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Exploring the role of *Moringa oleifera* in Food science and Nutrition

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Abstract

Moringa oleifera is a miraculous tree, with multiple edible parts, each having unique nutritional and medicinal properties. In the past, *M.oleifera* was used in traditional healing practices, and currently, it is incorporated into everyday food products. It serves as a plentiful reservoir of essential vitamins, minerals, and proteins. The abundance of nutraceuticals present in *M.oleifera* is responsible for its immense bioactive properties that could prevent or alleviate many diseases. Bio-fortification has become an emerging concept to deal with nutritional deficiencies, and the fortification of *M.oleifera* has been found to be effective in combating malnutrition. Ever since green nanotechnology has evolved, several attempts are being made to synthesize nanoparticles using extracts of *M.oleifera* and to further characterize their properties. In this comprehensive review, we delve into the phytochemical and bioactive characteristics of *M.oleifera*, its function as a potent bio-fortificant, and its potential as a green tool in the synthesis of nanoparticles.

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Keywords: Moringa oleifera; phytochemical composition; bioactive properties; biofortification; green synthesis; nanoparticles, food fortificant.

1. Introduction

Moringa oleifera is a versatile tree that belongs to the family *Moringaceae*. It grows naturally in India and Pakistan and it is commercially cultivated in various regions including India, Africa, South and Central America, as well as numerous tropical and sub-tropical areas[1]. Locally, *M.oleifera* is also called a drumstick tree. Most of the parts of this tree have their own unique properties and importance. It grows best at a moderate temperature ranging from 26 to 40^{o} C[2]. The leaves of *M.oleifera* are a rich source of protein[3]. Additionally, it contains a good quantity of Vitamins A and C [4]. The seeds of *M.oleifera* contain a significant amount of essential aminoacids [5], crude proteins, lipids, and some macro elements [6].

Various bioactive compounds, such as flavonoids, alkaloids, tannins, saponins, terpenoids etc., are present in most parts of *Moringa oleifera* [4] .It shows anti-oxidant, anti-microbial, anti-inflammatory, cardiac, and hepatoprotective and many more activities [7]. Due to the presence of different biomolecules, *M.oleifera* has a high nutritive value. It is helpful in combating malnutrition [8]. In ancient periods, the genus Moringa played a role in traditional medicines, where the leaves of *M.oleifera* were given to Maurian warriors to help them relieve from pain and gave them instant energy. Traditionally, the leaves were used in folk medicines in Arab countries [9]. The people of Thailand believed in the potential therapeutic role of *M.oliefera* against many diseases, and it was demonstrated that the seeds, pods, and leaves contained antioxidants [10].The natives of India use the leaves, fruit, and even flowers in different food items as they are highly nutrient-rich. The use of *Moringa oleifera* in treating different disorders is indicated in *The Ayurvedic Pharmacopoeia of India* [11]. The leaves have been used in the treatment of diseases ranging from asthma to diabetes [12].

The nutritional and phytochemical versatility of *M.oleifera* are being explored for the green synthesis of nanoparticles. Many studies are available depicting the nutritional and pharmacological potential of *Moringa oleifera*. Food fortification possibilities

