European Journal of Nutrition & Food Safety

Volume 16, Issue 8, Page 1-13, 2024; Article no.EJNFS.120062
ISSN: 2347-5641

The Multifaceted Benefits and Applications of *Moringa oleifera*: A Comprehensive Review

Rashmi Goswami [a], Damini Arya [b], Rukkiya Siddiqui [c*], Sawan Kumar [a], Olympica Sarma [d] and Niddhi Arora [a]

[a] Department of Veterinary Medicine, C.V.A.Sc., G.B.P.U.A.&T., Pantnagar, Uttarakhand, India.
[b] Department of Veterinary Gynaecology and Obstetrics, C.V.A.Sc., G.B.P.U.A.&T., Pantnagar, Uttarakhand, India.
[c] Division of Animal Nutrition, ICAR-IVRI, Izatnagar, Bareilly, Uttar Pradesh, India.
[d] Department of Animal Genetics and Breeding, C.V.A.Sc., G.B.P.U.A.&T., Pantnagar, Uttarakhand, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ejnfs/2024/v16i81489

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/120062

Review Article

Received: 08/05/2024
Accepted: 11/07/2024
Published: 12/07/2024

ABSTRACT

Moringa oleifera, commonly known as the Drumstick tree, is a multifaceted plant having extensive medicinal and nutritional applications. Various species of the plant are distributed across different tropical and sub-tropical areas around the world for diverse usage. It has also been recognized in Ayurveda as well as Unani systems of medicine for prevention and treatment of different diseases along with applications in environmental management, such as water purification and biopesticides.

**Corresponding author: Email: rukkiya1995@gmail.com;*

Cite as: *Goswami, Rashmi, Damini Arya, Rukkiya Siddiqui, Sawan Kumar, Olympica Sarma, and Niddhi Arora. 2024. "The Multifaceted Benefits and Applications of Moringa Oleifera: A Comprehensive Review". European Journal of Nutrition & Food Safety 16 (8):1-13. https://doi.org/10.9734/ejnfs/2024/v16i81489.*

The plant is rich in essential nutrients, including vitamins, minerals, amino acids, and various bioactive compounds like flavonoids, tannins, and saponins. Its leaves, pods, and flowers are used as dietary supplements, offering significant health benefits, particularly in underdeveloped countries. It is known for a wide range of pharmacological properties, such as antioxidant, immunomodulatory, anti-microbial, and anti-cancer activities, making it a valuable resource in traditional and modern medicine. Various scientific studies have highlighted its potential in reducing cholesterol, boosting immune responses, and inhibiting the growth of various pathogens as well as cancer cells. This review highlights the multifaceted utility of *Moringa oleifera i.e.,* nutritional value of *Moringa oleifera*, its phytochemical richness and certain therapeutic properties such as antioxidant, immunomodulatory, anti-microbial and anti-cancer properties thus showing its versatility.

Keywords: Anti-cancer; anti-microbial; antioxidant; immunomodulatory; Moringa oleifera.

1. INTRODUCTION

Moringa has various species distributed across the different tropical and sub-tropical areas around the world for diverse usage. There are about 12 varieties of Moringa species out of which some are *Moringa ovalifolia*, *Moringa drouhardii*, *Moringa longituba*, *Moringa oleifera etc.* [1]. *Moringa oleifera*, commonly known as Drumstick, benzoil tree, ben oil tree, Moringa, Shajmah, Sanjna or Sohanjna, is a commonly grown tree in India which belongs to Family Moringaceae. It is considered as a 'Magical tree' or 'Miracle Vegetable' because it is both a medicinal and a functional food. It is a perennial, deciduous soft wood tree with an average height of 10-12 m and has been used in traditional medicine and different industries for centuries [2,3,4]. It has application in many fields as most of the plant parts are edible and is having important medicinal properties [5]. It has also been recognized in Ayurveda as well as Unani systems of medicine for prevention and treatment of different diseases, for *e.g*., fatigue, bronchitis, hay fever, gastric ulcers and skin diseases. The leaves, immature pods and flowers of Moringa can be used as high nutritive supplement having various important pharmacological properties [6]. It contains several nutrients such as vitamins, minerals and fatty acids [7] and various active ingredients such as steroids, tannins, triterpenoids, flavonoids [8]. Leaves of Moringa are highly nutritious and a very good and cheap source of protein, vitamins A, B, C and E, β-carotene, folic acid, pyridoxine, riboflavin, niacin, different minerals, amino acids and different phenolic compounds [9] and it was also found to be rich in gallic acid, quercetin glycosides, kaempferol and chlorogenic acid [10]. Apart from this it has other applications such as animal forage, alley cropping, blue dye, fertilizer, biogas, green manure, gum, honey and sugar cane juice clarifier, bio-pesticide, honey, tannin for tanning hides, pulp, ropes, water purification *etc.* [11,12]. Its seed can be used in waste water treatment [11]. Thus, *Moringa oleifera* represents an important multitasking crop. It is consumed by humans in very diverse ways, as the leaves are known to be rich in tocopherols, ascorbic acid, carotenoids and have high nutritional value thus, the powder of the Moringa leaves is traditionally consumed by pregnant and lactating women in under-developed countries [13]. It has also been used for the treatment of bronchitis, asthma, diarrhoea, epilepsy, diabetes, anaemia, skin infections, *etc.* [14]. It is also found to be very useful feed supplement in animals because leaves of the plant are of high nutritive value [15].

The present review aims to amalgamate the extensive uses of *Moringa oleifera*, highlighting its significance as a versatile plant with immense medicinal and nutritional applications. A holistic potential of *Moringa oleifera* is discussed along with its phytochemistry showing its antioxidant, immunomodulatory, antimicrobial and anticancer properties.

2. PHYTOCHEMISTRY Of *Moringa oleifera*

Moringa oleifera is found to be rich in various compounds like glucosinolates and isothiocyanates [16], alkaloids such as Moringinine and Moringine are present in stem bark [17], pigments such as alkaloids, kaempferol, rhamnetin, isoquercitrin and kaempferitrin are present in flowers [18]. In a study, it was reported that maceration of the dried leaves of *Moringa oleifera* with 70% ethanol provided highest yield of the extract of 40.50% w/w. In the HEK-293 (Human Embryonic Kidney-293) cells the median effective dose of 70% ethanolic extract of Moringa was found to

