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MORINGA OLEIFERA: EXPLORING THE NUTRITIONAL AND MEDICINAL POTENTIAL

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ABSTRACT

For both its medicinal and non-medicinal uses, the *Moringa oleifera* tree sometimes called the "tree of life" or the "miracle tree" is a significant herbal plant. Wounds, discomfort, ulcers, inflammation, cancer, heart disease and liver illness are all traditionally treated with this herb. Pharmacological investigations have shown that plant extracts have anti-inflammatory, hepatoprotective and cardioprotective properties. It was discovered that all parts of the plant contain bioactive components. Alkaloids, flavonoids, anthraquinones, vitamins, glycosides and terpenes are among the over a hundred chemicals isolated from *Moringa oleifera*. Furthermore, the plant contains new isomers with powerful antioxidant, anticancer, antihypertensive, hepatoprotective and nutritional properties; these include muramoside A and B, niazimin A and B. This review acknowledges the many uses of Moringa, both conventional and alternative, as well as its pharmacological properties, nutrition and other uses. Hence, additional research is needed to delve into the plant's mechanism of action in order to discover and separate the active or synergistic chemicals responsible for its medicinal properties.

KEYWORDS

Moringa Oleifera, Pharmacological Activity and Phytochemistry.

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INTRODUCTION

A native of the sub-Himalayan plains of Afghanistan and India, *Moringa oleifera* is the most extensively cultivated species of the monogeneric family Moringaceae. Many tropical regions have become naturalised habitats for this fast-growing tree, which has many other names and was used by ancient civilisations such as the Romans, Greeks and Egyptians. It is also called the horseradish tree, drumstick tree, benzolive tree, kelor, marango, mlonge, moonga, mulangay, nebeday, saijhan,

sajna, or Ben oil tree. Despite its low-quality timber, this perennial softwood tree has been touted for generations for its traditional medicinal and industrial applications. It is cultivated in many parts of the world, including India, Ethiopia, the Philippines, Sudan, tropical Asia, the Americas, the Caribbean, Florida and the Pacific Islands. It is also a major crop in India, the Philippines and Sudan. People have been eating Moringa for a long time since it is edible in every aspect. As per Fuglie's findings[1]. Moringa has a wide range of applications: biomass production for alley cropping, animal feed (leaves and treated seed-cake), biogas (leaves), blue dye (wood), fencing (living trees), fertiliser (seed-cake), foliar nutrients (leaf juice), green manure (leaves), gum (tree trunks), honey (flower nectar), medicine (all plant parts), ornamental plantings, biopesticide (leaves mixed with soil to prevent seedling damping off), pulp (wood), rope (bark), tanning hides (bark and gum) and water purification (powdered seeds). Moringa seed oil, or Ben oil, is a pleasant, non-sticking, non-drying oil that can withstand rancidity; it yields 30-40% by weight. It has a long history of usage, including in salad dressings, as a fine machine lubricant and in the creation of fragrance and hair care items[2]. Powdered Moringa seeds are most commonly used in Western countries to filter water by flocculating impurities[3-5]. However, the seeds have many other culinary and medicinal purposes, including green eating, roasting, powdering and infusing tea or curries[4]. Some have recently argued that this tree provides an excellent native supply of easily digestible protein, calcium, iron, vitamin C, and carotenoids that could be useful in many of the world's so-called "developing" nations, where malnutrition is a big problem. *Moringa oleifera*, the most common species of the Monogeneric Moringaceae family, hails from the sub-Himalayan areas of Bangladesh, Afghanistan, Pakistan and India. Many communities rely on this versatile tree for survival[6]. Commercial cultivation takes place in a number of nations and areas around the world, including Asia, Africa, Hawaii, Mexico and South, Central America. Some people call it the "horseradish tree" due to the earthy flavour of its roots, while others call it the "drumstick tree" because, when the seeds are immature, the pods resemble drumsticks. One more name for this plant: "ben oil tree"[7] because of the oil it produces from its seeds. The young seed pods are eaten by certain locals, and fresh leaves are staples in their cuisine due to the abundance of nutrients they contain. Moringa oleifera is one name for this plant; however, its many bioactive substances have earned it additional names, such as the "miracle tree" in the realms of traditional medicine and nutrition[8]. Rapidly expanding and drought-tolerant, deciduous trees and shrubs can reach heights of about 12 meters. Species such as Morelia arborea, Morelia arivae, Morelia concanensis, Morelia drouhardii, Morelia ruspolian, Morelia longituba, Morelia stenoprtala, Morelia peregrina, Morelia pygmaea, Morelia borziana, Morelia hildebrandtii and Morelia ovalifolia are among those included. The presence of naturally occurring chemicals in these plants gives them therapeutic potential. One tree in particular, the Moringa oleifera, stands out in this region due to its many beneficial effects on human health. A little evergreen or deciduous tree, *Moringa oleifera* typically grows to a height of 10-12m. It grows quickly and is known for its aromatic leaves. The tripinnate leaves of a tree are topped by a spreading crown of sparse, drooping branches and thick, corky, white bark[9].

The global nutritional profile is comprised of proteins, vitamins, minerals and carotenoids, which are present in all parts of the plant. The utilisation of Moringa plants has been shown to alleviate malnutrition in newborns and nursing mothers[10]. The leaf is a rich source of protein, minerals, vitamins A and C and other essential nutrients. Furthermore, Moringa contains around 46 antioxidants, making it a very powerful natural source of these compounds. The destruction of free radicals' harmful effects on the human body is an important function of antioxidants. The active components of *Moringa oleifera* include antioxidant flavonoids, tannins, saponins, alkaloids, phenolics and triterpenoids, which have antibacterial

characteristics[11]. The nutritious content of these plant leaves is said to be retained for several months after they are dried, roasted, or consumed fresh. The dry season is a time when other foods are scarce. As other food sources have either vanished or drastically reduced, *Moringa oleifera* blooms at the end of a long dry period and can thrive into luxuriant foliage, suggesting that this plant could be used as a food crop for humans[12]. According to popular belief, the native medicines come from a single plant family that has a long history of usage in traditional medicine. In addition, this plant has a wide variety of medicinal uses, including those of the root, flower seed oil, and bark of the leaves[13,14]. Healing qualities of *Moringa oleifera* include helping with hypertension, anxiety, and diarrhoea, as well as acting as a natural diuretic[15,16]. Dysentery and colitis are two other conditions it helps alleviate[17,18]. Inflammatory conditions, including bronchitis, headaches, and glandular swelling, can be alleviated topically using moringa leaves[19]. In addition to alleviating joint discomfort, the pods are beneficial to the liver[20]. Herbalists have found that the roots alleviate a variety of conditions, including kidney stones[21], liver problems[22], inflammation[23], ulcers[24] and earaches and toothaches[25]. As a fever remedy and to induce abortions, the Indians utilise the gum extracted from this plant[26,27]. This plant's seeds are used to cure cancer, bladder and prostate issues, and have laxative properties[28]. The seeds may alleviate arthritic pain by modifying oxidative stress and decreasing inflammation[29]. In addition to improving the health of the general population, preparations created from the plant's leaves aid nursing mothers and malnourished infants. These compounds stimulate the production of oestrogen, which stimulates the development of mammalian tissues and ultimately leads to milk secretion. When it comes to combating stunted growth in youngsters younger than three, they play a crucial role. Those suffering from sleeplessness[30] and wound care[31] can also benefit from the leaves. These days, moringa is a mainstay in many beauty products. Ancient Egyptians also used it to produce ointments for the skin[32]. There has been an assessment of the ability of *Moringa oleifera* plants to clean up wastewater from aquaculture. There are potential economic, health and environmental benefits to using it instead of or in addition to standard coagulants because studies have shown that it may simultaneously remove water cloudiness, suspended particles and microbes[33]. In comparison to other typical meals, moringa has an exceptionally high concentration of vitamins and minerals, earning it widespread acclaim for its superior nutritional profile. It has seven times the vitamin C of oranges, ten times the vitamin A of carrots, seventeen times the calcium of milk, nine times the protein of yoghurt, fifteen times the potassium of bananas and twenty-five times the iron of spinach, according to[34]. Particularly important for human growth and development is the mineral calcium, which is abundant in this plant. As an example, the calcium content of eight ounces of milk is around 300 to 400mg, but this plant's leaves provide 1000mg and Moringa powder can deliver more than 4000mg of calcium, an essential component of bone density. Moringa powder can be used to treat anaemia instead of iron tablets. Beef has just 2 milligrammes of iron, whereas powdered Moringa leaves have 28 milligrammes. Nutrition is a source of zinc, a vital element for sperm cell growth and development as well as nucleic acid production. In a healthy diet, the recommended daily requirement for zinc is 25.5-31.03mg/kg, which is the quantity of this element discovered in *Moringa oleifera* leaves[35]. Many people believe that tree bark can alleviate a wide range of medical issues, from ulcers and toothaches to hypertension. Furthermore, it has been found that the roots can alleviate toothaches, helminthiasis and paralysis. Aphrodisiac chemicals, ulcer cures and spleen enlargement are all made from the flowers[19,36,37]. In every tropical and semitropical region of the world, *Moringa oleifera* thrives when the temperature is between 25 and 35 degrees Celsius. It needs 250-3000mm of net precipitation per year and soil that is loamy or sandy and has a pH between slightly acidic and moderately alkaline[38,39]. Nutrient distribution at different places is different for *Moringa oleifera*. Somewhat different nutritional

components are found in plants grown in India and Nigeria[40]. Recent pharmacological studies have shown that various Moringa extracts have a wide range of medicinal uses, such as reducing inflammation, improving fertility, mending wounds and fighting cancer. In this review, we will compile the most recent information on the pharmacological effects, worldwide studies, toxicological, phytochemistry and general characteristics of *Moringa oleifera*. Traditional Herbal Remedies Using *Moringa oleifera* According to Traditional Ayurvedic Medicine, different parts of *Moringa oleifera* have different physiological properties and therapeutic uses, which are believed to have different effects on different people depending on their body type and whether they are Vata or Kapha. *Moringa oleifera* has a number of useful characteristics, including acridity and bitterness, thermogenic capabilities, aid in digestion, carminative and anthelmintic actions, constipation, pain relief and anti-inflammatory activities. Furthermore, it helps with menstruation, makes you sweat, makes more pee, is good for your eyes, makes you feel warm, helps with expectoration, raises your haemoglobin levels, dissolves stones in your urinary tract, is an antidote, stimulates your body's processes and makes you blister. Dyspepsia, anorexia, helminthiasis, diarrhoea, colic, bloating, otalgia, paralysis, inflammation, menstrual irregularities, dysmenorrhea, fever, dysuria, urolithiasis, ascites, ophthalmic ailments, cough, bronchial asthma, cardiac disorders, abscesses, and otolaryngological infections are all conditions that it relieves when the Vata and Kapha constitutions are misaligned. Thermogenic, bitter, abortifacient, anti-fungal and stimulating to cardiovascular and circulatory systems; it also has caustic and bitter tastes. Ascites can be alleviated by addressing dermatophyte infections and Vata-Kapha imbalances[41,42]. In Figure No.1, we can see the nutritional and medicinal benefits of *Moringa oleifera*.