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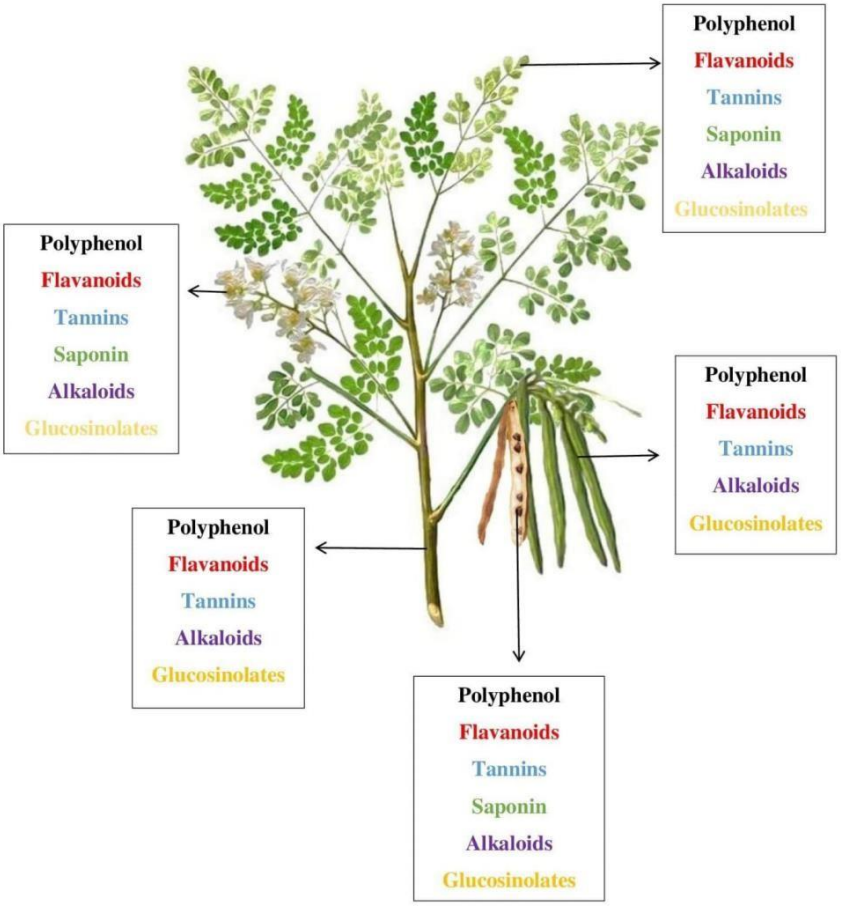
 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

using extracts of Moringa are also being investigated. Given the importance of *Moringa oleifera* in various industries like food, pharmaceutical and nutraceuticals, we thought it would be worthwhile to do a comprehensive review on the state-of-the-art developments with respect to this.

2. Phytochemical and Nutritional composition of different parts of *Moringa oleifera.*

Moringa oleifera is one of the most nutritious plants cultivated with its leaves being the richest source of vitamins , minerals, phytochemicals , antioxidants and trace elements. It also contains plant hormones, secondary metabolites, bioactive substances and many other ingredients. Thus it is considered as the best perennial tropical vegetable[13]. Different parts of the plant such as leaves, flowers, stem, fruits and seeds contain an abundance of nutraceuticals, which is schematically illustrated in Figure 1.

Figure 1
Phytochemical composition of various parts of *Moringa oleifera*



ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

Moringa also contains high amount of proteins and essential amino acids, though the carbohydrate and fat content are low [14]. Its fresh leaves contain 6.7g protein, 1.7g fat , 12.5g carbohydrate and 0.9g fiber. Amino acids such as Met , Thr , Ile ,Lys and Val are also present which makes it comparable to meat proteins [15].

In addition to the many essential phytochemicals present in the various parts of the Moringa plant, it is also a rich source of different vitamins and minerals. According to Fuglie , seasons , location , climate and environmental factors influence the nutrient composition of Moringa plant. [16]. Vitamin A was found abundantly in hot wet season, while Vitamin C and Iron content were more in cool dry season [17]. With every part of Moringa containing important nutraceuticals, it can be called a storehouse of nutrients and antinutrients . The different vitamins and minerals present in *Moringa oleifera* are summarized in Table 1.