be 378.36 µg/ml [19]. Ethanolic extract of the leaves of Moringa is found to be rich in secondary metabolites such as flavonoids, tannins, saponins, alkaloids, steroids and anthraquinone which may be responsible for the therapeutic potential of the Moringa leaves [20]. The methanolic extract of *Moringa oleifera* showed the presence of highest number of phytochemicals as compared to extracts prepared in other solvents namely alkaloids, tannins, phenolics, carbohydrate, amino acids and terpenoids [21]. The plant is rich in rhamnose, glucosinolates and isothiocyanates [22]. GC-MS analysis of aqueous extract of *Moringa oleifera* leaves showed the presence of various phytochemicals *i.e.,* 1,3-dihydroxyacetone dimer; acetic acid; 4(1H)-pyrimidinone, 2,6- diamino-; 4H-pyran-4-one, 2,3-dihydro-3,5- dihydroxy-6-methyl-; 2-hexynoic acid; butanedioic acid, 2-hydroxy-2- methyl-, (S)-; 3,3'-iminobispropylamine; 1-hexanamine; 1,3-dioxolan-2-one, 4,5-dimethyl-; 2-butenethioic acid, 3-(ethylthio)-, s- (1-methylethyl) ester; propanamide, N,N-dimethyl-; 2-isopropoxyethyl propionate; D-mannoheptulose; azetidin-2-one 3,3-dimethyl-4-(1- aminoethyl)-; carbonic acid, butyl 2-pentyl ester; tetra acetyl-d-xylonic nitrile; alpha-D-glucose; 1H-cyclopenta[c]furan-3(3aH)-one, 6,6a-dihydro-1-(1,3-dioxolan-2- yl)-, (3aR,1-trans,6a-cis)-; 3-[1-(4-Cyano-1,2,3,4-tetrahydronaphthyl)] propanenitrile; quinolinium, 1-ethyl-, iodide; N-isopropyl-3-phenylpropanamide; propanamide; 1,2-ethanediamine, N-(2- aminoethyl)-; 1,4-benzenediol, 2-methyl- and ethene, ethoxy- [23]. The GC-MS analysis of methanolic extract of *Moringa oleifera* leaves revealed majorly the presence of 1,3-propanediol; 2-ethyl-2-(hydroxymethyl)- (21.19%); propionic acid; 2-methyl-, octyl ester (15.02%); ethanamine; N-ethyl-N-nitroso- (5.21%); and 9,12,15-octadecatrienoic acid, (Z,Z,Z)- (5.00%). The IC_{50} of aqueous and methanolic extract of Moringa leaves was found at a concentration of 4.65 µl/ml and 1.83 µl/ml, respectively after an incubation period of 30 minutes. Another important finding was that the methanolic extract of Moringa leaves was found to have higher number of phytochemicals as compared to its aqueous extract. The majority of phytochemicals present in *Moringa oleifera* leaves are water soluble and show positive results for alkaloids, flavonoids, terpenoids, diterpenes, phytosterols, carbohydrates, glycosides, tannins and coumarine. Ethanolic extract of leaves of Moringa was found positive for polyphenols, glycosides, tannins and terpenoids and chloroform extract of Moringa leaves was found positive for cardiac glycosides and steroids [24].

3. NUTRITIONAL VALUE OF *Moringa oleifera*

All parts of the plant are enriched with protein, vitamins, minerals, essential amino acids and different phenolic compound. It is also found that the leaves of Moringa contain a negligible amount of anti-nutritional factors such as trypsin inhibitors, saponins, tannins and phytates [25]. Moringa leaves have a relatively higher percentage of crude protein which may range from 25% to 32% which is easily digestible as it contains higher proportion of pepsin soluble nitrogen (82-91%) and low proportion (1-2%) of acid detergent insoluble protein. Proximate analysis of Moringa leaf powder was performed on dry matter basis and the nutrient profile was found to be 93.45% dry matter, 29.62% crude protein, 10.23% crude fibre, 37.50% carbohydrate, 14.25% ash, 8.40% ether extract, 2.65% calcium, 0.48% phosphorus, 2034.82 kcal/kg metabolizable energy [25]. *Moringa oleifera* leaf powder was used to replace canola meal in different groups of broilers and it was found that with gradual increase in level of Moringa leaf powder as replacement of canola meal, a higher feed intake was observed [26]. Leaves of the plant may contain tannin levels upto 2% which interferes with biological utilization of protein, carbohydrate, and lipids in monogastric animals [27]. The mineral make-up, vitamin make-up and amino acid make-up of leaves of *Moringa oleifera* is show in Table 1, Table 2 and Table 3, respectively.

Table 1. Mineral make-up of *Moringa oleifera* leaves [28]

Minerals	Leaves (mg/kg)
Calcium (Ca)	4900
Phosphorous (P)	3600
Potassium (K)	13800
Sodium (Na)	6700
Magnesium (Mg)	2700
Manganese (Mn)	122
Iron (Fe)	415
Zinc (Zn)	47
Copper (Cu)	12

4. ANTI-NUTRITIONAL FACTORS PRESENT IN *Moringa oleifera*

Anti-nutritional factors can be defined as substances which are generated in natural feed

ingredients *via* normal metabolism of plants, which interact with the chemical composition or interfere with digestion or metabolic processes in the body by different mechanisms, and pose an effect contrary to optimum nutrition but it also depends on the digestive process of the ingesting animal [31]. These anti-nutritional factors may be responsible for inhibiting protein digestion and utilization, energy utilization, anti-vitamin factor or may also disrupt the immune function. The majority of factors responsible for anti-nutritional effects on animals include, plant lectins, polyphenols, phytic acid, protease inhibitors, tannins *etc*. [32]. Tannins are phenolic compound that interact with enzyme trypsin or amylase or their substrate to form indigestible complex thus making it less palatable and thus reducing feed intake. Percentage of tannins can be reduced by the process of drying, fermentation or silaging upto15-30% [33] as the content of tannins in Moringa leaves ranges from 12.0 to 20.6 mg/g [34], thus in practical application better feeding is seen after processing the leaves by these methods. The phytates and oxalate level in *Moringa oleifera* leaves are lower than those in other household vegetables and on dry matter basis these are 22.3 mg/g [35] and 27.5 mg/g [36] respectively. Saponins are also present in the leaves of the plant that are responsible for providing better taste to the plants but on dry matter basis only 4.7–5 g/kg of saponin is present which doesn't cause any adverse effect on livestock [37]. Less fibre content is present in leaves of the plant *i.e.,* 5.89% on dry matter basis but it is negligible and have no adverse effects as anti-nutritional factor. Lignin can be used as source of energy in ruminants as rumen microbes can degrade this into monosaccharides but it is difficult to digest by monogastric animals as they don't secrete enzymes responsible for lignin digestion [38] and as the tree grows the amount of lignin present in its leaves increases [39]. Thus, the processing of Moringa leaves *via* various methods is found to be beneficial to reduce the levels of certain anti-nutritional factors, and thereby enhancing their nutritional value and palatability for livestock consumption.

5. MEDICINAL PROPERTIES OF *Moringa oleifera*

Beyond its nutritional value, *Moringa oleifera* has been traditionally used in herbal medicine for its diverse therapeutic properties such as antioxidant, immunomodulatory, anti-microbial and anti-cancer which are mentioned in the text below.

