consumed in large amounts. Consequently, the use of bitter apricot seeds for medical purposes is limited, and it should be noted that amygdalin is not an effective cancer treatment [57].

16. Prune *(Prunus domestica)*

Although the prune fruit—rich in phytochemicals and antioxidants—is known for various health-promoting actions, the amygdalin content in the prune seeds can cause amygdalin toxicity, notwithstanding its anticancer activity. Thus, prune seeds (derived from dried plums) are generally not recommended for consumption. The fruit treats constipation, fever, and hypertension, among other ailments. Studies have revealed its laxative, digestive, and anti-inflammatory properties attributed to its phenolic compounds and fatty oils content. *In vitro* assays have demonstrated its antibacterial and antioxidant effects and potential role in preventing certain diseases [58].

17. Chinese red date *(Ziziphus jujuba)*

Chinese red date seeds, also known as the jujube seeds, have been used in traditional Chinese medicine (TCM) for thousands of years. The fruits and seeds of *Ziziphus jujuba*, commonly known as jujube or red date, contain various bioactive compounds with potential health benefits, such as antioxidant, anti-inflammatory, and anticancer activities. The seeds have been used to treat insomnia and anxiety. Polysaccharides in jujube seed extract have shown immunomodulatory effects [59].

18. Cassia *(Cassia obtusifolia)*

Cassia seeds—used in traditional oriental and Chinese medicine, primarily as a tea—are beneficial in various ailments, including constipation, blurred vision, and hypertension. The seeds contain several bioactive compounds, polysaccharides, and phenolic compounds, which have potential health benefits. Polysaccharides from Cassia seeds demonstrate antioxidant activity, suggesting their potential as functional food ingredients [60]. Cassia seed extract exhibits neuroprotective, anti-inflammatory, and anticoagulant properties, indicating a potential role in treating neurological disorders [61].

19. Peach *(Prunus persica)*

Peach seeds improve blood circulation and dissolve blood clots [62]. Peach seed extract possesses antioxidant properties and potential antihypertensive and anti-inflammatory effects, as it contains bioactive compounds such as phenols and flavonoids [63]. Peach seeds contain β-sitosterol, a compound with potential cholesterol-lowering effects. While the seeds have not been widely studied for medicinal purposes, their potential health benefits suggest that they may have applications in developing functional food and nutraceuticals [62].

20. Hemp *(Cannabis sativa)*

Hemp seeds contain various bioactive compounds, including fatty acids, proteins, and minerals, with potential health benefits. Hemp seed oil—rich in linolenic acid—decreases platelet aggregation, a risk factor for cardiovascular disease [64]. Hemp seed proteins have potential nutraceutical applications due to their functional and bioactive properties, including antioxidant and anti-inflammatory effects [65]. However, due to the psychoactive tetrahydrocannabinol (THC) content of some Cannabis sativa strains, its use in medical care remains controversial and regulated.

21. Croton *(Codiaeum variegatum)*

Croton seeds do not have significant medical applications. Various parts of the Croton plant—including its leaves, flowers, and fruits—have been traditionally used in herbal medicine to treat various ailments, such as diarrhea, fever, and infections [66]. However, no significant evidence suggests that the seeds have significant medicinal properties. Some bioactive compounds found in croton plants

(phenolic compounds and tannins) exhibit antioxidant and antidiarrheal properties *in vitro* [66,67]. However, croton seeds contain various toxic compounds, including crocin and croton resin, which have purgative effects that can cause vomiting and diarrhea when ingested in large amounts [66]. Thus, caution is advised with its use.

22. Lychee *(Litchi chinensis)*

Lychee seeds are used to relieve colds and pain. Several bioactive compounds—coumarin derivatives, flavonoids, and phenolic acids—have been identified in lychee seeds. They possess antioxidative, anti-inflammatory, and hepatoprotective properties [68]. Lychee seed peptide hydrolysates have anti-inflammatory activities [69].

23. Plantain *(Plantago major)*

Plantain seeds are used to treat dysentery and inflammatory conditions. The seeds are beneficial in wound healing and respiratory conditions due to their high mucilage content [70]. Plantain seed extract exhibits antimicrobial properties, suggesting potential applications as an antimicrobial agent [71].

24. Cowherb *(Vaccaria hispanica)*

Cowherb seeds promote lactation and alleviate nausea and vomiting during pregnancy [72]. The seeds contain several bioactive compounds, including saponins and C-glycosylflavone. These compounds demonstrate pharmacological activities, such as antifungal and cytoprotective properties [73,74]. Cowherb seeds have been used as a surface-active extract in pharmaceutical, food, and cosmetic industries due to the presence of saponins [75]. Nevertheless, their effectiveness and safety still need to be more conclusive.