Table 1

Vitamins and Minerals in *Moringa oleifera*

Nutritional content	**mg/100 g of edible portion of fresh Moringa leaves**	**References**
(A) Vitamins		
Vitamin A	6.8	[16]
Vitamin B	423	
Vitamin B1	0.21	
Vitamin B2	0.05	
Vitamin B3	0.8	
Vitamin C	220	
Vitamin E	448	[18]
(B) Minerals		
Calcium	440	
Phosphorus	70	
Potassium	259	

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

Copper	1.1	[16]
Magnesium	24	
Iron	0.7	
Sulphur	137	

3. Bioactive properties of different parts of the *Moringa oleifera* plant

3.1. Antioxidant activity

The seeds of *Moringa oleifera* are found to contain various compounds with antioxidant properties [19].It has also been reported that *M.oleifera* leaves have high antioxidant activity [20], and some mature leaves contain enzymatic and non-enzymatic antioxidant activities [21]. Antioxidant properties are also shown by aqueous extracts of *M. oliefera* seeds[22] and phenolic compounds present in flowers[23]. The same attribute is also seen in the pods [24] and the root extracts of *M.oleifera* [25].

3.2. Anti-inflammatory activity

Ethyl acetate fraction of the extract of *Moringa oleifera* leaves was shown to exhibit antioxidant properties and further reported to inhibit human macrophage induced cytokine production induced by cigarette smoke. These results support the beneficial role of Moringa in treating serious inflammatory conditions induced by cigarette smoke [26]. Seed extracts [27] and root barks [28] of *M. oleifera* have also been shown to have anti-inflammatory properties in treating colitis and ulcers, respectively. Studies carried out on gamma-aminobutyricacid-enriched *M. oleifera* leaves produced by fermentation with *Lactobacillus plantarum* LK-1 showed that the fraction could alleviate LPS induced inflammatory response [29].The roots of *M.oliefera* were known to contain the polysaccharide MRP-1, which significantly contributed to its anti-inflammatory activity[30].

3.3. Anti-microbial activity

There are reports that the lectins present in *Moringa oleifera* seeds could suppress the growth of *Candida* [31].The leaves of *M.oleifera* showed good antibacterial activity against some gram-positive and gram-negative organisms [32]. In another study, fruit flesh extracts of *M.oliefera* inhibited the growth of certain pathogens, such as *Staphylococcus aureus* and *Psuedomonas aeruginosa* [33]. Anti-mircobial action was also exhibited by barks of most *M.oleifera* types towards *Citrobacter fruendii*, *Pseudomonas fluorescens*, etc [34].

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

3.4. Anti-cancer activity

Studies are available that highlight the potential efficacy of *Moringa oleifera* plant material in treating cancer. Ethanol extract of the seeds of *M.oleifera* exhibited anti-tumor activities and further studies in mouse models attributed this property to the presence of niazimicin [35].The anticancer properties of *M.oleifera* fruit parts were studied in hepato-cellular carcinoma and found to have cytotoxic effects [36].Nanocomposites based on the extracts of root and leaves of Moringa were found to induce apoptosis in cancer cell lines proving the prospects of Moringa based nanomaterials as anticancer agents. [37].

3.5. Anti-diabetic activity

Moringa oleifera contains bioactive components that can confer anti-diabetic properties [38]. Leaves of *M.oleifera* exhibited a significant role in treating diabetes-linked renal failures in rats as well as type 2 diabetes [39]. Ethanolic extract of Moringa leaves was found to inhibit α-amylase activity and hence proved to be effective against diabetes[40].

3.6. Cardioprotective activity

A study by Nandave et al demonstrated the cardioprotective effect of *Moringa oleifera* leaves that could prevent myocardial damage in rats [41]. N-alpha-rhamnopyranosyl vincosamide, an alkaloid extracted from *M.oleifera* leaves, was found to have protective effects on myocardial necrosis [42] .Another group of investigators reported that the seeds of *M.oleifera* reduced cardiovascular damage caused by myocardial infraction [43].

3.7. Immunomodulatory activity

Extracts of *Moringa oleifera* were reported to induce immune modulation in mice through increased IgA production and cytokine responses and were suggested for use as a protective mucosal adjuvant[44]. In another study, extracts of *M. oleifera* leaves strengthened the immune system against certain viral strains in mice [45] and stimulated humoral and cell-mediated immune response [46]. A recent study demonstrated that when *M. oleifera* leaf extract was incubated with BV-2 microglia cells, it maintained the viability of the cells[47].