Table 2. Vitamin make-up of *Moringa oleifera* leaves [29]

Minerals	Leaves (mg/100 gms)
Vitamin A	18.9
Thiamin (B1)	2.02-2.64
Riboflavin (B2)	20.5-21.3
Niacin (B3)	7.6-8.2
Cynocobalamin (B12)	2.64
Vitamin C	15.8-17.3
Vitamin D	ND
Vitamin E	10.8
Vitamin K	ND

Table 3. Amino acid make-up of *Moringa oleifera* leaves [30]

Essential amino acids	Leaves (mg/100 gms)
Arginine	1780
Histidine	716
Isoleucine	1177
Leucine	1960
Lysine	1637
Methionine	297
Phenylalanine	1640
Threonine	1357
Tyrosine	2650
Tryptophan	486
Valine	1413
Non-essential amino acids	
Alanine	3033
Serine	1087
Cysteine	10
Proline	1203
Glycine	1533
Glutamic acid	2530
Aspartic acid	1430

6. ANTIOXIDANT PROPERTIES

The antioxidants are known to produce their effect by directly reacting with reactive oxygen species, chelating the catalytic metal ions and/or quenching the reactive oxygen species [40]. Natural antioxidants which include phenolics and flavonoids are bioactive and safer to use as compared to synthetic antioxidants. In a study, it was found that *Moringa oleifera* supplementation caused a significant decrease in triglycerides and total cholesterol levels in heat stressed chickens [41]. HPLC–MS analysis on ethanolic extract of *Moringa oleifera* showed presence of quercetin and kaempferol glycosides. It was also found that the total antioxidant activity of extracts from 1 mg *Moringa oleifera* leaf was

approximately equal to the total antioxidant activity of 0.95–1.35 mmol $FeSO_4$. The free radical scavenging activity of extracts from 1 mg leaf was approximately equivalent to that of 0.026 mg oligomeric proanthocyanidins (OPC) and IC_{50} value of the Moringa leaf extract was found to be 0.7440 mg/L in DPPH radical scavenging assay [42]. The acetone extract of *Moringa oleifera* leaves had a total phenolic content of 120.33 mg tannic acid equivalent/ gm, total flavonoid content of 295.01 mg quercetin equivalent/ gm, total flavonol of 132.74 mg quercetin equivalent/ gm and proanthocyanidin content of 32.59 mg catechin equivalent/gm whereas aqueous extract of *Moringa oleifera* leaves contained 40.27, 45.1, 18.10 and 16.91 mg of respective equivalents. The Moringa fed group showed higher level of total phenols and proanthocyanidins, highest DPPH %, 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic) acid (ABTS)% and highest reducing power. Moringa fed broilers showed highest concentration of reduced glutathione (GSH), catalase and superoxide dismutase (SOD) [43]. Aqueous leaf extract of *Moringa oleifera* showed significant increase in DPPH free radicle scavenging activity, superoxide anion and nitric oxide radical scavenging activity and decreased lipid peroxidation and extent of DNA damage. The mature leaves of Moringa were found to have higher level of activities of enzymatic as well as non-enzymatic antioxidants [44]. 70% ethanolic extract of the dried leaves of *Moringa oleifera* has a DPPH scavenging activity with EC_{50} 62.94 µg/ml and a Ferric reducing antioxidant power (FRAP) value of 51.50 mmol $FeSO_4$ equivalent/100 g extract [19]. Methanolic extract of *Moringa oleifera* leaves showed a concentration dependent increase in free radical scavenging activity, DPPH radical scavenging activity, hydrogen peroxide scavenging activity and nitric oxide free radical scavenging activity [45]. Its supplementation was found to have significant decrease in triglyceride and total cholesterol levels and significantly increase HDL (high density lipoprotein) in heat stressed birds thus showing beneficial effect on the lipid profile of the broilers. There was also a significant increase in blood glutathione peroxidase (GSH-Px), and mRNA expression of GSH-Px, SOD and catalase and a significant decrease in level of liver and muscle tissue Thiobarbituric acid reactive substances (TBARS) of heat stressed broilers [41]. Moringa leaves were found to have a total phenolic content ranging between 2.1 and 4.6 g Gallic Acid Equivalent/100 g dry matter and total flavonoid content ranging between 0.9 and 1.8 g catechin equivalent/100 g DM varying in age from 30, 45 and 60 days of leaves. The methanolic extract had the highest amount of total phenolics while ethanolic extract had the highest content of flavonoids. With increase in the age of leaves vitamin C content as well as carotenoid content decreased significantly and was found to be highest in 30-day old leaves whereas tocopherol content increased significantly as the age of the leaves progressed to 60 days. When the DPPH radical scavenging activity of *Moringa oleifera* leaves was measured it was found that ethanolic extract of 60 days old leaves had highest activity 71.1%. The $ABTS^+$ radical scavenging activity was higher in 30-day-old *Moringa oleifera* leaves. The total antioxidant capacity was found highest in aqueous extract of 60 days old leaves. FRAP of Moringa leaves was found to be maximum in the methanolic extract of 45-day-old and was minimum in 60 days old leaves [46]. Leaves of Moringa were having two times more total phenolic content and three times more total flavonoid content as compared to the commonly consumes South African vegetables like cabbage, spinach, broccoli, cauliflower and peas, thus exhibiting greater antioxidant activity as compared to these vegetables. The DPPH free radicle scavenging assay showed that the fresh crushed Moringa leaves had highest scavenging activity followed by Moringa flower, leaves collected from younger trees, leaves collected from older trees and then other vegetables [47]. Total phenolic content of *Moringa oleifera* leaf meal was 377 gallic acid equivalents (GAE)/g and antiradical activity was 63%. Broilers fed with Moringa meal were found to have reduced lipid peroxidation in the liver as well as spleen at higher dose rates [6]. Ethanolic extract from the flowers, inflorescence rachis, fundamental tissue of stem and leaf tissue of *Moringa oleifera* contained at least three flavonoids and the saline extract from the flowers and leaf tissue revealed at least two flavonoids and the antioxidant activity was stronger in ethanolic extract as compared to the saline extract and also the best scavenging capacity against DPPH radical was found in ethanolic extract of leaves [7]. The sample of Moringa plant taken in winter was having higher ash content (except the stalk part), calcium and phenolic components (except the leaf part) and stronger antioxidant activity than the summer samples. The total phenolic component in 100gm of leaf, stem and stalk of Moringa was found to be 181.3-200.0 mg, 71.9-134.4 mg and 68.8-93.8 mg catechin equivalent, respectively. The leaves of Moringa were having the highest

antioxidant activity followed by stem and stalk in both winter as well as summer samples. The methanolic extract of Moringa had high DPPH radical scavenging activity, reducing power, hydrogen peroxide scavenging activity and higher superoxide dismutase activity [39]. At a concentration of 5 µl/ml the free radicle scavenging potency with 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical of aqueous extract was found to be 35.8% and that of methanolic extract was found to be 88.5% at initial point of time and this may be due to presence of higher number of polyphenolic compounds isolated in methanolic extract. The ethanolic extract of *Moringa oleifera* at a concentration of 100 mg/ml had a total phenolic content of 2.59 mg Gallic Acid Equivalent (GAE)/ml and that of aqueous extract was found to be 1.49 mg GAE/ml and the total phenolic content of ethanolic extract was 3.82 mg QE/ml and that of aqueous extract was 3.75 mg QE/ml. 5 mg/ml concentration of Moringa extract showed a DPPH radical scavenging activity of around 72% for both ethanolic as well as aqueous extract [24].