25. Indian prickly ash *(Zanthoxylum rhetsa)*

Indian prickly ash seeds, used in Indian medicine, contain bioactive compounds, such as phenolic compounds, having antimicrobial and antioxidant properties [76]. Additionally, the plant's seeds and bark exhibit cytotoxic potential against melanoma cancer cells [77]. Indian prickly ash is commonly used for hair loss and wound healing [76,78].

Most of the seeds mentioned above have shown potential for use in medical care due to their health-promoting properties and minimal adverse effects. Further research is necessary to explore their full potential in medical care and nutrition. Table 1 summarizes the seeds' properties, effects, conditions treated, and precautions in use.

Plant Seeds	Properties/Effects	Conditions Treated	Precautions
Neem seeds (*Azadirachta indica*)	Anti-inflammatory, antioxidant, antibacterial	Respiratory disorders, periodontitis, dermatological conditions	–
Moringa seeds (*Moringa oleifera*)	Anti-inflammatory, antidiabetic, anti-cancer	Inflammatory conditions, hyperglycemia, diabetes, cancer, arthritis	–
Nigella seeds (*Nigella sativa*)	Anti-inflammatory, anticancer, immunomodulatory, gastroprotective	Hyperlipidemia, cancer, chronic diseases, atherosclerosis	–
Chinaberry seeds (*Melia azedarach*)	Antibacterial, insect repellent, insecticidal	Bacterial infections, insect-borne diseases	Toxic compounds; caution in use

Elephant kola seeds (*Buchholzia coriacea*)	Antibacterial, insecticidal, insect repellent	Gastrointestinal bacterial infections	Toxic compounds; controlled oral intake recommended
Rosary pea seeds (*Abrus precatorius*)	Antioxidant, anti-inflammatory, antimicrobial	–	Highly toxic compound (abrin); strict control in use required
Balsam apple seeds (*Momordica balsamina*)	Antiviral, antifungal, anti-tumor, antibacterial	Diabetes, cancer, infections	Toxic compounds; caution in use
Safflower seeds (*Carthamus tinctorius*)	Blood circulation, pain relief, functional foods	Liver injury, hepatomegaly	–
Coriander seeds (*Coriandrum sativum*)	Diuretic, antioxidant, antibacterial, antibiotic alternative	Digestive issues, blood glucose control	–
Papaya seeds (*Carica papaya*)	Vermifuge, anti-fertility, antioxidant, anti-diabetic	Liver cirrhosis, parasitic infections, amoebiasis	Toxic compounds; caution in use
Job's tears seeds (*Coix lacryma-jobi*)	Anti-proliferative, antioxidant, anti-cancer potential	Edema, diarrhea	–
Tamarind seeds (*Tamarindus indica*)	Antioxidant, anti-inflammatory	Malnutrition, diabetes, hypertension, obesity	Medicinal use (Ldi-n-butyl maleate) should be approached with caution
Betel palm seeds (*Areca catechu*)	Anti-inflammatory, antidiabetic	Inflammatory conditions, diabetes, headache	Limited medical use; caution due to adverse effects
Lotus seeds (*Nelumbo nucifera*)	Sedative properties, antioxidant, potential functional foods	Restlessness, palpitations, insomnia	–
Bitter apricot seeds (*Prunus armeniaca*)	Antioxidant, antimicrobial, potential anticancer, neuroprotective	Respiratory and digestive ailments, antioxidant	Cyanide release from amygdalin; limited medical use
Prune seeds (*Prunus domestica*)	Anticancer	–	Amygdalin content
Chinese red date seeds (*Ziziphus jujuba*)	Antioxidant, anti-inflammatory, anticancer, immunomodulatory, potential functional foods	Insomnia, anxiety	–
Cassia seeds (*Cassia obtusifolia*)	Antioxidant, neuroprotective, anti-inflammatory, anticoagulant	Constipation, blurred vision, hypertension	Potential adverse effect; controlled intake recommended
Peach seeds (*Prunus persica*)	Antioxidant, antihypertensive, anti-inflammatory, potential nutraceuticals, blood circulation, dissolves blood clots	Insomnia, anxiety, and cancer	Limited medicinal study
Hemp seeds (*Cannabis sativa*)	Anti-inflammatory, antioxidant, nutraceuticals	Cardiovascular risk reduction	Psychoactive THC content; regulated and controversial medical use

Croton seeds (*Codiaeum variegatum*)	Purgative	–	Toxic compounds; caution in use
Lychee seeds (*Litchi chinensis*)	Antioxidative, anti-inflammatory, hepatoprotective	Colds, pain, insomnia, anxiety, cancer	–
Plantain seeds (*Plantago major*)	Anti-inflammatory, antimicrobial, wound healing	Dysentery, inflammatory conditions, respiratory conditions, skin conditions	–
Cowherb seeds (*Vaccaria hispanica*)	Anti-fungal, cytoprotective properties, lactation promotion, anti-nausea during pregnancy	Nausea and vomiting during pregnancy.	Effectiveness and safety inconclusive
Indian prickly ash seeds (*Zanthoxylum rhetsa*)	Antimicrobial, antioxidant, cytotoxic potential, wound healing	Melanoma cancer, hair loss, appetite loss, digestive disorders, musculoskeletal disorders	–