3.8. Neuroprotective activity

Moringa oleifera is known to have a significant role in neuroprotection[48] .In a study, pyrole-2-carbaldehyde and some analogs extracted from the seeds of *M.oleifera* demonstrated neuroprotective function[49] .Some studies have investigated the use of

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

M.oleifera in ischemic stroke [50] ,and other Alzheimer's neurodegenerative diseases [51]. Prevention of nicotine-induced cerebellar injury in rats could be done to an extent by *M.oleifera* [52]. More research is warranted to find out the involvement of *M.oliefera* in neuroprotection since it could prove beneficial in the battle against neurodegenerative disorders.

3.9. Antispasmodic and Hepatoprotective activities

Intestinal spasm was found to be inhibited by the seeds of *Moringa oleifera*, but at the same time, roots, leaves, flowers, and stalks showed no antispasmodic activity [53]. Oral administration of *M.oleifera* leaves to rats resulted in significant protective effects on muscular tissues against the damage caused by valproic acid [54].The oil preparation of *M.oleifera* seeds effectively improved hepatic markers, thus being involved in hepatoprotective activities [55] , and the leaf extract managed lead acetate-induced perturbation in hepatic tissue [56]. Intake of cadmium chloride could increase liver function enzymes such as AST, ALP, and ALT, but when it was treated with *M.oleifera*, a reduction in these markers could be observed, thereby contributing to hepatoprotection [57].

3.10. Wound healing property

Moringa oleifera seeds are known to have promising wound healing properties [58]. A silver nanocomposite synthesized from polysaccharide, a bioactive component in *M.oleifera* was found to have application in wound dressing[59]. Functional wound dressings[60] and scaffolds [61] were also developed using *M.oleifera* extracts for healing purposes.

3.11. Antinephropathic activity

Moringa oleifera seed oil produced remarkable protection against gentamicin-induced renal failure [62]. It has been reported that the introduction of *M.oleifera* leaf extract reduced renal injuries caused by methotrexate through the restoration of renal biomarkers [63]. Very recently, studies reported that *M.oleifera* based feed supplements could sufficiently decrease renal failures due to renal ischemia[64] . *M.oleifera* also had an effect on renal cancers induced by 7,12-dimethylbenz[a]anthracene [65].

3.12. Anti-aging effect

The leaves of *Moringa oleifera* contained constituents that favored anti-aging properties that could be effectively applied against skin wrinkling in the future [66].

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

M.oleifera has also been utilized in the synthesis of nanoliposomes, which managed photoaging due to UV exposure [67].

4. Moringa Oleifera as a food fortificant

About 7.3% of the global burden of disease is due to micronutrient deficiency. Also it has been estimated that the iron and vitamin A deficiency rank among the 15 leading causes of the global disease burden. . In recent years the value of fortifying foods and beverages with essential minerals and vitamins has been recognized as a cost-effective way for nutrient delivery to large populations and for reducing the nutritional concerns in developing countries. Food fortification is defined as a practice of addition of key vitamins and minerals such as iron, zinc, iodine, vitamins to food to improve their nutritional content. *Moringa oleifera* with its high nutritive value and phytochemical composition could serve as an effective food fortificant that could compensate for many mineral and vitamin deficiencies. The following section summarizes the recent developments in the research conducted towards use of *Moringa oleifera* as a fortificant in various food items.

4.1. Dairy products

Akajiaku et al. (2018) incorporated *Moringa oleifera* leaf powder at different ratios in the production of yogurt and the results showed that 1g of *Moringa oleifera* leaf powder scored the highest for general acceptability and also improves the nutritional value of yogurt[68]. Similarly, Hekmat et al. (2015) and Hassan et al. (2016) concluded that for balancing the sensory properties with nutritional value, a fortification level of 0.5% w/w was optimal[69,70].In a related study, addition of 0.5 to 2% of dried *Moringa oleifera* leaves into yogurt was found to promote fermentation by increasing Lactic acid bacteria and improves textural and bioactive qualities[71]. Moringa leaves were added into curd and their chemical, microbiological and organoleptic properties during storage were evaluated by Singh et al. (2015)[72]. The study concluded that the extract improves the nutritional, microbiological and organoleptic properties of curd. To prevent malnutrition in women and children, Nadeem et al. (2012) formulated buttermilk by blending dried leaves of *Moringa oleifera* resulting in an increase of calcium, iron, protein, Vitamin C, Vitamin B1, Vitamin B2 and Vitamin B3 levels[73]. Cream cheese from pure buffalo milk with *Moringa* leaf powder mixed at various concentrations was