7. IMMUNOMODULATORY ACTIVITY

It was found that when canola meal in broiler ration was gradually replaced with 8% *Moringa oleifera* leaf powder the antibody titre against infectious bursal disease virus was highest. The antibody titre against Newcastle disease virus in broilers was also improved with gradual increase in dietary *Moringa oleifera* leaf powder [26]. Increased antibody titre in birds fed with *Moringa oleifera* in diet may be due to the presence of lectin in the Moringa leaves which is responsible for modulating the defence system of body and thus claimed to be an immune boosting plant [12]. In a study, the levels of IL-2 and IL-6 of broiler chickens supplemented with Moringa were better as compared to those without Moringa supplementation in heat stressed or normal grown broilers in which their levels were significantly down-regulated [41]. Ethanolic extract of dried seeds of *Moringa oleifera,* was found to inhibit spleen weight as well as circulatory leukocyte and splenocyte counts in mice administered sheep RBC as the antigen. There was inhibition of delayed-type hypersensitivity reaction as there was decrease in mean foot pad thickness at 48 h interval. There was amelioration in the production of the humoral antibody titre and there was down-regulation of macrophage phagocytosis due to carbon particles [48]. A novel polysaccharide, designated as MOP-3 (*Moringa oleifera* polysaccharide-3), was extracted and isolated from the leaves of *Moringa oleifera* and in the immunomodulatory assay it was suggested that MOP-3 could significantly enhance pinocytic capacity and increase the secretion of reactive oxygen species (ROS), nitric oxide (NO), interleukin-6 (IL-6), and tumour necrosis factor-*α* (TNF-*α*) by up-regulating the corresponding mRNA expression levels in murine macrophage cell line (RAW 264.7 cells) [49]. *Moringa oleifera* is known to inhibit chronic inflammation, such as asthma, ulcerative colitis, and metabolic diseases. It can attenuate physical and chemical irritation-induced immune disorders, such as metal intoxication, drug side effects, or even the adverse effect of food additives. Autoimmune diseases, like rheumatoid arthritis, atopic dermatitis, and multiple sclerosis, can also be inhibited by *Moringa oleifera* [50]. The antibody titre measured by using haemagglutination inhibition assay against new castle disease was significantly improved in broilers fed with *Moringa oleifera* leaf meal [51]. Dietary inclusion of *Moringa oleifera* leaf meal (up to 10%) in feed of *Sparus aurata* (gilthead seabream) showed improvement in leucocyte phagocytosis of head kidney/ pronephros (important endocrine organ in teleost fishes, homologous to mammalian adrenal glands and plays an important role in the immune system, stress response, and blood cell production), respiratory burst and peroxidase activities. An inclusion of 5% showed an increase in serum humoral components, including protease, alternative complement activity (ACH_{50}) and lysozyme activities and also an increase in IgM level. An increase in skin-mucosal immunity such as protease, antiprotease, peroxidase and lysozyme activities were also found. It also led to an upregulation of the intestinal mucosal immunity genes (*lyso* and *c3*), tight junction proteins (*occludin* and *zo-1*) and anti-inflammatory cytokines (*tgf-β*) and a downregulation of pro-inflammatory cytokine (*tnf-α*) [52]. Methanolic extract of *Moringa oleifera* was found to significantly increase the levels of serum immunoglobulins. There was significant increase in circulating antibody titre in indirect haemagglutination test. The extract also produced significant increase in adhesion of neutrophils, attenuation of cyclophosphamide induced neutropenia and an increase in phagocytic index in carbon clearance assay. It was also found that the lower dose of the extract was more effective than the higher dose [53] the possible reason for which may be the optimal

dose-response relationship, which suggests that the desired immunomodulatory response was achieved at lower dose without inducing toxicity or adverse reactions that could occur at higher doses. Methanolic leaf extract of *Moringa oleifera*, when given at a dose of 1000 mg/kg body weight in cyclophosphamide treated rats led to significant increase in WBC, lymphocyte, and neutrophil counts and a significant neutrophil adhesion was found. There was a significant dose-dependent increment in the mean hemagglutination antibody titre to sheep red blood cells (SRBC). Thus, the extract showed significant changes in humoral as well as cell mediated immunity [54]. A novel polysaccharide (MOP-2) was extracted and purified from the leaves of *Moringa oleifera* by hot water extraction and chromatographic purification and it was found that it could significantly enhance the proliferation and pinocytic capacity of the RAW264.7 macrophage cells. MOP-2 was able to promote the secretion of ROS, nitric oxide (NO), interleukin-6 (IL-6), and tumour necrosis factor-*α* (TNF-*α*) by activating mRNA expressions of iNOS, IL-6 and TNF-*α* and thus can be developed as a novel natural immunoregulatory agent in functional foods [55]. When the cells from spleen of Balb/C mice were grown in RPMI medium in presence of aqueous extract of *Moringa oleifera* Lam. leaf, it was found that in flowcytometry assay the extract at low doses was able to increase the cell number of $CD4^+$ and $CD8^+$ cells and in higher doses there was significant increase in $B220^+$ cells when compared to the control [56]. When leaf extract of *Moringa oleifera* was administered orally to cyclophosphamide treated rats, there was a significant dose-dependent increase in total WBC count and percentages of neutrophil, eosinophil, monocytes, and lymphocytes. There were significantly reduced serum hepatic enzymes (Alanine transaminase, Aspartate aminotransferase and Alkaline phosphatase) and the administration of *Moringa* extract was able to reverse the effects of cyclophosphamide on blood parameters and hepatic enzymes in a dose dependent manner [57].

8. ANTI-MICROBIAL ACTIVITY

Crude aqueous and methanolic extract of Moringa at a concentration of 50mg/ml was found to have antibacterial activity against different pathogenic bacteria of humans namely, *Proteus* spp., Multidrug-resistant (MDR) of *Escherichia coli, Shigella* spp., *Salmonella paratyphi*, *Pseudomonas aeruginosa*, *Klebsiella* spp., *Escherichia coli*, *Salmonella typhi*, MDR of *Klebsiella* and *Staphylococcus aureus*. Methanolic and isopropanol extract of *Moringa oleifera* at a concentration of 80 mg/ml showed significant anti-fungal activity. Hexane, benzene and isopropanol fractions of *Moringa oleifera* also showed activity against Hepatitis-B virus [21]. It was found that, the ethyl acetate, ethanol and chloroform extract of Moringa leaves was found to have a significant anti-microbial activity against many bacteria such a *E. coli, P. aeruginosa, Klebsiella spp., Streptococcus pneumoniae* and *Bacillus cereus* and anti-fungal activity against *Aspergillus niger, Aspergillus. flavus, Trichoderma* sp. and *Candida* sp. [20]. It was also found that the ethanolic extract was most effective against majority of the microbes which may be due to higher polarity of ethanol. In a study, it was reported that the aqueous, ethanolic and methanolic extract of *Moringa oleifera* showed varying degree of antibacterial activity against *S. aureus, E. coli* and *Bacillus subtilis* and out of all the extracts methanolic extract showed maximum antibacterial activity against *S. aureus* [45]. In another study, it was found that the acetone leaf extract of *Moringa oleifera* was found to have a significant inhibitory effect on shedding of *Eimeria* oocyst in faeces of broilers which was found to be in a concentration dependent manner *i.e.* 1,2,3,4 and 5 g/kg body weight with an inhibitory effect of 96.4 %, 97.4%, 98.7, 99.1 and 99.8 % inhibition of *Eimeria* oocyst shed in the faeces respectively. Similarly, the groups treated in the same sequence has a body weight increase of 20.0, 22.0, 26.0, 29.0 % and 34.0 % respectively and the extract given at the dose rate of 5g/kg body weight showed highest body weight gain [58]. In another study it was reported that the ethanolic extract of *Moringa oleifera* leaves was found effective against *E. coli, S. aureus, B. subtilis* and *P. aeruginosa* in a decreasing order [24] which might be due to presence of high level of terpenoids and tannins in the extract [59] as tannins are able to inhibit the cell wall synthesis [60] and terpenoids are known to cause dissolution of cell walls of microbes by weakening the membranous tissues [61]. Another finding was that the aqueous extract of the plant was found to have antibacterial activity against *P. syringica* and the reason for this may be presence of diterpenes in the aqueous extract which can damage cell wall of gram-negative bacteria that contain phospholipids and lipopolysaccharides as barriers [62]. Apolar extracts of seeds of *Moringa oleifera* showed a