Table 1: *Plant seeds, properties, effects, conditions treated, and precautions*

Applications of plant seeds in medical care

Plant seeds have been traditionally used as herbal remedies in many cultures to treat various medical conditions. For example, a survey of medicinal plants commonly used by Kavirajes (traditional medicinal practitioners) in Bangladesh revealed that medicinal plants treat multiple diseases, including dental, skin, respiratory, and digestive disorders [79].

Additionally, several plant seeds have been found to have potential for use in treating hyperglycemia. Some studies suggest that specific plant seeds, such as moringa and okra seeds, have hypoglycemic effects and may be used as part of diabetes treatment regimens [19,80]. Furthermore, certain plant seeds can address malnutrition. Papaya and legume seeds are examples of potent nutraceuticals. They contain several essential vitamins and minerals for addressing malnutrition and promoting healthy growth and overall well-being [81].

In another study, the anti-inflammatory properties of certain plant seeds were found to be beneficial in treating skin conditions, including dermatitis and psoriasis [82]. Some plant seeds have possible applications in treating cardiovascular conditions. A comprehensive review of plant seed oils and their biomedical functions found some such oils possess cardioprotective properties, with specific fatty acids potentially reducing the risk of cardiovascular diseases [83].

Moreover, particular plant seeds have probable applications in ophthalmic conditions. Plant seeds, such as those of the neem tree, have been shown to have anti-inflammatory and antimicrobial properties with promising applications in treating certain eye conditions [84]. Many studies have shown the potential for plant seeds to treat respiratory disorders effectively. For example, certain seed extracts have bronchodilatory effects, ameliorating respiratory conditions such as asthma [85]. See Table 1.

Adverse effects and caution in usage

Plant seeds have been found to have numerous beneficial properties for human health. However, it is essential to recognize that certain plant seeds have harmful adverse effects. Thus, they must be used with caution. These adverse effects include toxicities, allergic reactions, and drug interactions.

Several studies have documented the adverse effects and poisoning related to medicinal or harmful plants, including their seeds. Poisoning from plant seeds can induce severe symptoms, including cardiac arrest, respiratory failure, and gastrointestinal complications. Nescience of toxic plants and their identification can lead to severe toxicity and adverse health effects [86].

In addition to direct toxicities, some otherwise benign plant seeds have harmful or morbid effects when consumed in large amounts or combined with certain medications—including ocular side effects, drug interactions, hyperlipidemia, and even death [86–88].

Using plant seeds for medicinal and nutritional purposes must be done cautiously. Adverse health effects can be prevented or minimized by correctly identifying the plants, having clinical knowledge of dosage, and awareness of side effects when combined with other medications. Moreover, plant seeds—as medical remedies—do not always have a positive therapeutic response for every individual.

Clinical studies on plant seeds

Clinical studies on plant seeds have investigated the efficacy and safety of using seeds for treating various health conditions. Clinical evidence suggests some plant seeds may improve cardiovascular health, support weight loss, manage diabetes, and lower blood pressure.

Studies have found that consuming various seeds, including flax, pumpkin, and sesame seeds, benefits cardiovascular health. Research findings indicate that consumption of these seeds lowers total and low-density lipoprotein (LDL) cholesterol levels, reduces blood pressure, and lowers the risk of cardiovascular diseases. The various compounds in seed components, such as dietary fiber, phytochemicals, and polyunsaturated fatty acids, are responsible for these health benefits [89].

Certain plant seeds have applications in weight loss. A review of clinical studies on plant extracts suggests specific extracts reduce body weight and fat mass. While the precise biological mechanism remains unclear, the hypolipidemic and antioxidant properties of the seed extracts may explain their effect on body weight [90].

Several plant seeds have been found to help manage diabetes. Studies suggest that specific plant seeds exhibit hypoglycemic properties, regulating blood sugar levels in people with diabetes or pre-diabetes. For instance, various studies explored plant seeds' hypoglycemic potential, such as in nigella seeds oil and fenugreek seeds extract. The results revealed that consumption of these seeds reduces blood glucose levels and supports insulin sensitivity [90,91].

Moreover, some plant seeds have beneficial effects on blood pressure. Clinical studies examined the impact of nigella seed oil on blood pressure in healthy volunteers. This randomized, placebo-controlled trial concluded that participants who received nigella seed oil supplements for eight weeks had significantly lower systolic and diastolic blood pressure than those in the placebo group [91].