The cooling potency and bitter taste of *Moringa oleifera* are its defining characteristics. The plant also has anti-inflammatory and analgesic benefits, is an anthelmintic, promotes eye health, and is a rich source of vitamins A and C. It helps with scurvy, wounds, tumours, inflammations, Vata-Kapha imbalances and helminthic infestations. In addition to its cooling impact, analgesic and anti-inflammatory properties, purgative capabilities, ability to reduce fever, and improvement of ocular health, it has caustic and bitter tastes. Ophthalmic diseases, inflammation, intermittent fever, and neuralgic pain are among the conditions for which it is suggested[29]. Although it is not included in traditional TCM books and is not widely recognised as a conventional Chinese herb, the Chinese herbal medicine compendium does describe the Himalayan *Moringa oleifera*. However, a Southern Yunnan form has been found that possesses seeds without wings. Originating in India, *Moringa oleifera* was brought to China in the 1960s and widely grown as an ornamental plant. It spread to several regions, including Guangdong, Taiwan and Yunnan, where it is called "lamu" in Mandarin. Although its nutritional value is acknowledged, traditional Chinese medicine (TCM) emphasises the gustatory and thermal properties of herbs or meals to ascertain their suitability for individuals according to their constitution and thermal tendencies. Most people eat *Moringa oleifera* for its leaves, which have a bittersweet flavour and a cooling effect that goes down. Due to its cooling properties, caution should be used around people who have cold constitutions or yang deficiency, which manifests as a lack of warmth, drowsiness and other symptoms of cold syndrome[43].

Nutrition

When it comes to fighting malnutrition, moringa trees have a long history of use, particularly with nursing mothers and infants. Trees for Life, Church World Service and Educational Concerns for Hunger Organisation are three NGOs that have promoted Moringa as "natural nutrition for the tropics." The nutritious content of the leaves is said to remain intact whether consumed raw, cooked, or stored as a powder for months at room temperature. Because it is in full leaf towards the end of the dry season-a time when other foods are usually scarce-

moringa is particularly promise as a food source in the tropics. The nutritional benefits of Moringa have been extensively documented in numerous articles published in scholarly and popular journals. Trees for Life made the often-repeated claim a long time ago that "ounce-for-ounce, Moringa leaves contain more Vitamin A than carrots, more calcium than milk, more iron than spinach, more Vitamin C than oranges, and more potassium than bananas" and that the protein quality of Moringa leaves is comparable to that of eggs and milk. Any reader familiar with Moringa will recognise this claim. Lowell Fuglie, who has recorded oral histories in Senegal and other parts of West Africa, reports (and has captured on camera) numerous cases of nutritional rescue that have been linked to Moringa, which these readers will also recognise[1,44]. In reality, the nutritional benefits of Moringa are already widely recognised, therefore there is no doubt that consuming Moringa leaf powder in times of impending starvation will result in major health benefits. Still, it's obvious that there's a lot of value in the results of well supervised and recorded clinical trials. There is a strong cultural and traditional tendency in many tropical communities to use plants for both culinary and medicinal purposes, making it difficult to classify plants according to their intended use (e.g., bark, fruit, leaves, nuts, seeds, tubers, roots, flowers)[45]. While the more well-known uses of Moringa in agro-forestry and water purification are mostly ignored in this review, the references to its nutritional and therapeutic properties are included. For further information on Moringa's nutritional properties, interested readers can refer to the reviews written by the NGOs listed above (especially the references)[1,46,47].

Medicinal Uses and Pharmacological Properties

The Ayurvedic and Unani medical systems have long acknowledged the many therapeutic benefits of *Moringa oleifera*[48]. Below is a list of the pharmacological properties and therapeutic qualities attributed to different sections of Moringa.

Antihypertensive, diuretic and cholesterol lowering activities

Cardiovascular diseases can greatly benefit from this plant's diuretic, lipid- and blood pressure-lowering components. The Wealth of India (1962) and others have noted that drinking juice from moringa leaves can help stabilise blood pressure[49]. Isolated from Moringa leaves, the substances responsible for decreasing blood pressure include nitrile, mustard oil glycosides and thiocarbamate glycosides[50-52]. The majority of these substances are extremely uncommon completely acetylated glycosides[52]. They typically contain thiocarbamate, carbamate, or nitrile groups. Using bioassay-guided fractionation, four pure compounds were isolated from the active ethanol extract of Moringa leaves: Niazinin A, niazinin B, niazimicin and niazinin A + B. These compounds exhibited a potential calcium antagonist activity in decreasing blood pressure in rats[53]. Pods of *Moringa oleifera* were fractionated using activity-directed methods and the hypotensive principles known as thiocarbamate and isothiocyanate glycosides were isolated[52]. The hypotensive activity of methyl phydroxybenzoate and β-sitosterol in Moringa oleifera pods has been investigated and found to be promising[54]. Additionally, diuretic activity has been discovered in Moringa roots, leaves, flowers, gum and the water infusion of seeds[55,56]. These diuretic components are likely to work together to lower blood pressure as a whole. The presence of a bioactive phytoconstituent, specifically β-sitosterol, may explain why the crude extract of Moringa leaves significantly lowers cholesterol levels in the serum of rats on a high-fat diet[57]. Research on hypercholesteremic rabbits has shown that eating moringa fruit can lower blood levels of cholesterol, phospholipids, triglycerides, LDL cholesterol, VLDL cholesterol, the atherogenic index lipid and the lipid profiles of the liver, heart and aorta. Additionally, it has been observed to increase the excretion of faecal cholesterol[58].

Antispasmodic, antiulcer and hepatoprotective activities

Antispasmodic activity has been reported in the roots of *Moringa oleifera*[59]. Moringa leaves have been the subject of extensive pharmacological research, and it has been determined that the ethanol extract and its constituents exhibit antispasmodic effects, potentially through calcium channel blockade[59,60]. The traditional use of the ethanol extract of *Moringa oleifera* leaves in diarrhea is based on the presence of 4-[α-[L-rhamnosyloxy] benzyl]-o-methyl thiocarbamate [trans], which has been ascribed to its antispasmodic activity[59]. Additionally, the traditional applications of this plant in the treatment of gastrointestinal motility disorders are established by the pharmacological premise of spasmolytic activity shown by various constituents[61]. In rats, the methanol fraction of *Moringa oleifera* leaf extract exhibited hepatoprotective and antiulcerogenic properties. The antiulcer component of this plant is widely distributed, as evidenced by the antiulcer effect that aqueous leaf extracts also demonstrated[62]. It has also been observed that moringa roots contain hepatoprotective properties. The presence of quercetin, a well-known flavonoid with hepatoprotective activity, may be the reason for the notable hepatoprotective effect observed in the aqueous and alcohol extracts of Moringa flowers[63].

Antibacterial and antifungal activities

According to reports, moringa roots are abundant in antimicrobial compounds and exhibit antibacterial action[64]. According to reports, they contain pterygospermin, an active antibiotic principle with potent antibacterial and fungicidal properties. The antibacterial and fungicidal properties of its flowers are attributed to a similar chemical[65]. The presence of 4-α-L-rhamnosyloxybenzyl isothiocyanate is responsible for the root extract's antimicrobial activity[66]. The antibacterial and antifungal properties were found to be attributed to the aglycone of deoxy-niazimicine [N-benzyl, Sethyl thioformate], which was separated from the chloroform fraction of an ethanol extract of the root bark[67]. It has been demonstrated that the bark extract has antifungal properties[68] and that the stem bark juice has antibacterial properties against Staphylococcus aureus[69]. It was discovered that the fresh leaf juice inhibited the growth of human-pathogenic bacteria [Pseudomonas aeruginosa and Staphylococcus aureus[70].

Antitumor and anticancer activities

According to Makonnen *et al*, 1997, Moringa leaves may have antitumor properties. An *in vitro* assay was used to test the potential antitumor promoting activity of OEthyl-4[α-L-rhamnosyloxy] benzyl carbamate, 4[α-L-rhamnosyloxy]-benzyl isothiocyanate, niazimicin and 3-O-[6′-O-oleoylα-D-glucopyranosyl]-β-sitosterol. The results showed significant inhibitory effects on Epstein–Barr virus-early antigen. In chemical carcinogenesis, niazimicin has been suggested as a strong chemopreventive agent[71]. Additionally, the seed extracts have been shown to have an impact on antioxidant parameters, skin papillomagenesis in mice and hepatic carcinogen-metabolizing enzymes[72]. In mice, neomycin and a seed ointment both inhibited Staphylococcus aureus pyodermia[73]. Niaziminin, a thiocarbamate derived from *Moringa oleifera* leaves, has been shown to prevent Epstein-Barr virus activation triggered by tumor promoters. The isothiocyano group is a crucial structural component for activity, as evidenced by the fact that naturally occurring 4-[[4′-O-acetyl- α-irhamnosyloxy benzyl] substantially suppressed tumor-promoter driven Epstein-Barr virus activation[74].