significant concentration-dependent antimicrobial activity against *S. aureus* and *S. epidermidis*. 4 mg/ml of the seed extract reduced the viability of these bacteria up to 50% and it was associated to the content of specific fatty acids [63]. 0.5%, 0.75% and 1% incorporation of *Moringa oleifera* leaves in chicken sausages showed low pH value, decreased TBARS and low Total Plate Count throughout the storage period and thus showing the antioxidant and antimicrobial potential of Drumstick leaves in chicken sausages [64]. *Moringa oleifera* leaf extract (8% b/v, 4% b/v and 2% b/v) was able to inhibit the growth of *S. epidermidis* by showing the inhibition zone (14 mm, 10.8mm and 9.3 mm) around the extract [65]. Using minimum inhibitory concentration (MIC), the growth inhibition of *P. aeruginosa* and *E. carotovora* were found to be 86 ± 1% (ethyl acetate extracts of roots) and 79 ± 0.3% (ethanolic extracts of leaves), respectively, thus showing anti-bacterial activity of various parts of *Moringa oleifera* [66]. In a study, it was reported that chloroform extraction was the best extraction method to extract antimicrobial compounds from *Moringa oleifera* and bark of the plant showed higher number of antimicrobial compounds compared to leaves and roots of the pant. The extract showed significant activity against *Salmonella enteritica* and *Listeria monocytogenes* was found to be most resistant to all the type of the extract [67]. A new compound (*Moringa* A) from *Moringa oleifera* seeds was found to inhibit virus replication in host cells and protects infected cells from the cytopathic effect induced by Influenza A viruses. The EC_{50} and EC_{90} values of *Moringa* A for Influenza A viruses were 1.27 μM and 5.30 μM, respectively, when RAW264.7 cells were infected. *Moringa* A was observed to decrease the inflammatory cytokines TNF-*α*, IL-6, IL-1β, and IFN-β in H1N1 infected RAW264.7 cells. *Moringa* A was found to inhibit the expression and nuclear transfer of the cellular protein transcription factor EB (TFEB) and weaken the autophagy in infected cells, which could be an important antiviral mechanism [68].

9. ANTI-CANCER EFFECT

Although several advancements have occurred in field of chemotherapeutics but it is also associated with various adverse effects such as nausea, anaemia, skin irritation, nephrotoxicity and infertility *etc.* [69]. So, natural resources are one of the major sources of anti-cancer drugs and more than 60% of the presently available cancer drugs are derived from natural sources. The leaf extract of Moringa has undergone extensive research for its anti-cancer properties. Its leaves are rich in various important phytoconstituents such as polyphenols and flavonoids which are known to possess antioxidant as well as anti-cancer properties [70]. Dichloromethane leaf extract of *Moringa oleifera* showed and IC_{50} of 112-133 μg/ml at killing cancer cells of various cell lines *i.e.,* human liver cancer cell line (HepG2), human colorectal adenocarcinoma cell line (Caco-2), and Michigan Cancer Foundation-7 (MCF-7). The extract also showed chemoprevention as shown in quinone reductase (QR) induction assay as there was significant induction of QR [71]. 20 μg/ml of *Moringa oleifera* leaf extract showed significant anti-cancer activity against primary leukemia cells harvested from patients with acute myeloid leukemia and acute lymphoblastic leukemia and HepG2 cells in the MTT assay [72]. The soluble cold distilled water (4°C) extract of *Moringa oleifera* with a concentration of 300 μg/ml was able to induce apoptosis, inhibit tumour cell growth, and decrease the level of internal ROS in human lung cancer cells suggesting that treatment with *Moringa oleifera* significantly reduced cancer cell proliferation and invasion. There was higher cytotoxicity against cancer cells as compared to healthy cells. When A549 cells were treated with the extract there was downregulation of many oncogenes and iPS-induction genes when observed with western blot and RT-PCR [73]. F1 fraction of *Moringa oleifera* leaves showed potential cytotoxic effects in Hep-2 cell lines with a 50% of cytotoxicity inhibition (CTC_{50}) value of 12.5±0.5 μg/ml. In the same study it was found that *Moringa oleifera* leaf fraction at the dose rate of 5 mg/kg and 10 mg/kg, orally showed significant reduction in body weight and increase in mean survival time in Dalton's lymphoma ascites model in mice as compared to the control and treatment with the leaf fraction was comparable to 5-Fluorouracil treatment in rats [74]. Leaves of Moringa are known to possess cytotoxicity as it contains various flavonoids such as quercetin, kaempferol and myricetin that are known to possess anti-cancer activity. These compounds also possess cytotoxicity because they can induce apoptosis through intrinsic pathways by inhibition of mitogen-activated protein kinase (MAPK), extracellular-signal-regulated kinase 1/2 (ERK 1/2), c-Jun N-terminal protein kinase 1 (JNK), and protein kinase C (PKC) [75]. In a study it was reported that *Moringa oleifera* leaf extracts induced the apoptosis of HepG2 cells

(human hepatocellular carcinoma) and in hollow fiber assay it was found that the oral administration of the leaf extract significantly reduced (44-52%) the proliferation of the HepG2 cells and A549 lung cancer cells [76]. n-hexane fraction of *Moringa oleifera* leaves was found to be rich in 10 phenolic compounds *viz*. quercetin, gallic acid, sinapic acid, vanillic acid, 4-hydroxy-3-methoxy benzoic acid, p-coumaric acid, m-coumaric acid, 4-hydroxy-3-methoxy cinnamic acid, caffeic acid, and syringic acid. It showed 50% reduction in Hela cancer cell viability at a concentration of 416 µg/ml [77]. GC-MS analysis of aqueous extract of *Moringa oleifera* showed the presence of presence of quinic acid, octadecanoic acid, hexadecanoic acid (palmitic acid), *α*-tocopherol (Vitamin-E) and ɣ-sitosterol as major bioactive compounds. It was able to reduce the tumour volume and tumour weight and increased their life expectancy. *In vitro* cytotoxicity assays showed that the extract induced dose and time-dependent toxicity in Ehrlich ascites carcinoma and Human laryngeal carcinoma cells. Flow cytometric analysis confirmed significant induction of apoptotic cells by changing the mitochondrial membrane potential in Ehrlich ascites carcinoma cell line [78].

