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## Bioactive compounds of Muskmelon (*Cucumis melo* L.) and their role in human health: A comprehensive review on nutraceutical and pharmacological properties

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### Abstract

Muskmelon (*Cucumis melo* L.) is an economically important fruit rich in essential nutrients and diverse phytochemicals, including phenolic acids, flavonoids, carotenoids, vitamins, minerals, volatile compounds and seed-derived bioactives. These constituents contribute to its broad spectrum of nutraceutical and pharmacological activities. This review comprehensively synthesizes current knowledge on the nutritional composition, phytochemical diversity and therapeutic potential of muskmelon, emphasizing its antioxidant, anti-inflammatory, antidiabetic, antimicrobial, cardioprotective, hepatoprotective, anticancer, gastroprotective and neuroprotective properties. The synergistic interactions among its bioactive compounds play a central role in mitigating oxidative stress, modulating inflammatory pathways, supporting metabolic regulation and enhancing overall physiological resilience. Additionally, muskmelon exhibits significant promise in nutraceutical applications, including the development of functional foods, supplements, seed oil formulations and value-added products. The valorization of muskmelon by-products, especially rind and seeds, offers opportunities for sustainable processing and waste reduction. Despite its considerable potential, research gaps persist in standardized phytochemical profiling, bioavailability studies, cultivar-specific analysis and clinical validation. Future advancements in omics technologies, breeding programs and innovative processing methods will be instrumental in realizing muskmelon's full value as a functional and therapeutic fruit. Overall, muskmelon represents a natural, accessible and sustainable nutraceutical resource with strong relevance to preventive healthcare and future food-based therapeutic strategies.

### 1. Introduction

Muskmelon (*Cucumis melo* L.) occupies an important position among fruit crops due to its wide adaptability, rich cultural history and exceptional nutritional and phytochemical value. As a member of the Cucurbitaceae family, muskmelon shares lineage with other important crops such as watermelon, pumpkin, cucumber and squash. Yet, unlike these relatives, muskmelon stands out for its unique aromatic profile, high carotenoid content, natural sweetness and diverse morphological variations. Over centuries, muskmelon has been cultivated not only as a source of food and refreshment but also as a therapeutic fruit integrated into traditional medical systems across Asia, Persia, the Middle East and the Mediterranean. Ancient Indian Ayurvedic texts describe muskmelon as a cooling fruit used to alleviate heat-induced imbalances, support digestion, detoxify the body and treat inflammation-related disorders. Similarly, Persian medical manuscripts mention its use in managing urinary troubles, constipation, jaundice and dehydration. These early accounts highlight

muskmelon's longstanding reputation as both a nutritive and medicinal fruit. In the contemporary world, muskmelon has gained new scientific relevance due to the widespread shift toward natural health-promoting foods. Modern dietary patterns, characterized by processed foods, sedentary lifestyles and nutrient-poor consumption, have contributed to the global rise of chronic non-communicable diseases (NCDs) such as diabetes mellitus, hypertension, cardiovascular disorders, obesity, cancer and neurodegenerative diseases. These conditions share a common underlying pathology oxidative stress and inflammation resulting from an imbalance between reactive oxygen species (ROS) and the body's antioxidant defense systems (Silva *et al.*, 2025). Fruits rich in bioactive compounds, particularly polyphenols, carotenoids, flavonoids and vitamins, play a pivotal role in restoring this balance. Muskmelon, being naturally rich in such phytochemicals, has emerged as a promising candidate for nutritional interventions aimed at disease prevention and health promotion.