Other diverse activities

Other varied actions of Moringa oleifera have also been documented. Aqueous leaf extracts have an antioxidant effect, control thyroid hormone and can be utilized to treat hyperthyroidism[62,75,76.] Mice's bone marrow chromosomes were significantly protected from radiation by a methanol preparation of *Moringa oleifera* leaves[65]. Thyroid hormone level can be effectively regulated by moringa leaves[76]. M. oleifera leaf may be useful as a preventative or therapeutic anti-HSV [Herpes simplex virus type 1] medication and may be effective against the acyclovir-resistant version,

according to a recent report[77]. With their anthelmintic properties, the flowers and leaves are also thought to have great medicinal value[78]. It has been demonstrated that giving rabbits leaf juice lowers their blood glucose levels[79]. Scientific proof that Moringa oleifera is a significant source of naturally occurring phytochemicals is bringing the plant to the fore and laying the groundwork for future promising advancements. Additionally, 212 different commercially available health formulations contain different parts of *Moringa oleifera*. Certain protein fractions found in moringa seeds are beneficial for skin and hair health. Oil cake has yielded two novel active ingredients for the cosmetics sector. Peptides from Moringa seeds make up Purisoft®. It prevents premature skin aging and shields the human skin from environmental factors. With its dual properties of anti-pollution and hair conditioning/strengthening, the seed extract of M. oleifera is a widely recognized and inventive hair care treatment.

Water purifying attributes of m. Oleifera seed

Moringa seeds as coagulant

To date, moringa seeds have been identified as one of the most effective natural coagulants[80]. As an alternative to synthetic coagulants, crushed seeds can be used effectively[81]. Traditional beliefs in Sudanese medicine hold that alum can induce gastrointestinal problems and Alzheimer's disease, thus rural women treat the extremely murky Nile water with seed crude extract instead[82-85]. When it comes to highly turbid water, moringa seeds work just like alum in terms of coagulation[82]. The initial turbidity determines the coagulation efficacy of *Moringa oleifera*; reports indicate that M. oleifera can reduce turbidity by 92% to 99%[82]. Moringa seeds can withstand surface and groundwaters that are moderately to highly alkaline because to their softening qualities, pH correcting abilities and natural buffering capacity. An additional function for Moringa seeds is as an antibacterial for water purification[86]. The seed is thought to be a naturally occurring organic polymer[87]. These dimeric proteins, which have a molecular weight of around 1300 Da and an iso-electric point ranging from 10 to 11, are the active components[80]. You can dissolve this protein powder in water with no problems at all. Water or a salt solution (often NaCl) can be used to extract the coagulant protein from Moringa. The coagulant protein yields vastly different amounts and levels of effectiveness when extracted using salt and water, respectively. The salt extract outperforms the water extract in terms of coagulation performance when presented in its crudest form[88]. The salting-in process, which results in an increase in the concentration of soluble proteins, could account for this. It may not be practical, either financially or technically, to purify the *Moringa oleifera* coagulant protein from the unrefined salt extract. There are a variety of theories regarding how the coagulant protein of Myxomyxomyces oleifera really coagulates. It has been characterised as bridging between particles[89] and adsorption and charge neutralisation[80,90]. High molecular weight polyelectrolytes are primarily characterised by flocculation caused by inter-particle bridging. The clotting mechanism most likely isn't a bridging effect because the *Moringa oleifera* coagulant protein is so little [6.5-13 k Da]. Adsorption and charge neutralisation could be the key destabilisation mechanisms, given the tiny size and large positive charge ($pI \geq 10$).

Microbial elimination with Moringa seeds

According to research, a recombinant protein in moringa seeds has the ability to flocculate both Gram-positive and Gram-negative bacterial cells, demonstrating the seeds' antimicrobial qualities[91-93]. In this situation, bacteria can be eliminated by settling in a similar way to how colloids are eliminated in water that has been appropriately coagulated and flocculated[94]. However, the seeds may also directly affect microorganisms, which would inhibit their growth. It is believed that antimicrobial peptides work by either blocking vital enzymes or by rupturing the cell membrane[95-97.] Revealed that bacteriophage replication could be inhibited by Moringa seeds. 4[α-Lrhamnosyloxy] benzyl isothiocynate is the compound responsible for the seeds' antimicrobial properties[98].

Moringa seeds as biosorbent

Cadmium [Cd] could be extracted from aqueous media using moringa seeds, a less costly biosorbent[99]. The aqueous solution of Moringa seed is a heterogeneous complex mixture having numerous functional groups, particularly low molecular weight organic acids [amino Kumar *et al*. International Journal of Phytomedicine 2 (2010) 210-216 acids]. It has been discovered that these amino acids make up a physiologically active class of binding agents that function even at low concentrations. Their capacity to interact with metal ions is likely to enhance the sorption of metal ions[100]. A negatively charged environment is produced by the proteineous amino acids, which also have a number of structurally related pH-dependent characteristics and are crucial for metal binding[99].

Phytochemical Composition of *Moringa oleifera*

Understanding the different features of *Moringa oleifera* and its derivatives has been thoroughly explored through research. The genus Moringa has been found to have over 90 different chemicals with possible medicinal uses. This classification encompasses a wide range of substances, including proteins, amino acids[101], phenolic acids[102], carotenoids[103], alkaloids[104], glucosinolates[105], flavonoids[8], sterols[106], terpenes[107], tannins and saponins[108], fatty acids[109], glycosides and polysaccharides[110]. Numerous bioactive substances, mostly secondary metabolites, have been discovered by analysis of the chemical makeup of *Moringa oleifera* numerous constituents. These include glucosinolates, phenolic acids like gallic, ellagic, chlorogenic, ferulic acids and flavonoids like kaempferol, vanillin, and quercetin. These substances are rich in antimicrobial, medicinal and nutritional qualities. However, variables including temperature, sun exposure, soil composition and geographic location can affect how much of these chemicals are present in *Moringa oleifera* isolates.

Amino Acids

Proteins, lipids, carbs and dietary fibers are among the more than 90 nutrient-dense chemical components found in *Moringa oleifera*. Proteins make up around 25% of the dry weight of *Moringa oleifera*, making them the most abundant nutrient among the numerous found in different parts of the plant[111]. There are known to be at least 19 different amino acids in this plant, including both essential and non-essential ones. Lipids make up around 30% of the dry weight of seeds, mostly oleic acid, saturated palmitic acid and stearic acid[112]. The main constituents of *Moringa oleifera* leaves are linolenic acid, palmitic acid and lipid molecules. Moreover, dried leaves have a high nutritional content, which suggests that the plant is a valuable food source[113].

Vitamins and Minerals

Numerous vitamins and minerals can be found in the whole *Moringa oleifera* plant. Calcium, one of the numerous minerals present in Moringa, is regarded as one of the most important for human growth and development. Between 11,300 and 23,000 International Units of vitamin A are estimated to be present in fresh *Moringa oleifera* leaves. Vision, development, immunologic competency, cell division, proliferation of cells and a process known as apoptosis, maintenance of epidermal tissue, and cognitive function are only a few of the physiological processes that depend on vitamin A[114]. The nutritional data for *Moringa oleifera* is shown in Table No.1.

Flavonoids

This text highlights a wide range of bioactive compounds that may have potential medical benefits and are present in Moringa oleifera seeds and leaves. Flavonoids such myricetin, rutin, kaempferol, quercetin, isorhamnetin, procyanidin and catechin are abundant in *Moringa oleifera* leaves and seeds. Furthermore, leaves contain detectable levels of lutein pigments[8]. *Moringa oleifera* active ingredients are primarily responsible for its purported medicinal benefits. The leaves contained more than 35 chemicals, including β-sitosterol, pregna-7-dien-3-ol-20-one, palmitoyl chloride, cis-vaccenic acid, 5-O-acetyl-thio-octyl, tetradecanoic acid and α-l-rhamnofuranoside, according to a gas chromatography–mass spectrometry analysis[110,111,115].

Phenolic Acids

Moringa oleifera contains gallic, protocatechuic, caffeic, epicatechin, p-coumaric, o-coumaric, vanillin, syringic, cinnamic, gentisic and ferulic acids. These substances are derived mostly from the naturally occurring hydroxycinnamic acid and hydroxybenzoic acid present in plants, and they are part of a broader class of phenolic chemicals. Food-based phenolic acids have drawn more attention recently because of their effects on personal health. These compounds' positive benefits, such as their anti-mutagenic, anti-inflammatory, anti-cancer and antioxidant qualities, have been well investigated. In addition to being widely distributed in fruits and vegetables, they have also been found in significant quantities in the leaves of *Moringa oleifera*, a plant that is well-known for its nutritional benefits[116].

Gallic acid, which had a mass of about 1.034mg/g of dry weight, was the most abundant of these phenolic acids in dried *Moringa oleifera* leaves. It's interesting to note that prior research has only found trace amounts of gallic acid. Furthermore, different amounts of caffeic acid and chlorogenic acid were detected, ranging from 0.018 to 0.489mg/g and 0.409mg/g, respectively[106].

Alkaloids

Alkaloids are a class of basic nitrogenous chemicals. Primary, secondary, and tertiary amines are produced by the combination of these nitrogen atoms. Their therapeutic qualities make them very appealing. Alkaloids, such as aurnatiamide acetate that was extracted from the roots and two newly identified alkaloids, marumoside A and B, have been discovered in *Moringa oleifera* leaves[104,108]. Moreover, the stem of the plant contains moringinine and moringin-type alkaloids[109].