The anti-hypertensive effects of nigella seeds might be related to their composition, which includes potent bioactive agents such as thymoquinone.

Various plant seeds help manage chronic conditions such as diabetes, cardiovascular diseases, and hyperlipidemia. Some seeds are rich sources of nutrients that can positively impact human health. However, studies have also revealed that the inappropriate use of these seeds may result in adverse health effects if taken in large doses or if plant parts have been stored improperly [92].

While studies have established the efficacy of some seeds as anti-diabetic agents, their excessive consumption can result in hypoglycemia, exacerbating diabetes complications [93]. Therefore, the dosage, mechanism of action, and potential side effects of seed use in humans should be thoroughly examined, and recommendations should be made on their usage.

Limitations and challenges in using plant seeds in medical care

Lack of standardization in seed preparation and dosage

The need for more standardization in seed preparation and dosage for human medical care poses a significant challenge in using plant seeds for medicinal purposes. Due to limited regulations, various seed preparations' composition, purity, and potency may differ significantly, leading to inconsistent effects and adverse health outcomes. Factors such as the plant part used, the extraction method, storage conditions, and variations in genetic diversity can also contribute to variations in seed quality and efficacy. Standardization is critical in ensuring seed-based medicines' quality, safety, and efficacy, particularly in vulnerable populations [94,95].

Moreover, several studies indicate that the lack of appropriate dosage is one of the challenges in using traditional medicines. Poor quality control can result in ineffective or adverse dosage. Limitations of accurate and safe dosage standards and shortfalls in quality control repeatedly raise concerns for adverse health outcomes, toxicity, and pharmacokinetic variations when using plant seeds for medical purposes. Thus, seed preparation and dosage standardization are required to ensure the safety and efficacy of products derived from these seeds.

Limited clinical studies on some plant seeds

Clinical studies investigating the therapeutic potential of plant seeds are limited, and more research is needed to confirm their efficacy and safety. Some studies describe preclinical data and limited clinical case reports, but the evidence on human research remains limited. A review of clinical studies on herbs for diabetes management reports that few human studies are available to support using specific seeds in managing diabetes [90]. Some plant seeds may be used in transgenic plants for biopharmaceutical production, but most clinical trials have been limited to animal models, cell lines, or small clinical trials [96,97].

For some medicinal plant seeds, the available data are based mainly on studies using animal models, and further clinical trials are needed to evaluate their safety and efficacy in humans [98,99]. While existing literature on the potential therapeutic properties of some plants appears promising in preclinical studies, the current data on their therapeutic efficacy in humans needs to be revised, manifesting the need for the expansion of research in clinical trials and controlled studies.

Regulatory challenges in introducing plant-based treatments to medical care

Including plant-based treatments in medical care poses significant regulatory challenges. Most traditional medicines, including plant-based remedies, do not adequately meet the regulations for testing and licensing of drugs, potentially leading to safety concerns. Establishing practical and comprehensive guidelines and documentation on plant-based medicines, from production, distribution, and use, is challenging due to the need for formal regulatory mechanisms [100].

Most authorities recognize the need to streamline regulatory frameworks in an era of rising demand for plant-based treatments and solutions. Regulatory frameworks and guidelines for plant-based medicines are being developed by the World Health Organization's guidelines for assessing herbal medicines' quality, safety, and efficacy and the European Union's Traditional Herbal Medicines Directive [100–102]. These initiatives include the goals of high production standards, quality control, and protocols for patient safety.

Conclusion

Plant seeds have been used for thousands of years as an essential source of nutrition, culinary ingredients, and herbal remedies. Their therapeutic potential is attributed to their richness in bioactive compounds, such as phytochemicals, polyphenols, and lignans.

Current research explores various potential applications of plant seeds in medical care, including developing drugs and nutraceuticals. Consumption of plant seeds has been shown to have potential health benefits, including antioxidant, anti-inflammatory, antimicrobial,

and antibacterial effects. Additionally, plant seeds have been found effective in treating several conditions, including respiratory disorders, cardiovascular diseases, diabetes, and eye and skin conditions.

Nevertheless, medical use of plant seeds raises concerns about adverse side effects and toxicity, indicating the necessity of proper dosage guidelines, knowledge of side effects, and proper identification of the plants.

Adequate regulatory frameworks are required to promote safe and effective plant seeds-based therapies.

The potential therapeutic benefits of plant seeds could contribute significantly to medical treatments and human health and well-being. Although they have a promising future, further research is needed to recognize their full potential and identify any harmful effects in human medicine.

Conflict of Interest Statement

The authors declare that this paper was written without any commercial or financial relationship that could be construed as a potential conflict of interest.

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Volume 19 Issue 1 January 2024