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

formulated by Ojoriz et al. (2013)[74]. Mohamed et al. (2018) reported that the addition of *Moringa oleifera* leaf extract to cream cheese at varied ratios increased its shelf life[75].

4.2. Bread and other bakery products

Investigators have made several attempts to either reduce or completely replace the amount of wheat flour used in bread formulation. The effect of replacing wheat flour with 1-5% w/w Moringa leaf or 5-15% Moringa seed flour has been reported as a means to fortify bread [76]. However, the green coloring and herbal flavors due to the increased fraction of Moringa leaf powder decreased the demand for bread. About 67% of increased protein content has been reported in fortification of wheat flour with *Moringa oleifera* seed flour [77]. Some authors concluded that the antimicrobial properties of Moringa leaves have a significant impact on yeasts therefore affecting the structure of bread [78].

Moringa oleifera seed[77] or leaf [79,80] has been reported to be employed in wheat biscuits or cookie fortification. Higher protein content was reported in wheat cookies fortified with 10% *Moringa oleifera* seed flour than those fortified with 10% *Moringa oleifera* leaf powder [81,79]. The cookies fortified with Moringa leaves can be used as an alternative to eggs and milk by vegetarians as it enables them to consume the same content of protein [81]. Kolawole et al. (2013) reported the use of 20% *Moringa Oleifera* leaf powder in the fortification of wheat cake that resulted in improved nutritional content [82].

4.3. Meat products

The wide use of synthetic antioxidants in the food industry to increase the shelf life and improve color and taste stability of meat products have been considered as a risk factor for degenerative diseases such as cancer [83]. Studies showed that the aqueous Moringa leaf extract inhibits lipid and myoglobin oxidation in raw beef thus preserving the red color of raw meats. Also the microbial content in raw beef treated with aqueous Moringa leaf extract was found to be consistently lower which indicates that Moringa could potentially prolong the shelf life of raw meats [84]. One of the major disadvantages of addition of Moringa leaf extract is that high concentration can give rise to unwanted flavor and coloration.

4.4. Beverages

Beverages are considered as good vehicles for the delivery of nutritional supplements

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

as they are easy to be consumed along with meals[85]. Dry leaf powder, fresh leaf and leaf aqueous extract of Moringa is used in different percentage ranges. The increased nutritional value, especially antioxidant capacity and the contents of phenol and proteins was the main beneficial aspect. An attempt was made to fortify a refreshing beverage jaljeera with the addition of *Moringa Oleifera* leaf powder by Vijaya Paramar (2019) and they could successfully optimize acceptable products of chapatti and jaljeera with much higher content of iron and calcium[86].Some authors have emphasized the necessity for further investigation into the integration of aqueous leaf extract into beverages to address the challenge of certain consumers rejecting drinks based on taste and color[87].

5. Green synthesis of nanoparticles using Moringa oleifera and their potential applications in food industry

5.1. Nanoparticles synthesis using *Moringa oleifera*

Green synthesis of nanoparticles is an emerging field due to its ecofriendly and sustainable perspectives. Several attempts have been made for employing *Moringa oleifera* in the production of nanoparticles. The unique metabolic profile of this plant, which includes flavonoids, alkaloids, glycosides, terpenes, and phenolics, presents a multitude of possible applications in the fields of remediation of pollution, medicines, nutritional products, and agriculture. Table 2 summarizes the features of bio-synthesized nanoparticles using *Moringa oleifera* extracts.