Glucomoringin, or 4-O-(L-rhamnopyranosyloxy)-benzyl glucosinolate, is the most prevalent glucosinolate in *Moringa oleifera*[105]. In the species, glucosesinolates are broadly dispersed. The sterol isolate sitosterol is found in the seeds and leaves, whereas -sitosterol-3-O-D-galactopyranoside, another sterol glycoside, is present in the bark[8,105]. Many terpenes and diterpenes are also found in the leaves; phytol is a notable diterpene alcohol that is widely disseminated because of its association with chlorophyll. In comparison to the trace amounts of terpenes and their derivatives, such as farnsylacetone, linalool oxide, isolongifolene, ionone and ionene, hexahydro-farnesyl acetone is more common[106].

Tannins, Fatty Acids and Sterols

Tanning agents are naturally occurring polyphenols found in fruits, vegetables, seeds and other plant parts. Tannins are widely used in the wine industry as fining agents, color stabilizers and to balance the complexity of wines by inhibiting the enzymes in infected fruits. The tannin content of the Moringa tree varies, with dried leaves having the maximum concentration (20.7mg/g). Tannins are also present in trace amounts in seeds. The total tannin concentration of the seeds is 0.890 ± 0.020mg GAE/g of dry matter, which is a percentage of their overall antioxidant content. Major fatty acids such arachidic, octacosanoic, oleic, and palmitic acids are found in *Moringa oleifera* seeds. Paullinic acid, behenic acid, linolenic acid and stearic acid are among the other fatty acids found in this plant. The sterol isolate β-sitosterol is found in *Moringa oleifera* seeds and leaves. Another type of sterol glycoside, β-sitosterol-3-O-β-D-galactopyranoside, has been extracted from *Moringa oleifera* bark. These sterols and tannins have a variety of pharmacological effects[106]. In Table No.2, further nutritional data is displayed.

Nutritional information for *Moringa oleifera*

Tannins and saponins, which regulate a range of pharmacological activities, are commonly found in *Moringa oleifera* seed oil extract[107]. Arachidic, stearic, octacosanoic, palmitic, oleic, linolenic, behenic and paullinic acids are among the many fatty acids found in *Moringa oleifera* seeds[108]. The ethanolic extract of *Moringa oleifera* yielded two glycosides, niazirin and niazirinin[109]. Gum exudates contain a variety of polysaccharides, such as glucuronic acid, D-xylose, D-galactose, L-rhamnose, L-arabinose and D-mannose[110].

Extraction Methods and Analytical Techniques for Phytochemical Analysis

The use of natural materials is still an area of great interest because of its many benefits. Numerous uses for *Moringa oleifera* have been shown in the food, cosmetic, pharmaceutical and other industries. The components of Moringa oleifera, including seed extract, seed oil and leaf extract, are examined in this review along with information on their phytochemical compositions, isolation processes, processing methods, and contemporary applications. Phytochemicals such as flavonoids, carotenoids, phenolics, tannins, chlorophylls, saponins, tocopherols and sterols are found in significant amounts in *Moringa oleifera*[127]. *Moringa oleifera's* strong antioxidant activity offers a number of medicinal advantages in various plant sections, including as anti-obesity, anti-hypertensive, anti-cancer, anti-diabetic, anti-arthritic, anti-inflammatory and wound-healing qualities. Furthermore, *Moringa oleifera's* numerous components have significant nutritional value and antimicrobial qualities that make them appropriate for a variety of uses in the production of pharmaceuticals, skincare ingredients, functional food products, biodiesel, and water treatment procedures.

Extraction and Processing

Conventional Methods

Solid-liquid extraction is the most straightforward method of chemical extraction. It entails moving solutes from a solid into a solvent and then separating the solvent to produce the desired extract. In one extraction technique, powdered moringa leaves were combined with a 70% ethanol solution and allowed to sit at room temperature for 48 hours. The mixture was periodically agitated to facilitate the extraction process. Others, on the other hand, employed a cold maceration technique in which 70% ethanol was used to soak Moringa leaves for five days at room temperature. A significantly higher yield of 14% was obtained by another extraction method that used methanol as a solvent with a solid-to-solvent ratio of 1:15 and shook at 500rpm for five hours at 30°C, proving the efficiency and affordability of the maceration technique[126]. Other solvent combinations were also examined, including macerating Moringa leaves in an ethanol–water mixture (7:3) for two days at room temperature and extracting them for seventy-two hours in an 80:20 percent ethanol–water solution. The final product can be obtained by drying the extract in air or in an oven, or by filtering and evaporating the solvent under low pressure after extraction. Acetone yielded a percentage of 14.30%, ethanol yielded 14.50%, water yielded 5.50% and ethanol and water yielded 17.50%. It's interesting to note that clean water did not completely eliminate Moringa leaves. Therefore, to facilitate the extraction of the different polar compounds present in the leaves, a combination of solvents may be more effective. In a different technique, Soxhlet extraction was carried out with a solid-to-solvent ratio of 1:10 and n-hexane solvent for nine hours at 70°C. The Soxhlet apparatus is an efficient way to extract Moringa leaves using an organic solvent. The yield of *Moringa oleifera* leaf extract was 10.7% when 95% ethanol was used in a Soxhlet extraction apparatus over an 8-hour period. Methanol is the preferred solvent for Soxhlet extraction and other researchers have used it to achieve a higher yield (18.56%). Although partial vacuum drying is typically used to evaporate the solvent in order to obtain the final extract, the high temperature of the extraction process may harm the sensitive bioactive ingredients[128].

Non-Conventional Methods of Extraction

One especially effective extraction method is ultrasonic-assisted extraction (UAE), which involves sonicating Moringa leaves for 15 minutes at room temperature with water and 0.1% formic acid. On the other hand, Moringa leaves were sonicated for 30 minutes at a solid-to-solvent ratio of 1:10 using 100% ethanol. Other studies examined the effects of UAE on Moringa leaves with a solid-to-solvent ratio of 1:50 (g/mL) at various temperatures (30, 35, 40 and 45°C) and times (15, 20, 25 and 30 min). In a different technique, it was discovered that 45°C and 30 minutes were ideal because higher temperatures accelerated the mass

transfer rate into the solvent and the solubility of the phytochemicals. Water may raise the previously calculated extraction rate and phenolic content in M. oleifera leaf extract, according to UAE conducted at 50°C with pure water, 50% ethanol, and 20% ethanol, a constant frequency of 20 kHz and an amplitude of 79mm. Cavitation, which helps break down the leaf cell wall and promotes the release of phytochemicals during extraction, can be caused by ultrasound waves passing through the extraction liquid. Additionally, the phytochemicals (alkaloids, saponins, tannins, steroids, phenolic acids, flavonoids, glucosinolates and anthocyanins) present in Moringa leaves are the focus of this study. These substances are useful in medicine and have applications in the food, cosmetic, and pharmaceutical sectors. The extraction method, solvent type, solvent-to-solid ratio, ambient temperature, stirring rate, and particle size all affect the phytonutrient concentrations in *Moringa oleifera* leaf extract. GC-MS (Gas Chromatography and Mass Spectroscopy) study of petroleum ether and dichloromethane samples of *Moringa oleifera* roots, which demonstrated interesting biological activity, revealed 102 compounds. Halo compounds, aromatics, alkamides, cyanides, fatty acids, alcohols, pyrazine, hydrocarbons, urea and N-hydroxyimine derivatives, unsaturated alkenamides, alkyne and indole are among the 13 categories of compounds into which these substances are divided. According to GC/GC-MS studies, the petroleum ether extract of the roots included 39 different compounds from nine different classes[128].

Pharmacological Activities

Antioxidant Properties and Mechanisms

Because *Moringa oleifera* leaves contain a variety of natural bioactive substances, including flavonoids, phenolics, vitamins A, E and ascorbic acid, they have a potent array of antioxidants. Both the aqueous, methanolic and ethanolic extracts made from the leaves and roots have shown remarkable antioxidant properties *in vitro*, demonstrating their abundance of antioxidant components and promise for treating disorders linked to oxidative stress in animal models. It has been shown that administering *Moringa oleifera* leaf extract can significantly reduce oxidative damage brought on by a high-fat diet. Notably, aqueous leaf extracts significantly increased the activity of key antioxidant enzymes like glutathione S-transferase, catalase, and superoxide dismutase while simultaneously lowering lipid peroxidation levels in both normoglycemic and diabetic rodent models. There is growing evidence that the extract's high phenolic and flavonoid content may protect against oxidative damage, benefiting those with diabetes as well as those with normoglycemia[9]. Additionally, a study of 60 postmenopausal women revealed that taking powdered *Moringa oleifera* leaves for three months led to significant reductions in serum levels of malondialdehyde, a measure of lipid peroxidation, as well as increases in ascorbic acid, superoxide dismutase and glutathione peroxidase, highlighting the plant's potent antioxidant potential[129]. Demonstrates *Moringa oleiferas* hepatoprotective, antioxidant and anti-inflammatory properties.