Scientific advancements in the last two decades have revealed that muskmelon is much more than a simple hydrating fruit. Its diverse phytochemical composition has been linked to antioxidant, anti-inflammatory, antidiabetic, anticancer, hepatoprotective, antimicrobial, cardioprotective and neuroprotective properties. Research indicates that muskmelon's rich vitamin C and  $\beta$ -carotene content enhance immune responses and improves cellular defenses against oxidative damage. The phenolic and flavonoid compounds

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contribute to free radical scavenging, enzyme regulation and inhibition of oxidative chain reactions. Additionally, muskmelon seeds traditionally discarded as waste are now recognized as highly nutritious, containing essential fatty acids, phytosterols, amino acids, vitamin E and potent antioxidants that contribute to metabolic and cardiovascular health. With rising global emphasis on sustainable food systems, valorizing muskmelon seeds and rind presents an opportunity to minimize waste and increase economic returns. Another driving factor for muskmelon's increasing scientific attention is the growing recognition of functional foods and nutraceuticals in global health systems. Nutraceuticals derived from fruits are now being incorporated into preventive healthcare, personalized nutrition and therapeutic dietary regimes. Consumers are increasingly seeking foods that offer not only nourishment but also specific health-enhancing effects. Muskmelon fits seamlessly into this paradigm due to its high nutrient density, low calorie content, digestive benefits, hydration capacity and natural sweetness, making it suitable for diverse populations including diabetics, athletes, children, pregnant women and elderly individuals. Despite its cultural, nutritional and medicinal significance, muskmelon remains underexplored in scientific literature when compared to other functional fruits such as berries, pomegranate and citrus fruits. Much of the existing research is fragmented, focusing on isolated chemical components or individual health benefits rather than offering a comprehensive synthesis of its phytochemical diversity and pharmacological potential (Manchali *et al.*, 2021). Furthermore, muskmelon varieties differ widely in flavor, texture, bioactive composition and therapeutic properties, suggesting that cultivar-specific studies are essential for accurate scientific characterization. Environmental factors such as soil type, climate, irrigation, pollination and maturity stages also influence the biochemical profile of muskmelon, making integrated research vital to understanding its full potential.

Another important aspect deserving attention is the global market and economic potential of muskmelon. The fruit is cultivated extensively in India, China, Iran, Turkey, the USA and several Mediterranean countries. Global demand continues to increase due to its pleasant sensory qualities and health attributes. As consumer awareness of nutraceuticals expands, muskmelon-based products including juices, extracts, powders, concentrates, seed oils and dietary supplements are likely to gain prominence in global health markets. The commercialization of muskmelon by-products also aligns with the circular bioeconomy model, contributing to environmental sustainability and income generation for farmers and processing industries. In addition to human health benefits, muskmelon also offers agricultural advantages. It is relatively drought-tolerant, adaptable to varied agroclimatic conditions and amenable to cultivation under both open-field and protected environments. These attributes make it a promising crop for climate-resilient agriculture, particularly in arid and semi-arid regions where nutritional insecurity is prevalent. Enhancing muskmelon production and utilization can thus contribute to dietary diversification and food security, especially in countries facing nutritional challenges. Given the expanding landscape of functional foods, phytomedicine and nutraceutical development, a comprehensive scientific review of muskmelon's bioactive compounds and pharmacological significance is timely and necessary. This review integrates extensive literature on muskmelon's nutritional composition, phytochemical richness, antioxidant mechanisms, therapeutic properties and nutraceutical applications. It aims to provide a unified scientific framework for understanding

muskmelon's multifaceted role in promoting human health. Furthermore, it highlights research gaps and future opportunities, encouraging further exploration of muskmelon as a functional food and potential therapeutic agent. By consolidating current knowledge, this review contributes not only to the nutritional and pharmacological sciences but also to horticulture, food technology and public health sectors seeking natural solutions for disease prevention and wellness enhancement.

## 2. Nutritional profile of muskmelon

Muskmelon is widely appreciated for its refreshing, hydrating properties, but its nutritional benefits extend far beyond its water content. The fruit contains a unique combination of essential nutrients, making it a valuable dietary component for maintaining overall health. Its nutritional richness is influenced by genetic factors, environmental conditions, soil fertility, irrigation practices and postharvest handling. Muskmelon's macronutrient composition consists primarily of natural sugars such as sucrose, glucose and fructose, which account for its pleasant sweetness and provide an immediate energy source. This natural sugar profile varies among cultivars but generally increases with fruit maturity. Although, muskmelon flesh contains low amounts of protein and fat, the seeds are nutritionally superior, containing up to 25-35% oil and 20-30% protein, depending on the cultivar. These seeds are rich in essential amino acids and polyunsaturated fatty acids, particularly linoleic acid, which is known to lower LDL cholesterol levels and support cardiovascular health (Table 1).