Table 2

Features of biosynthesized nanoparticles using Moringa oleifera extracts

Part of Moringa oleifera used	Nanoparticles	Size (nm)	Applications	Reference
Leaf	Ag	50–60	Antimicrobial and anti tumour activities	[88]

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

Flower	Ag	22	antimicrobial and sensing applications	[89]
Leaf	Au	15-30	antioxidant, antimicrobial and blood cytotoxicity Photocatalytic activity	[90]
Leaf	NiO	-	Antibacterial property and cytotoxic activity.	[91]
Leaf	ZnO	50	Antibacterial	[92]
Leaf and seed	Fe	-	Water treatment, antibacterial	[93]
Crude Gum	Al_2O_3	16	Water treatment	[94]
Flower	TiO_2	100	Wound healing	[95]

5.2. Applications of *Moringa oleifera* based nanoparticles in food industry

In food technology, it has been observed that incorporating components of *Moringa oleifera*, as a fortifying agent in various food items enhances their overall nutritional value and extends their shelf life [94,95]. Moringa leaf powder has been potentially used as a functional food ingredient. Furthermore, research is ongoing to develop methods of encapsulation, as most food preparation processes result in significant degradation of essential molecules such as probiotics, antioxidants, and vitamins. Compared to micrometer-sized systems produced by conventional micro-encapsulation methods, nanometer-sized delivery systems offer a larger surface area. This increased surface area can improve solubility, enhance bioavailability, enable better-controlled release, and facilitate more precise targeting of encapsulated compounds.

Food safety, particularly protection against food-borne diseases, remains a significant global public health concern in food processing. Presently, a considerable portion of nanotechnology applications in the food industry focuses on developing food packaging materials using nanotechnology. Metal and metal oxide nanoparticles have demonstrated resilience under harsh processing conditions, unlike organic antibacterial compounds, which tend to lose stability at high temperatures compared

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

to their inorganic counterparts [96]. Biologically synthesized nanomaterials are preferred over chemically synthesized ones due to the cytotoxic effects of the latter on cells. Lin et al. developed moringa oil-loaded chitosan nanoparticles embedded in gelatin nanofibers for controlling Listeria monocytogenes and Staphylococcus aureus on cheese. These nanofibers hold promise as active food packaging materials for food preservation.[97]. Silver nanoparticles (AgNPs) biosynthesized from the leaf extract of *Moringa oleifera* and coated onto low-density polyethylene films exhibit significant potential as a technological innovation for preventing microbiological contaminations, thereby ensuring food safety and preservation [98].

There is a growing industrial demand for active packaging that extends the shelf life of food while preserving its quality and safety. Green synthesized nanomaterials are considered superior alternatives for non-biodegradable and non-renewable packaging materials due to their environment friendly characteristics[99]. Silver nanoparticles synthesized using the leaf extract of *Moringa oleifera* coated over low-density polyethylene films was reported to have good antibacterial properties and hence proposed to be an alternative for the conventional food packaging materials [100]. In another study, Selenium nanoparticles synthesized using a rapid solvothermal method exhibited antibacterial activity against *Escherichia coli, Salmonella typhimurium* as well as *Bacillus cereus* [101]. The current research in the field of green synthesized nanomaterials using *Moringa oleifera* is believed to add a novel dimension to the realm of food science by developing new functional materials with various applications in the food, health, and related sectors.

Conclusion

Moringa oleifera stands as a versatile plant with immense potential to address both nutritional deficiencies and various health conditions. Its widespread availability, coupled with its rich nutritional profile and medicinal properties, makes it a valuable resource in the fields of medicine and nutrition. It has been well established that the elaborate phytochemical composition of the plant is responsible for its unique medicinal and nutritional properties. Though some studies are going on to look into the therapeutic potential of Moringa in various diseases, it is warranted to explore the possibilities in life-threatening diseases like cancer, viral outbreaks etc. Moreover, the research into nanoformulations and nanomaterials synthesized using *Moringa oleifera*

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11.Iss 13, 2022

also needs to be strengthened inorder to develop eco-friendly options in the food industry.

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