Anti-Inflammatory Effects

The use of extracts from a variety of plant parts, including as roots, stems, leaves, flowers, pods, and seeds, has confirmed *Moringa oleifera's* anti-inflammatory effectiveness. Like phenylbutazone, a nonsteroidal anti-inflammatory drug with analgesic and antipyretic effects, the root extract of *Moringa oleifera* dramatically slowed the onset of paw edema in a rat study[130]. Additionally, Th1/Th2 cytokine modulation using *Moringa oleifera* seed butanol extract reduced airway inflammation and acetylcholine-induced bronchospasms in guinea pigs. Furthermore, after consuming *Moringa oleifera* dry seed powder, participants with mild to moderate asthma showed a significant increase in Forced Vital Capacity (FVC), Forced expiratory volume (FEV) and peak expiratory flow rate (PEFR) with no negative side effects[131]. The presence of bioactive chemicals, including quercetin, in *Moringa oleifera* is thought to be responsible for its anti-inflammatory properties. The capacity of quercetin to suppress NF-kB activity, which is crucial for the swelling process, is

astounding. Furthermore, M. oleifera leaves' higher concentrations of flavonoids and phenolic acids strengthen their anti-inflammatory qualities. Furthermore, in animal models, *Moringa oleifera* leaf extract and quercetin have been demonstrated to lower TNF-α and IL-6 secretion while controlling certain important indicators of inflammation, such as iNOS, IFN-gamma, and C-reactive protein[132]. In addition to their anti-inflammatory qualities, isothiocyanates derived from *Moringa oleifera* leaves also significantly reduce macromolecules like IL-1β, iNOS, TNF-α, and NO, demonstrating a strong inhibitory effect on the production of pro-inflammatory substances by RAW macrophages[133].

Antimicrobial and Antiviral Activities

The alcoholic root extract of *Moringa oleifera* contains the bioactive compound N-benzylethylthioformate, which is an aglycone derivative of deoxyniazimincin. Against a wide variety of bacteria and fungi, it demonstrates broad-spectrum antibacterial and antifungal properties. It is a good choice for treating infectious disorders and combating microbial resistance because of its capacity to restrict microbial development and obstruct fungal proliferation[134]. Furthermore, it has been discovered that methanolic extracts from *Moringa oleifera* leaves are useful in the treatment of urinary tract infections brought on by a variety of bacteria, including both gram-positive and gram-negative ones. Likewise, it demonstrates antimicrobial properties against typical illnesses brought on by *Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae* and *Staphylococcus saprophyticus*[135]. Extracts from the leaves, seeds, and stems of Moringa oleifera are tested for their ability to inhibit a variety of fungal strains, including Aspergillus flavus, Aspergillus terreus, Aspergillus nidulans, Rhizoctonia solani, Aspergillus niger, Aspergillus oryzae, Fusarium solani, Penicillium sclerotigenum, Cladosporium cladosporioides, Trichophyton mentagrophytes, several species of Penicillium, and Pullarium. In order to facilitate the development of innovative preventive measures against fungal diseases, the purpose of this study was to clarify the effectiveness of *Moringa oleifera* isolates as potential antifungal agents against a broad range of pathogenic fungi[134]. It is known that the unique bioactive components of Moringa oleifera seeds, such as 4-(α-l-rhamnosyloxy) benzyl isothiocyanates, are responsible for their antibacterial properties. Additionally, Moringa leaf juice has a strong anti-pathogenic ability against microorganisms that have a detrimental impact on human health. Remarkably, Botrytis cinerea, a necrotrophic disease that primarily damages plants, was totally controlled (99%) by the methanolic leaf extract[135]. Fruits of the *Moringa oleifera* plant exclusively contain alkaloids, flavonoids and steroids. Through mechanisms like protein denaturation and spore germination suppression, these components hinder the growth of Candida albicans cells due to the unique composition of their steroid rings. This complex phytochemical interaction demonstrates the versatility of *Moringa oleifera* antifungal properties as well as its potential as a natural remedy for Candida infections[136]. Bacillus cereus, *Staphylococcus aureus* and various forms of Aspergillus and Mucor are all very susceptible to the effects of moringa seed kernel extract. It may be helpful in treating infections brought on by *Pseudomonas aeruginosa* and *Escherichia coli*, though, as it appears to be less effective against these bacterial types. Only the apolar extract made from *Moringa oleifera* seeds has antibacterial activity that is specifically targeted at gram-positive bacterial strains, according to recent studies[137].

Anticancer Potential

The anticancer effects of the moringa plant's leaf are encouraging. The combination of O-Ethyl-4-(α-L-rhamnosyloxy) benzyl carbamate, 4-(α-L-rhamnosyloxy)-benzyl isothiocyanate, niazimicin and 3-O-(6′-O-oleoyl-β-D-glucopyranosyl)-sitosterol was evaluated for its antitumor potential using an *in vitro* assay, thanks to advanced scientific analysis. The crude 80% methanol extract of the tree's leaves was distilled to produce the extracts using various solvents such as chloroform, n-butanol, dichloromethane and hexane. To determine if the extracts were cytotoxic to MCF7

cells, the CellTiter 96® Aqueous One Solution Cell Proliferation (MTS) assay was utilised. We used Annexin V-FITC analysis to probe apoptosis and we used Western blotting to confirm our findings using specific proteins, including caspase 8, p53, Bax and cytochrome c. The results showed that the dichloromethane extract was cytotoxic to MCF7 cells at concentrations of 5µg/mL, but had no effect on MCF 10A cells, which are not malignant. At 9.5, it had the highest selectivity index (SI) value of any of the extracts that were tested. Furthermore, it induced cell death in MCF7 cells at an early stage and increased the levels of caspase 8, p53, and the pro-apoptotic protein Bax. The anticancer effects of this plant's active ingredients are most likely due to its ability to induce cell death, according to research. Interestingly, they showed remarkable suppression of the Epstein-Barr virus early antigen 36, suggesting they can generate tumours to a lesser extent. Many believe that niazimicin can significantly reduce the risk of cancer by acting as a chemopreventive. Antioxidant characteristics, cutaneous papillomagenesis in mouse models and the modulation of hepatic carcinogen-metabolizing enzymes are only a few areas where seed extracts have shown positive benefits. Moringa compounds have a wide variety of uses in cancer research and treatment, as these results show[138]. The combination of neomycin and an ointment made from the seeds effectively cured Staphylococcus aureus pyoderma in mice. One of the thiocarbamates found in *Moringa oleifera* leaves, niaziminin, blocks tumour promoter-induced Epstein-Barr virus activation. On the other hand, the naturally occurring 4-[(4′-O-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate successfully suppressed tumor-promoter-driven Epstein-Barr virus activation, suggesting that the isothiocyanate group plays a crucial role in its activity[139]. To lessen the inflammatory reaction in the hind paws of mice caused by carrageenan, an ethanol extract made from dried seeds was given to the animals. Also, this crude ethanol concentrate's butanol, water and hexane fractions all exhibited anti-inflammatory properties. Surprisingly, when given orally to mice, the ethyl acetate part actually enhanced inflammation and showed signs of toxicity. In addition, the crude ethanol extract effectively reduced the production of Epstein-Barr virus-early antigen (EBV-EA) from 12-O-tetradecanoylphorbol-13-acetate (TPA), suggesting that it could be a potential agent for tumour promotion. Numerous diseases have been linked to increased levels of inflammatory mediators and reactive oxygen species (ROS). Thus, in order to control inflammation and oxidative stress, it is essential to target these pathways individually. Standard anti-inflammatory drugs are associated with intrinsic health problems, which is driving interest in studying alternate therapeutic approaches. In addition to nitriles, glycosidic glucosinolates, isothiocyanates, carbamates, and thiocarbamates, research has revealed that *Moringa oleifera* seeds contain a wide array of bioactive chemicals. Strong anti-inflammatory and antioxidant characteristics are exhibited by these compounds[139]. Figure No.3 illustrates the process by which *Moringa oleifera* may inhibit the growth of cancer cells.

Immunomodulatory Effects

Strong active substances such as cyanogenic glycosides and isothiocyanates, which have demonstrated potent immunostimulatory activities and significantly enhance the host's immune response, were discovered in the plant extract made with methanol. According to a recent thorough analysis, several bioactive compounds are purposefully used to strengthen their hosts' immune systems in order to cure a range of immune-mediated illnesses, such as diabetes, hypertension, and malignancies[140]. An major topic of neuroprotection study is *Moringa oleifera*. In mice with dementia after amyloid beta peptide injection, it can be an antioxidant, enhance cognitive function, and act as a neuroprotectant[140,141].

Both aqueous and hydroalcoholic extracts of *Moringa oleifera* leaves have been shown to significantly lower cerebral lipid peroxidation while simultaneously increasing catalase and superoxide dismutase activity levels in the brain[141]. Furthermore, when primary hippocampal neuron

cells were cultured with an ethanolic extract made from *Moringa oleifera* leaves, a comprehensive examination of the extract's neuroprotective qualities revealed a notable stimulation of neurite outgrowth. Significant increases in dendritic and axonal branching as well as length were indicative of this stimulation. Our findings clearly show that *Moringa oleifera* has the potential to be a neuroprotective adjuvant because of its ability to reduce oxidative stress[142].

Hepatoprotective and Nephroprotective Activities

The amazing potential of *Moringa oleifera* leaves to lessen drug-induced liver and kidney damage in animal models is supported by scientific findings. Numerous investigations have clarified *Moringa oleifera's* hepatorenal protective potential against a range of pharmaceutical drugs, including acetaminophen, gentamicin, pyrazinamide, rifampicin and isoniazid. The main source of its quality protection is its leaves.More precisely, when rats were given *Moringa oleifera* leaf extract, their blood levels of important indicators like urea, creatinine, alkaline phosphatase, aspartate aminotransferase and alanine aminotransferase dropped as a result. These results were supported by histological analyses, which demonstrated that patients treated with M. oleifera showed a considerable decrease in drug-induced hepatic and renal system damage. Additionally, *Moringa oleifera* roots and flowers have significant hepatoprotective qualities against acetaminophen-induced hepatotoxicity in both aqueous and alcoholic extracts. Reduced levels of bilirubin, alkaline phosphatase, and serum transaminases (alanine aminotransferase and aspartate aminotransferase) indicate this, pointing to a complex protective mechanism provided by *Moringa oleifera*[143,144].