The micronutrient composition of muskmelon further enhances its nutritional value. One of the most notable contributions is its high vitamin A content in the form of  $\beta$ -carotene, particularly in orange-fleshed varieties.  $\beta$ -carotene not only acts as a potent antioxidant but is also a precursor to vitamin A, which supports vision, immune defense and skin health. Muskmelon is also a rich source of vitamin C, which enhances collagen synthesis, improves iron absorption and strengthens antioxidant defense mechanisms. The combination of vitamin A and vitamin C makes muskmelon particularly beneficial for enhancing immunity and protecting the body from oxidative stress.

The fruit also provides moderate quantities of vitamin K, niacin, riboflavin and vitamin B6, which contribute to metabolic activities, enzyme functions and energy production. Seeds contain vitamin E, a lipid-soluble antioxidant that protects cell membranes from oxidative damage. The presence of folate in muskmelon is crucial for DNA synthesis and cell division, making it important for pregnant women and individuals with high cellular turnover. Mineral-rich, muskmelon provides essential elements such as potassium, magnesium, calcium and phosphorus. Potassium is particularly abundant, contributing to cardiac regulation, blood pressure control and neuromuscular function. Magnesium supports energy metabolism, protein synthesis and nerve function, while calcium aids in skeletal development and bone maintenance. Trace elements such as zinc, iron and copper further contribute to enzymatic functions, immune regulation and antimicrobial activity. Another important nutritional characteristic of muskmelon is its dietary fiber content. While the flesh contains moderate levels of soluble and insoluble fibers, the rind is exceptionally rich in fiber and can be valorized as a functional ingredient in dietary supplements or food products. Dietary fiber supports gastrointestinal health by enhancing peristalsis, reducing constipation, promoting

healthy gut microbiota and aiding in detoxification. Consumption of high-fiber fruits like muskmelon may help lower cholesterol levels and regulate blood sugar by slowing glucose absorption. Muskmelon plays a vital role in hydration and electrolyte restoration due to its high-water content and presence of potassium and magnesium. It is

widely consumed in summer months to protect against dehydration, heat stress and mineral loss. This hydrating capacity supports kidney function, assists in detoxification and helps maintain optimal bodily fluids, especially in individuals with high physical activity levels (Mallek-Ayadi *et al.*, 2022).

**Table 1: Nutritional composition of muskmelon**

Nutrient category	Component	Approximate content (per 100 g fresh weight)	Health significance
<b>Macronutrients</b>	Water	85-90 g	Hydration, electrolyte balance
	Carbohydrates	7-9 g	Energy source
	Natural sugars (glucose, fructose, sucrose)	6-8 g	Readily available energy
	Proteins	0.5-1.0 g	Tissue repair
	Fats	0.1-0.3 g	Minimal content
<b>Fiber</b>	Dietary fiber	0.9-1.2 g	Digestive health
<b>Vitamins</b>	Vitamin A ( $\beta$ -carotene)	170-350 $\mu$ g	Vision, immunity
	Vitamin C	30-40 mg	Antioxidant, collagen synthesis
	Vitamin E	0.05-0.2 mg	Lipid antioxidant
	Vitamin K	2-4 $\mu$ g	Blood clotting
	B-complex vitamins	Trace	Metabolism
<b>Minerals</b>	Potassium	250-300 mg	Blood pressure regulation
	Magnesium	10-13 mg	Nerve and muscle function
	Calcium	7-10 mg	Bone health
	Iron	0.15-0.3 mg	Hemoglobin synthesis
	Zinc	0.1-0.2 mg	Enzyme function