10. CONCLUSION

Moringa oleifera stands out as a multifunctional plant with several medicinal and nutritional benefits so also known as 'Magical Tree'. It has a rich phytochemical composition, including glucosinolates, isothiocyanates, flavonoids, and other bioactive compounds, and these bioactive compounds are responsible for its wide-ranging therapeutic properties. The bioactive compounds present in the plant extract help to mitigate oxidative stress and enhance immune function. Additionally, its antimicrobial properties make it effective against a broad spectrum of pathogens. It also shows hope in cancer treatment through its ability to induce apoptosis and inhibit tumour growth. The application of Moringa extends beyond human consumption to animal feed, water purification, and industrial uses. *Moringa oleifera* stands out as an essential and beneficial crop for diverse applications because of its profound health benefits and multifunctional uses.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Leone A, Spada A, Battezzati A, Schiraldi A, Aristil J, Bertoli S. Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. International Journal of Molecular Sciences. 2015;16(6):12791-12835.
2. Verma SC, Bannerji R, Mirra G, Nigam SK. Nutritional value of Moringa. Current Science. 1976;45:769-771.
3. Kumar A, Sharan N, Gupta S, Kumari S. Potential anticancer activity of some medicinal plants *in vitro* and *in vivo* study. International Journal of Basic & Clinical Pharmacology. 2022;11(6):680-691.
4. Radovich T. Farm and forestry production and marketing profile for Moringa (*Moringa oleifera*). Permanent Agriculture Resources (PAR), Holualoa, HI, USA; 2011.
5. Nebolisa NM, Umeyor CE, Ekpunobi UE, Umeyor IC, Okoye FB. Profiling the effects of microwave-assisted and soxhlet extraction techniques on the physicochemical attributes of *Moringa oleifera* seed oil and proteins. Oil Crop Science. 2023;8(1):16-26.
6. Meireles D, Gomes J, Lopes L, Hinzmann M, Machado J. A review of properties, nutritional and pharmaceutical applications of *Moringa oleifera*: integrative approach on conventional and traditional Asian medicine. Advances in Traditional Medicine. 2020;20(4):495-515.
7. Moyo B, Masika PJ, Hugo A, Muchenje V. Nutritional characterization of Moringa (*Moringa oleifera* Lam.) leaves. African Journal of Biotechnology. 2011;10(60):12925-12933.
8. Sonkar N, Singh N, Santra AK, Mishra S, Roy M, Pathak R, Soni A, Verma LP, Verma M. Phytochemical analysis of *Moringa oleifera* leaves collected from the adjoining areas of Durg district of Chhattisgarh, India. Journal of Pharmacognosy and Phytochemistry. 2020;9(1):2204-2206.

9. Ariani LN, Estiasih T, Sunarharum WB, Khatib A. Potential of moringa (*Moringa oleifera*) leaf powder for functional food ingredients: A review. Czech Journal of Food Sciences. 2023;41(1):8-20.
10. Singh BN, Singh BR, Singh RL, Prakash D, Dhakarey R, Upadhyay G, Singh HB. Oxidative DNA damage protective activity, antioxidant and anti-quorum sensing potentials of *Moringa oleifera*. Food and Chemical Toxicology. 2009;47(6):1109-1116.
11. Kansal SK, Kumari A. Potential of *Moringa oleifera* for the treatment of water and wastewater. Chemical Reviews. 2014;114(9):4993-5010.
12. Fuglier LJ. The Miracle Tree: *Moringa oleifera*, Natural Nutrition for the Tropics (1st ed.). Church World Service; 1999.
13. Yiblet Y, Adamu E. Nutritional composition and phytochemical evaluation of some selected wild edible plants in tach gaint district, northwestern Ethiopia. The Scientific World Journal. 2023;2023(1):6670648.
14. Abdull Razis AF, Ibrahim MD, Kntayya SB. Health benefits of *Moringa oleifera*. Asian Pacific Journal of Cancer Prevention. 2014;15(20):8571-8576.
15. Leone A, Spada A, Battezzati A, Schiraldi A, Aristil J, Bertoli S. Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. International Journal of Molecular Sciences. 2015;16(6):12791-12835.
16. Nguyen VT, Stewart J, Lopez M, Ioannou I, Allais F. Glucosinolates: Natural occurrence, biosynthesis, accessibility, isolation, structures, and biological activities. Molecules. 2020;25(19):4537.
17. Faizi S, Siddiqui BS, Saleem R, Siddiqui S, Aftab K. Isolation and structure elucidation of new nitrile and mustard oil glycosides from *Moringa oleifera* and their effect on blood pressure. Journal of Natural Products. 1994;57(9): 1256-1261.
18. Faizi S, Siddiqui B, Saleem R, Siddiqui S, Aftab K, Gilani A. Novel hypotensive agents, Niazimin A, Niazimin B, Niazicin A and Niazicin B from *Moringa oleifera*; isolation of first naturally occurring carbamates. Journal of the Chemical Society, Perkin Transactions I. 1994;20:3035-3640.
19. Tariq I, Yasmin A, Imran A, Akhtar H, Afzaal M, Azeem M, Pant R, Abid J, Islam F, Zahoor T, Kinki AB. A review on extraction technique and immune-boosting properties of *Moringa oleifera* Lam. International Journal of Food Properties. 2023;26(1):2493-508.
20. Oladeji OS, Odelade KA, Oloke JK. Phytochemical screening and antimicrobial investigation of *Moringa oleifera* leaf extracts. African Journal of Science, Technology, Innovation and Development. 2020;12(1):79-84.
21. Bagheri G, Martorell M, Ramírez-Alarcón K, Salehi B, Sharifi-Rad J. Phytochemical screening of *Moringa oleifera* leaf extracts and their antimicrobial activities. Cellular and Molecular Biology. 2020;66(1): 20-26.
22. Khan AS, Ali QZ. Moringa-The Miracle Tree: An overview of its nutritional and medicinal properties. Asian Journal of Biochemistry, Genetics and Molecular Biology. 2023;15(3):32-44.
23. Bhalla N, Ingle N, Patri SV, Haranath D. Phytochemical analysis of *Moringa oleifera* leaves extracts by GC-MS and free radical scavenging potency for industrial applications. Saudi Journal of Biological Sciences. 2021;28(12):6915-6928.
24. Mehmood A, Naveed K, Khan SU, Haq NU, Shokat MF, Iqbal M, Ali S, Nisar S, Ahmad J, Rehman AU, Ur S. Phytochemical screening, antioxidants properties and antibacterial efficacy of Moringa leaves. Journal of Xi'an Shiyou University, Natural Science Edition. 2022;18(10):59-70.
25. Makkar HP, Becker K. Nutrients and anti-quality factors in different morphological parts of the *Moringa oleifera* tree. The Journal of Agricultural Science. 1997;128(3):311-322.
26. Liaqat S, Mahmood S, Ahmad S, Kamran Z, Koutoulis KC. Replacement of canola meal with *Moringa oleifera* leaf powder affects performance and immune response in broilers. Journal of Applied Poultry Research. 2016;25(3):352-358.
27. Amad AA, Zentek J. The use of *Moringa oleifera* in ruminant feeding and its contribution to climate change mitigation. Frontiers in Animal Science. 2023; 4:1137562.
28. Alikwe PC, Omotosho MS. An evaluation of the proximate and phytochemical composition of *Moringa oleifera* leaf meal as potential feedstuff for non-ruminant livestock. Agrosearch. 2013; 13(1): 17-27.