Antifungal Activity

Extracts from the leaves, seeds and stems of *Moringa oleifera* have been shown to have an inhibitory effect on a number of fungal strains, such as Aspergillus flavus, *A. terreus, A. nidulans, A. niger, A. oryzae, Rhizoctonia solani, Fusarium solani, Penicillium sclerotigenum, Trichophyton mentagrophytes*, *Cladosporium cladosporioides* and *Penicillium species*[134]. The antibacterial action of *Moringa oleifera* seeds is believed to be due to 4-(alpha-L-rhamanosyloxy) benzyl isothiocyanates, which are their active components[146]. Furthermore, Moringa leaf juice showed promise against human-harming microorganisms. The methanolic extract of leaves inhibits the necrotrophic plant fungus Botrytis cinerea by almost 99%[136]. The fruit of *Moringa oleifera* contains alkaloids, flavonoids and steroids that limit the growth of Candida albicans by either weakening the protein or stopping spore germination because of the steroid ring[137]. Strong inhibitory effects on Aspergillus species, Bacillus cereus, Staphylococcus aureus, and Mucor species were observed in the extract from moringa seed kernels. Its effectiveness against *P. aeruginosa* and *E. coli* was diminished, though. This implied that the concentrate from Moringa seed kernels might be utilized to treat infections caused by all species, but not by *P. aeruginosa* and *E. coli*[146].

Cardioprotective Activity

The freeze-dried alcoholic and aqueous extract of *Moringa oleifera* exhibited a cardioprotective effect in animals with isoproterenol-induced myocardial infarction. The hemodynamic effects of isoproterenol were successfully treated by chronic *Moringa oleifera* treatment, which also increased the levels of enzymes like SOD, catalase, lactase dehydrogenase, glutathione peroxidase, and creatine kinase. Butanolic extract has been shown to be an important source of antioxidants in rats with isoproterenol-induced cardiac necrosis[147]. Furthermore, it was found to significantly reduce myocardial necrosis and inflammatory reactions due to the presence of N-α-rhamnopyranosyl vincosamide[148]. Moringa leaves significantly lowered cholesterol levels in hypertensive rats by preventing hypertension. It was discovered that the active components niazirimin A, niazirimin B and niazimincin were believed to be in charge of this activity[27]. Compounds such as niazimin-A, niazicin-A and niaziminin-B are purportedly present in the plant extract of *Moringa oleifera*. These compounds

were demonstrated to have potent antihypertensive effects when they were targeted at ACE, an essential renin-angiotensin system enzyme. Researchers found that the compounds exhibited a greater affinity for the angiotensin-converting enzyme than captopril and enalapril when they used protein–ligand docking to track this activity[149]. One of the main factors influencing blood pressure regulation and the emergence of diseases like hypertension, renal disease and other cardiovascular disorders is the angiotensin enzyme rennin. The study found that *Moringa oleifera* and two other plants (*Azadirachta indica and Hibiscus sabdariffa*) inhibited the enzyme with percentage inhibitions (71.8%, 74% and 73.4%) compared to common medications (captopril and enalapril). Moringa's activity is due to a component known as β-sitosterol[150].

Hypocholesterolaemic and Hypolipidemic Activities

Indians use *Moringa oleifera* leaves as a hypocholesterolemic medication in their herbal remedies for obese patients. Therefore, the scientific justification for their use in hypercholesterolemia was examined. The study found that when a high-fat diet was combined with the crude leaf extract of *Moringa oleifera*, the increases in serum, liver, and kidney cholesterol levels brought on by the diet were decreased by 14.35% (115-103.2mg/100mL of serum), 6.40% (9.4-8.8mg/g wet weight), and 11.09% (1.09-0.97mg/g wet weight), respectively. In terms of blood cholesterol, the effect was statistically significant. Serum total protein levels did not change significantly. However, the crude extract caused a 15.22% increase in serum albumin (46-53g/L). Additionally, this value was shown to be statistically significant. The study found a strong pharmacological basis for the use of Moringa oleifera leaves in India and that they have a noticeable hypocholesterolemic effect. It is also effective in reducing serum concentrations of VLDL (called very-low-density lipoprotein) and LDL (called low-density lipoprotein) by consuming fruit from *Moringa oleifera*. In addition to these advantages, *Moringa oleifera* leaf extract is also known to reduce the progression of atherosclerotic plaques. Although few human trials have been done, some research has indicated that *Moringa oleifera* may be helpful in treating dyslipidemia and diabetes[22].

Health Benefits and Therapeutic Applications

Modern Therapeutic Applications Based on Scientific Evidence

This investigation's conclusive results highlight the potential usefulness of conventional methods for assessing the effectiveness of natural health and cosmetic product formulations. As an insecticide used in aquaculture to protect young fish from predators and parasites, neem oil has negative consequences. However, by applying *Moringa oleifera* leaf extract, these effects were effectively mitigated. Researchers found that Moringa is a good dietary supplement since it contains few harmful ingredients and a wealth of beneficial ones, including proteins, lipids, and amino acids (especially sulphur)[151]. One of the active components of Moringa leaf extract, palmitic acid, has a wide range of medicinal uses. The pharmacological efficacy of the compound was investigated in a group study that pitted it against a battery of different bacteria and fungi. Impressive efficiency was on display as it achieved the widest inhibitory zone compared to its fungal and microbial competitors. An innovative medicine delivery vehicle was created by blending Moringa extract with nanoparticle technology. This pushed the bounds of innovation to new heights. In addition to facilitating the transition to precision medicine, this strategic integration boosts medication bioavailability. Not only is Moringa utilised in pharmaceuticals, but it is also extensively employed in other industries, such chicken raising. Among its many weapons is the ability to ward off infectious diseases like the Newcastle Disease Virus (NCDV), as well as germs and parasites[29]. Furthermore, by regulating the early development of crops like peanuts, wheat, maize and tomatoes, Moringa is an impressive example of an agricultural breakthrough. Increased production volume and sustainability in agriculture are outcomes of this connection's

promotion of robustness and vitality. It has many applications in agriculture, but it was also an early adopter of sustainable pest management practices. The production of biopesticides from Moringa's naturally occurring bioactive chemicals is a step towards sustainable agriculture and offers a more cost-effective option. With this idea, pest treatment becomes more accessible and people are better able to adapt to varied ecological environments since they leave less of an ecological footprint[152]. Among the many nutrients and growth regulators found in *Moringa oleifera's* water-based extract are gibberellins, cytokinins and indoleacetic acid. When transformed into a plant bio-stimulant, it outperforms the more traditional chemical fertilisers and insecticides employed in contemporary farming practices while being demonstrably safer. An essential plant hormone, zeatin is largely responsible for plants' exceptional drought tolerance. It's a key player in plants' capacity to endure dry environments. Therefore, plants grown under dry conditions infused with methanol-based Moringa extracts had substantially better growth characteristics than plants grown with adequate irrigation. Many African communities utilise moringa because it is inexpensive and can improve water quality. This can be useful when dealing with turbidity, alkalinity, and COD, among other difficulties. Alternatively, Moringa could be used in environmentally friendly water treatment procedures to minimise turbidity in water instead of alum[9]. Because of its resistance to plant diseases, it is a superior choice for biopesticide applications. Soil amended with moringa leaves helped numerous plants recover from damping-off disease caused by Pythium debaryanum[6]. Surprisingly, Moringa is said to have various parts that contribute to one's emotional and spiritual wellness, including fruit, blossoms, leaves, seeds and roots. Integrative medicine approaches that take into account both conventional wisdom and new scientific evidence may benefit from a variety of these plants[29].

Safety and Toxicity Considerations

The comprehensive study used a variety of experimental methods to determine the maximum safe dose of *Moringa oleifera*, a plant with several health benefits. A comprehensive examination of several plant components was conducted using animals, including leaves, seeds and stem bark, as part of a multidisciplinary effort to determine any potential toxicity. An element of this research involved administering an aqueous methanol extract of *Moringa oleifera* to female albino Wistar rats that were not pregnant. Blood samples were taken for analysis after a randomly selected cohort was given an oral dose of the extract at a dosage of 2000mg/kg. Some critical measures that were regularly watched included total bilirubin, aspartate aminotransferase (AST) and alanine aminotransferase (ALT). Experiments on female Wistar rats showed that the lethal dose, when supplied as an aqueous extract, was more than 2000mg/kg, suggesting that the amount was well within the safe range[153]. The researchers in this study wanted to know whether Moringa leaf powder was safe to give to Sprague-Dawley rats. Extensive studies were conducted to assess the potential risks and fatalities associated with sun-dried leaf consumption orally at doses ranging from 200mg/kg and up. Multiple large-scale studies have verified that Moringa leaf extract is safe to use up to the recommended dosage; these studies found no negative side effects. There has to be a lot of research into the toxicological profile of Moringa oleifera seeds. Researchers examined the health consequences of methanolic extracts by subjecting animals to acute and sub-acute toxicity tests. At a threshold level of 4000mg/kg, acute poisoning symptoms began to manifest. The lethal dose, or doses over 5000mg/kg, have tragically been associated with fatalities. At concentrations below 3000mg/kg, no adverse effects were detected. After the experimental rats were given the seed extract sub-acutely, their weight dropped dramatically ($p < 0.05$) and at a dose of 1600mg/kg, the concentrations of ALT and AST (alanine and aspartate transferases) rose significantly ($p < 0.05$). According to these results, *Moringa oleifera* seed extract is perfectly safe to consume and utilise in medical and nutritional contexts[155]. Despite some

negative side effects in the short term, research on the nutritional value of *Moringa oleifera* seed extract is encouraging. The study's acute symptoms highlight the importance of taking dosage into account and developing more precise formulation procedures to lessen the likelihood of side effects. Despite this obvious effect, additional research into the nutritional benefits of seed extract is warranted because of its promising use in functional foods and dietary supplements[154]. In addition, the extract from the stems and bark of *Moringa oleifera* was tested for toxicity using acute and sub-acute toxicity studies, which showed that it was safe up to a dosage of 2000mg/kg/day when administered orally. These results demonstrate that the stem bark of *Moringa oleifera* is safe to consume orally and suggest that it may have medical use due to its bioactive components. The safety profile of the extract was also elucidated by data from a 60-day subacute toxicity trial. After administering doses ranging from 250 to 1500mg/kg, the control group's sperm parameters (quality), biochemical parameters and haematological parameters did not alter noticeably, as demonstrated by the lethal dose of 1585mg/kg. More comprehensive toxicity studies are required to understand the safety profile of plant extracts, as shown by these results[155].