29. Annongu A, Karim OR, Toye AA, Sola-Ojo FE, Kayode RM, Badmos AH, Alli OI, Adeyemi KD. Geo-assessment of chemical composition and nutritional evaluation of *Moringa oleifera* seeds in nutrition of broilers. Journal of Agricultural Science. 2014;6(4):119-124.
30. Oliveira JTA, Silveira SB, Vasconcelos IM, Cavada BS, Moreira RA. Compositional and nutritional attributes of seeds from the multiple purpose tree *Moringa oleifera* Lamarck. Journal of the Science of Food and Agriculture. 1999;79(6):815-820.
31. Soetan KO, Oyewole OE. The need for adequate processing to reduce the antinutritional factors in plants used as human foods and animal feeds: A review. African Journal of Food Science. 2009;3:223-232.
32. Shi HH, Liao JM, Li Y, Guo L, Wang C, Peng ZT. Feeding value of woody forage in pig production and treatment technology of anti-nutritional factors. Pratacultural Science. 2018;35:1556-1567.
33. Vitti DM, Nozella EF, Abdalla AL, Bueno IC, Silva Filho JC, Costa C, Bueno MS, Longo C, Vieira ME, Cabral Filho SL, Godoy PB. The effect of drying and urea treatment on nutritional and anti-nutritional components of browses collected during wet and dry seasons. Animal Feed Science and Technology. 2005;122:123-133.
34. Teixeira EM, Carvalho MR, Neves VA, Silva MA, Arantes-Pereira L. Chemical characteristics and fractionation of proteins from *Moringa oleifera* Lam. leaves. Food Chemistry. 2014;147:51-54.
35. Stevens CG, Ugese FD, Otitoju GT, Baiyeri KP. Proximate and anti-nutritional composition of leaves and seeds of *Moringa oleifera* in Nigeria: A comparative study. Agro-Science. 2015;14:9-17.
36. Salgado N, Silva MA, Figueira ME, Costa HS, Albuquerque TG. Oxalate in foods: extraction conditions, analytical methods, occurrence, and health implications. Foods. 2023;12(17):3201.
37. Moyo B, Masika PJ, Hugo A, Muchenje V. Nutritional characterization of Moringa (*Moringa oleifera* Lam.) leaf. African Journal of Biotechnology. 2011;10(60): 12925-12933.
38. Srivastava S, Mudgal V, Jain RK. Lignin - Its role and importance in animal nutrition. International Journal of Livestock Research. 2012;2:7-23.
39. Shih MC, Chang CM, Kang SM, Tsai ML. Effect of different parts (leaf, stem and stalk) and seasons (summer and winter) on the chemical compositions and antioxidant activity of *Moringa oleifera*. International Journal of Molecular Sciences. 2011;12(9):6077-6088.
40. Richards A, Chaurasia S. Antioxidant activity and reactive oxygen species (ROS) scavenging mechanism of eriodictyon californium, an Edible Herb of North America. Journal of Chemistry. 2022;2022(1):6980121.
41. El-Deep MH, Dawood MAO, Assar MH, Ijiri D, Ohtsuka A. Dietary *Moringa oleifera* improves growth performance, oxidative status, and immune related gene expression in broilers under normal and high temperature conditions. Journal of Thermal Biology. 2019;82:157-163.
42. Wang Y, Gao Y, Ding H, Liu S, Han X, Gui J, Liu D. Subcritical ethanol extraction of flavonoids from *Moringa oleifera* leaf and evaluation of antioxidant activity. Food Chemistry. 2017;218: 152-158.
43. Qwele K, Muchenje V, Oyedemi SO, Moyo B, Masika PJ. Effect of dietary mixtures of moringa (*Moringa oleifera*) leaves, broiler finisher and crushed maize on anti-oxidative potential and physico-chemical characteristics of breast meat from broilers. African Journal of Biotechnology. 2013;12(3):290-298.
44. Sreelatha S, Padma PR. Antioxidant activity and total phenolic content of *Moringa oleifera* leaves in two stages of maturity. Plant Foods for Human Nutrition. 2009;64:303-311.
45. Kumar V, Pandey N, Mohan N, Singh RP. Antibacterial and antioxidant activity of different extracts of *Moringa oleifera* leaves - an *In vitro* study. International Journal of Pharmaceutical Sciences Review and Research. 2012; 12(1):89-94.
46. Nobossé P, Fombang EN, Mbofung CMF. Effects of age and extraction solvent on phytochemical content and antioxidant activity of fresh *Moringa oleifera* L. leaves. Food Science and Nutrition. 2018;6:2188-2198.
47. Pakade V, Cukrowska E, Chimuka L. Comparison of antioxidant activity of *Moringa oleifera* and selected vegetables in South Africa. South African Journal of Science. 2013;109(3/4):1154-1158.
48. Mahajan SG, Mehta AA. Immunosuppressive activity of ethanolic