Future Perspectives and Research Directions

Extracts from *Moringa oleifera's* many parts, including its roots, seeds and oils, include bioactive chemicals that may have anti-inflammatory, antihypertensive, antiproliferative, antibacterial and anticancer properties, among many others. Researchers have meticulously confirmed this capability through *in-vivo* and *in vitro* tests conducted on live organisms. An important step towards better nutritional profiles, better human welfare and progress in food production sustainability efforts is the incorporation of bioactive chemicals obtained from Moringa oleifera Lam. into the human diet. Two important characteristics that dictate the effectiveness of bioactive substances are their inherent bioactivity and stability. Their molecular composition and capacity to maintain bioactive properties when integrated into food matrices are directly related to these features. Integrating conventional and innovative methods from the chemical, thermal and biotechnological fields can substantially improve the utilisation of these bioactive compounds in food and drink compositions. Emerging as a potential technology in the food sector, encapsulation offers a sophisticated means to transfer bioactive molecules from M. oleifera into the gastrointestinal tract while ensuring the finished products are affordable, safe, and have a pleasant sensory experience. Hence, unlike conventional food products, creating nutritious meals that include *Moringa oleifera* bioactive substances necessitates meticulous customisation while considering both environmental sustainability and cost-effectiveness. Reviewing the literature in depth reveals that spray drying is an effective and cost-effective encapsulation method, particularly when working with certain biopolymers like proteins or their derivatives. The encased materials' long-term durability is a reflection of how effective the process was. Research on the environmental impacts of various encapsulation procedures, such as the procurement of encapsulating matrices, is urgently needed. Several obstacles prevent the widespread cultivation of Moringa trees, even though it has the ability to alleviate poverty and malnutrition. This is especially true in areas like Nepal, where people are unaware of the tree's significance. Uncertainty in the market and a general lack of knowledge about farming practices are two additional problems. Improved nutrition and health, stronger rural communities and the attainment of broader socioeconomic development goals are all possible results of encouraging farmers in rural regions to cultivate Moringa trees. By substituting locally produced nutrient-dense substances for imported artificial supplements and pharmaceuticals, this might create funds for rural development operations. One advantage of Moringa plant extracts is their apparent lack of toxicity when used in the amounts often associated with their therapeutic effectiveness. Researchers have come to rely on *Moringa oleifera* and the species has

inspired numerous formulations employing different approaches. Incorporates *Moringa oleifera* into a wide variety of phytoformulations.

Table No.1: Phytoconstituents of *Moringa oleifera* leaves per 1 g net quantity

S.No	Phytoconstituents	Concentration	Category	Reference
1	Isoquercetin	1575.28g/g (*w*/*w*)	Flavonoids	113,114
2	Astragalin	0.153g/g (*w*/*w*)	Flavonoids	
3	Isorhamnetin	2.9mg/g (*w*/*w*)	Flavonoids	
4	4-(-L-rhamnopyranosyloxy) benzyl glucosinolate	33.9mg/g	Glucosinolates	
5	4-[(20-O-acetyl-_-L-rhamnosyloxy) benzyl] Glucosinolate	21.84 to 59.4mg/g	Glucosinolates	
6	Epicatechin	5.68mg/g	Flavonoid	
7	Ferulic acid	0.078mg/g	Phenolic acid	
8	Caffeic acid	0.409mg/g	Phenolic acid	
9	Ellagic acid	0.018mg/g	Phenolic acid	
10	Sinalbin	2.36mg/g	Glucosinolates	
11	Chlorogenic acid	0.018mg/g	Phenolic acid	
12	Gallic acid	1.034mg/g	Phenolic acid	
13	Salicylic acid	0.14µg/g	Phenolic acid	
14	4-[(40-O-Acetyl-_-Lrhamnosyloxy) benzyl]	2.16 to 5.0mg/g	Glucosinolates	

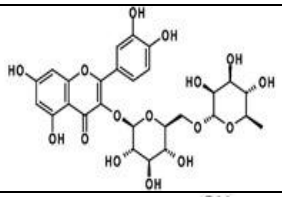
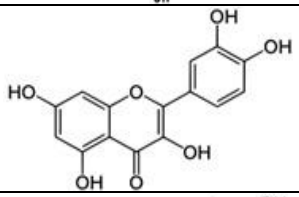
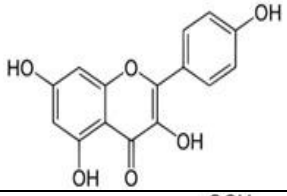
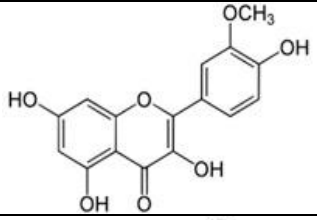
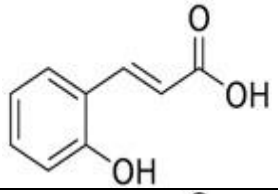
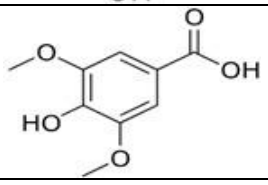
Table No.2: Moringin-type alkaloids

S.No	Category	Subcategory	Details	Reference
1	Comparison of Nutrient Content	Milk	Provides 300-400mg of certain nutrients	110
		Moringa Leaves	Offers significantly higher amounts, around 1000mg	117
		Moringa (whole plant) Powder	Surpasses with more than 4000mg of essential nutrients	111
2	Anemia Treatment	-	*Moringa* powder serves as a substitute for iron tablets, can be utilized in the treatment of anemia	110
3	Micronutrient Composition of *Moringa oleifera* (mg/100g)	Calcium	440-3650mg	20
		Magnesium	24-1050mg	
		Sulfur	137-925mg	
		Sodium	164.0-272mg	
		Potassium	259-2061mg	
		Phosphorus	70-300mg	
		Iron	0.85-126mg	
		Zinc	0.16-3.30mg	
		Copper	0.6-1.1mg	
4	Vitamin Content	Vit A	6.78-18.90mg	
		Vit B2	0.05-20.50mg	

		Vit B3	0.8-8.2mg	
		Vit B7	423mg	
		Vit B12	0.06-2.64mg	
		Vit C	17.3-220.0mg	
		Vit E	77mg	

Table No.3: Displays the structures of some of the major phytoconstituents separated from *Moringa oleifera*

Chemical constituents of *Moringa oleifera*

Plant Part	Phytoconstituent	Type	Chemical Structure	Therapeutic Potential	Reference
Leaves	Rutin (555.6µg/g)	Flavonoid		Maximum affinity towards BRAC-1 genes.	114,118
Leaves	Quercetin (2030.9µmol/100g)	Flavonoid		Anti-diabetic agent	119
Leaves	Kaempherol (197.6µg/g)	Flavonoid		Oxidative damage protective activity.	120
Leaves	Isorhamnetin (0.118mg/g)	Flavonoid		Antioxidant	121
Leaves	O coumaric acid (0.536mg/g)	Phenolic acid		Antioxidant and antimicrobial	122
Leaves	Syringic acid (trace amount)	Phenol		Antioxidant and antimicrobial	122

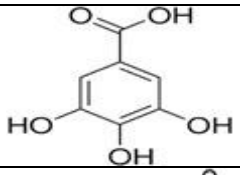
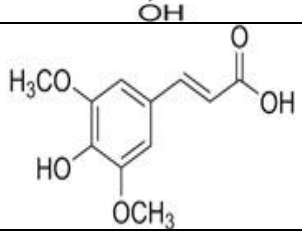
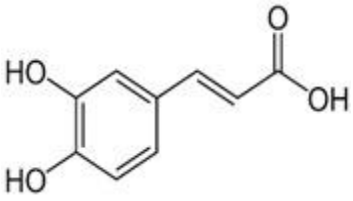
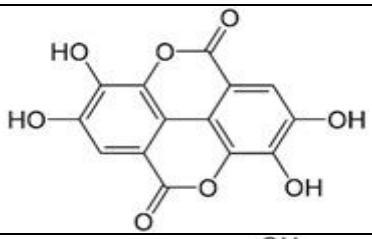
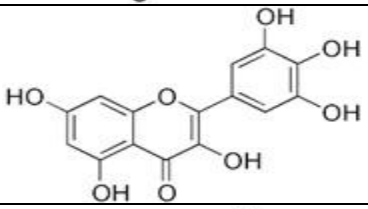
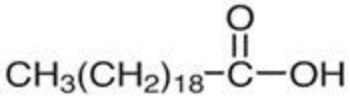
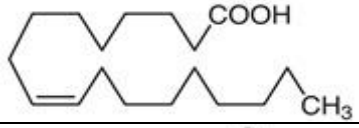
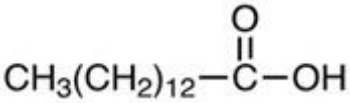
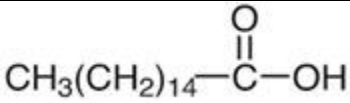
Leaves	Gallic acid (1.034mg/g)	Phenol		Anti-inflammatory, anti-neoplastic, antioxidant	122
Leaves	Sinapic acid (trace amount)	Phenol		Cardioprotective, renoprotective, neuroprotective, anxiolytic	122
Leaves	Caffeic acid (0.409mg/g)	Phenol		Enhances athletic performance, reduces fatigue, helps weight management, protects against HIV, herpes and cancer.	122
Leaves	Ellagic acid (0.078 to 0.128mg/g)	Polyphenol		Antiviral, antibacterial and antioxidant	122
Leaves and Seeds	Myricetin (5.804mg/g)	Flavonoid		Prevention of diabetes and its complications.	122
Seeds	Arachidic acid	Fatty acid		Increases mothers' milk production	123
Seeds	Oleic acid	Fatty acid		Reduces blood pressure, antioxidant	124
Seeds	Myristic acid	Fatty acid		Anxiolytic	125
Seeds	Palmitic acid	Fatty acid		Anti-leukemic effect	126