extract of seeds of *Moringa oleifera* Lam. in experimental immune inflammation. Journal of Ethnopharmacology. 2010;130(1):183-186.
49. Li C, Dong Z, Zhang B, Huang Q, Liu G, Fu X. Structural characterization and immune enhancement activity of a novel polysaccharide from *Moringa oleifera* leaves. Carbohydrate Polymers. 2020;234:115897.
50. Xiao X, Wang J, Meng C, Liang W, Wang T, Zhou B, Wang Y, Luo X, Gao L, Zhang L. *Moringa oleifera* Lam and its therapeutic effects in immune disorders. Frontiers in Pharmacology. 2020;11: 566783.
51. Rao SR, Raju MVLN, Prakash B, Rajkumar U, Reddy EPK. Effect of supplementing moringa (*Moringa oleifera*) leaf meal and pomegranate (*Punica granatum*) peel meal on performance, carcass attributes, immune and antioxidant responses in broiler chickens. Animal Production Science. 2018;59(2):288-294.
52. Mansour AT, Miao L, Espinosa C, García-Beltrán JM, Ceballos Francisco DC, Esteban MA. Effects of dietary inclusion of *Moringa oleifera* leaves on growth and some systemic and mucosal immune parameters of seabream. Fish Physiology and Biochemistry. 2018;44: 1223-1240.
53. Sudha P, Asdaq SM, Dhamingi SS, Chandrakala GK. Immunomodulatory activity of methanolic leaf extract of *Moringa oleifera* in animals. Indian Journal of Physiology and Pharmacology. 2010;54(2):133-140.
54. Nfambi J, Bbosa GS, Sembajwe LF, Gakunga J, Kasolo JN. Immunomodulatory activity of methanolic leaf extract of *Moringa oleifera* in Wistar albino rats. Journal of Basic and Clinical Physiology and Pharmacology. 2015; 26(6):603-611.
55. Dong Z, Li C, Huang Q, Zhang B, Fu X, Liu RH. Characterization of a novel polysaccharide from the leaves of *Moringa oleifera* and its immunostimulatory activity. Journal of Functional Foods. 2018;49: 391-400.
56. Rachmawati I, Rifa'i M. *In vitro* immunomodulatory activity of aqueous extract of *Moringa oleifera* Lam. leaf to the CD4+, CD8+ and B220+ cells in *Mus musculus*. The Journal of Experimental Life Science. 2014;4(1):15-20.
57. Obi A, Egwurugwu JN, Ojefa SO, Ohamaeme MC, Ekweogu CN, Ogunnaya FU. Immunomodulatory effects of hydromethanolic extract of *Moringa oleifera* leaf on male Wistar rats. Nigerian Journal of Experimental and Clinical Biosciences. 2018;6(1):26-32.
58. Ola-Fadunsin SD, Ademola IO. Direct effects of *Moringa oleifera* Lam (Moringaceae) acetone leaf extract on broiler chickens naturally infected with Eimeria species. Tropical Animal Health and Production. 2013; 45:1423-1428.
59. Manilal A, Sabu KR, Shewangizaw M, Aklilu A, Seid M, Merdekios B, Tsegaye B. *In vitro* antibacterial activity of medicinal plants against biofilm-forming methicillin-resistant Staphylococcus aureus: Efficacy of *Moringa stenopetala* and *Rosmarinus officinalis* extracts. Heliyon. 2020; 6(1):1-8.
60. Falowo AB, Mukumbo FE, Idamokoro EM, Lorenzo JM, Afolayan AJ, Muchenje V. Multi-functional application of *Moringa oleifera* Lam. in nutrition and animal food products: A review. Food Research International. 2018;106:317-334.
61. Putri GE, Rilda Y, Syukri S, Labanni A, Arief S. Highly antimicrobial activity of cerium oxide nanoparticles synthesized using *Moringa oleifera* leaf extract by a rapid green precipitation method. Journal of Materials Research and Technology. 2021;15:2355-2364.
62. Syeda AM, Riazunnisa K. Data on GC-MS analysis, *in vitro* antioxidant and antimicrobial activity of the *Catharanthus roseus* and *Moringa oleifera* leaf extracts. Data in Brief. 2020;29:105258.
63. Anzano A, de Falco B, Ammar M, Ricciardelli A, Grauso L, Sabbah M, Capparelli R, Lanzotti V. Chemical analysis and antimicrobial activity of *Moringa oleifera* Lam. leaves and seeds. Molecules. 2022;27(24):8920.
64. Jayawardana BC, Liyanage R, Lalantha N, Iddamalgoda S, Weththasinghe P. Antioxidant and antimicrobial activity of drumstick (*Moringa oleifera*) leaves in herbal chicken sausages. LWT-Food Science and Technology. 2015;64(2):1204-1208.
65. Mursyid M, Annisa RN, Zahran I, Langkong J, Kamaruddin I. Antimicrobial activity of moringa leaf (*Moringa oleifera* L.) extract against the growth of *Staphylococcus epidermidis*. IOP Conference Series: Earth and

Environmental Science. 2019;343(1): 012145.
66. Prabakaran M, Kim SH, Sasireka A, Chandrasekaran M, Chung IM. Polyphenol composition and antimicrobial activity of various solvent extracts from different plant parts of *Moringa oleifera*. Food Bioscience. 2018;26:23-29.
67. Dalukdeniya DA, De Silva KL, Rathnayaka RM. Antimicrobial activity of different extracts of leaves, bark and roots of *Moringa oleifera* (Lam). International Journal of Current Microbiology and Applied Sciences. 2016;5(7):687-691.
68. Xiong Y, Rajoka MSR, Mehwish HM, Zhang M, Liang N, Li C, He Z. Virucidal activity of Moringa A from *Moringa oleifera* seeds against Influenza A Viruses by regulating TFEB. International Immunopharmacology. 2021;95: 107561.
69. Liu HX, Liu QJ. Logistic role of carnitine shuttle system on radiation-induced L-carnitine and acylcarnitines alteration. International Journal of Radiation Biology. 2022;98(11):1595-1608.
70. Sankhalkar S, Vernekar V. Quantitative and qualitative analysis of phenolic and flavonoid content in *Moringa oleifera* Lam and *Ocimum tenuiflorum* L. Pharmacognosy Research. 2016;8(1):16-21.
71. Naw SW, Aini NS, Murtadlo AA, Tamam MB, Turista DD, Ullah ME. Phytochemical Screening of *Moringa oleifera* as Antioxidant and Anticancer through Chemoinformatics Approach. SAINSTEK International Journal on Applied Science, Advanced Technology and Informatics. 2023;2(01):7-11.
72. Khalafalla MM, Abdellatef E, Dafalla HM, Nassrallah AA, Aboul-Enein KM, Lightfoot DA, et al. Active principle from *Moringa oleifera* Lam leaves effective against two leukemias and a hepatocarcinoma. African Journal of Biotechnology. 2010;9(49): 8467-8471.
73. Jung IL. Soluble extract from *Moringa oleifera* leaves with a new anticancer activity. PLoS One. 2014;9(4): e95492.
74. Krishnamurthy PT, Vardarajalu A, Wadhwani A, Patel V. Identification and characterization of a potent anticancer fraction from the leaf extracts of *Moringa oleifera* L. Indian Journal of Experimental Biology. 2015;53:98-103.
75. Edwinanto L, Septiadi E, Nurfazriah LR, Anastasya KS, Pranata N. Phytochemical features of *Moringa oleifera* leaves as anticancer. Journal of Medicine and Health. 2018;2(1):680-688.
76. Jung IL, Lee JH, Kang SC. A potential oral anticancer drug candidate, *Moringa oleifera* leaf extract, induces the apoptosis of human hepatocellular carcinoma cells. Oncology Letters. 2015;10(3): 1597-1604.
77. Mumtaz MZ, Kausar F, Hassan M, Javaid S, Malik A. Anticancer activities of phenolic compounds from *Moringa oleifera* leaves: *In vitro* and *In silico* mechanistic study. Beni-Suef University Journal of Basic and Applied Sciences. 2021;10:1-11.
78. Barhoi D, Upadhaya P, Barbhuiya SN, Giri A, Giri S. Aqueous extract of *Moringa oleifera* exhibit potential anticancer activity and can be used as a possible cancer therapeutic agent: A study involving *In vitro* and *In vivo* approach. Journal of the American College of Nutrition. 2021; 40(1):70-85.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/120062