Table No.4: Different Phytoformulations of *Moringa oleifera*

S.No	Part of the Plant	Formulation	Application	Reference
1	Leaves	Polyherbal formulation	Anti-ulcer	156
		Polyherbal ointments	Edema	
		Lozenges	Anti-microbial activity	
		Film dressing	Wound healing	
		Effervescent tablets	Anti-anemia	
		Granules	Anti-inflammatory and anti-arthritic	
2	Seed	Micro-dispersion	Anti-inflammatory	-
		Nano-micelle	Mitochondrial cancer cell apoptosis	
		Anti-inflammatory cream	Anti-inflammatory	

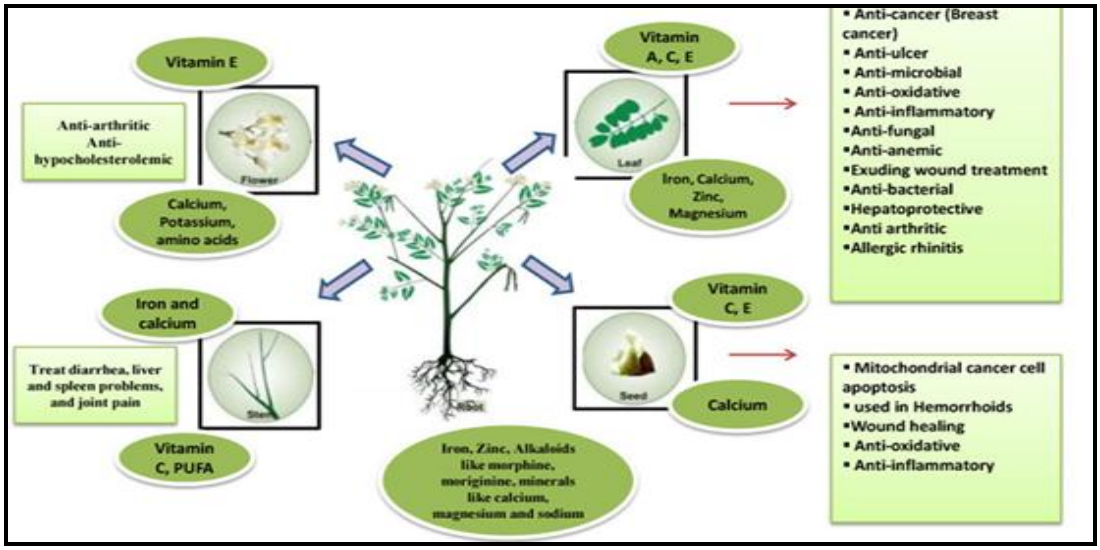


Figure No.1: Nutritional and therapeutic values of *Moringa oleifera* whole plant

Figure No.2: Moringa (*Moringa oleifera*)

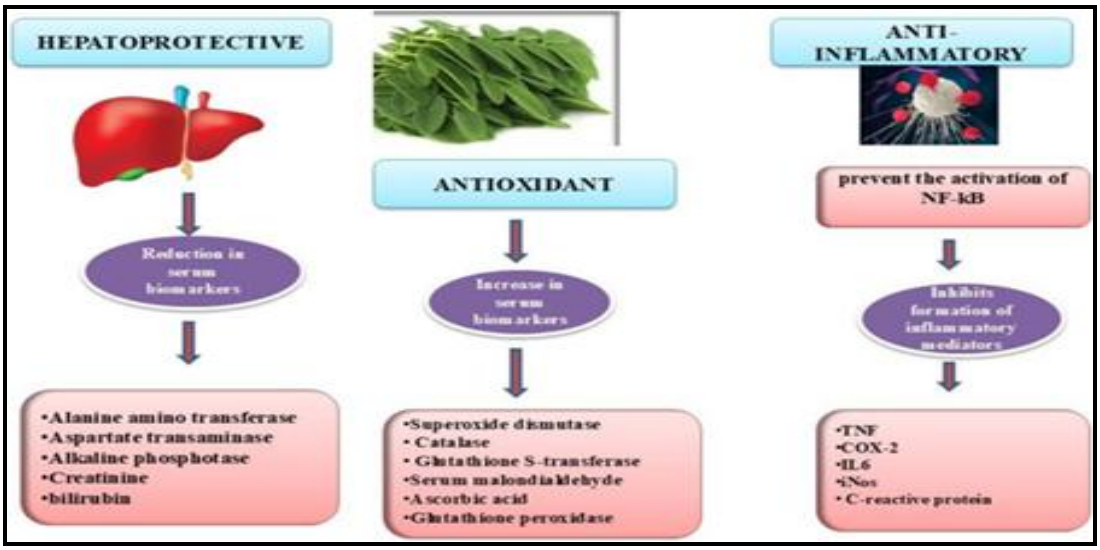


Figure No.3: Hepatoprotective, antioxidant and anti-inflammatory mechanisms of *Moringa oleifera*

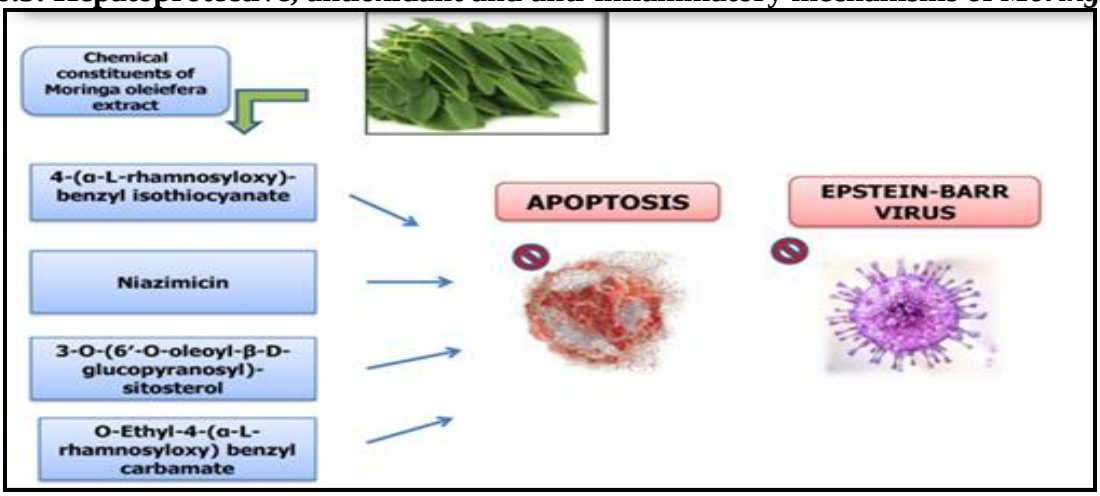


Figure No.4: Anticancer potential of *Moringa oleifera*

CONCLUSION

Bioactive compounds found in *Moringa oleifera* extracts (roots, seeds and oils) may have a wide range of potential medical uses, including the treatment of inflammation, hypertension, cancer, bacterial infections and cell proliferation. This capability has been thoroughly verified by researchers through *in-vivo* and *in vitro* studies performed on living organisms. To improve human welfare, nutritional profiles and food production sustainability, bioactive compounds derived from *Moringa oleifera* Lam. should be a part of everyone's daily diet. The efficiency of bioactive compounds is greatly influenced by two key characteristics: Their inherent bioactivity and stability. The molecular makeup and ability to retain bioactive characteristics when incorporated into food matrices are closely connected to these characteristics. Using both traditional and modern techniques from the chemical, thermal and biotechnological domains can greatly enhance the incorporation of these beneficial substances into beverage and food compositions. Emerging as a promising food industry technology, encapsulation provides a complex way to deliver bioactive molecules from *Moringa oleifera* to the intestines

while guaranteeing that the final products are reasonably priced, safe and have a nice flavour. So, unlike with traditional food products, making healthy meals using *Moringa oleifera* bioactive compounds requires careful tailoring while keeping costs down and the environment in mind. Thorough literature research has shown that spray drying is a viable encapsulation option, especially when dealing with certain biopolymers such as proteins or proteins' derivatives, because it is both effective and economical. The process's efficacy is shown by the encased materials' long-term durability. Immediate action is required to gather data on how different encapsulation processes, such the acquisition of encapsulating matrices, affect the environment. Despite its potential to reduce poverty and malnutrition, the broad cultivation of Moringa trees is hindered by a number of factors. This is particularly the case in Nepal, where the locals have no idea how important the tree is. Another issue is the general public's ignorance regarding farming methods and the market's volatility. Promoting Moringa tree cultivation among rural farmers has the potential to improve nutrition and health, fortify rural communities and help achieve larger socioeconomic development objectives. One possible way to generate revenue for rural development activities is to replace imported artificial supplements and medications with locally generated nutrient-dense substances. Among the many benefits of Moringa plant extracts is the apparent absence of toxicity at dosages often employed to achieve therapeutic effects. Scientists have grown to depend on *Moringa oleifera* and the species has sparked a plethora of formulations using various methodologies. Mixes *Myrica alternifolia* into several phytoformulations.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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