The nutritional composition of muskmelon is dynamic and varies considerably during ripening. As the fruit matures, sugar accumulation increases while starch levels decline. Carotenoid biosynthesis accelerates during late maturation stages, resulting in deeper flesh color and stronger antioxidant capacity. Storage conditions also influence nutritional quality. Exposure to high temperatures can degrade vitamin C and volatile compounds, whereas cold storage preserves bioactive components and prolongs shelf-life. Optimal postharvest handling, such as protection from mechanical injury and maintenance of proper humidity levels, further helps retain fruit quality. Comparatively, muskmelon offers a more balanced nutritional and phytochemical profile than other cucurbits. While watermelon is a superior source of lycopene and cucumber is known for its hydrating properties, muskmelon uniquely combines carotenoids, phenolic compounds, vitamins, minerals and flavorful volatiles. Pumpkin surpasses muskmelon in some carotenoid concentrations, but muskmelon seeds contain higher-quality oils suitable for nutraceutical applications. The aromatic profile of muskmelon, which is richer than that of cucumber or watermelon, is attributed to its unique volatiles such as esters, aldehydes and alcohols.

### 3. Phytochemical constituents of muskmelon

Muskmelon contains a diverse array of phytochemicals that vary across the fruit's pulp, rind and seeds. These compounds include phenolic acids, flavonoids, carotenoids, terpenes, volatile aromatics, fatty acids, sterols and polysaccharides. Collectively, they contribute

to the fruit's color, flavor, aroma, nutritional qualities and broad pharmacological activities. The phytochemical composition of muskmelon is strongly influenced by cultivar type, maturity stage, environmental conditions, growing practices and postharvest storage. Studies reveal that different cultivars can exhibit wide variations in total phenolic content, antioxidant capacity and carotenoid concentration. As muskmelon ripens, its phytochemical profile undergoes characteristic changes; carotenoid synthesis accelerates, phenolic content may decline, aroma volatiles intensify and sugar concentrations increase. Understanding muskmelon's phytochemical diversity is crucial to interpreting its nutraceutical and therapeutic potential (Table 2).

#### 3.1 Phenolic compounds

Phenolic compounds are among the most important antioxidant constituents of muskmelon. They act as free radical scavengers, metal chelators and modulators of oxidative pathways, thereby protecting cells from oxidative damage. In muskmelon, phenolics are distributed in varying concentrations among the rind, pulp and seeds, with the rind typically containing higher levels due to its exposure to environmental stressors. Phenolics in muskmelon include phenolic acids such as gallic acid, ferulic acid, caffeic acid, chlorogenic acid and p-coumaric acid. These acids participate in defense mechanisms and contribute to the fruit's antioxidant and anti-inflammatory properties. The biosynthesis of phenolic compounds in muskmelon is regulated by the shikimate and phenylpropanoid pathways (Ismail *et al.*,

2010). Environmental stressors such as UV light, temperature fluctuations and water stress can enhance phenolic accumulation, increasing antioxidant capacity. Ferulic acid and p-coumaric acid, in particular, play an essential role in reinforcing plant cell walls and protecting the fruit from oxidative stress. Chlorogenic acid, a major

hydroxycinnamic acid, is associated with improved glucose regulation and cellular antioxidant defense in humans. The high phenolic content in the rind suggests potential for utilizing muskmelon by-products in functional foods, herbal supplements and antioxidant-rich formulations.

**Table 2: Major phytochemicals identified in muskmelon**

Phytochemical class	Representative compounds	Primary source (Pulp/Rind /Seeds)	Biological activity
Phenolic acids	Gallic acid, caffeic acid, ferulic acid, chlorogenic acid	Rind > seeds > pulp	Antioxidant, anti-inflammatory
Flavonoids	Quercetin, kaempferol, apigenin derivatives	Pulp, rind	Antidiabetic, anticancer
Carotenoids	$\beta$ -carotene, lutein, zeaxanthin	Pulp (orange varieties)	Antioxidant, provitamin A
Volatile compounds	Esters, aldehydes, alcohols, sulfur compounds	Pulp	Aroma, antimicrobial
Fatty acids	Linoleic acid, oleic acid	Seeds	Cardioprotective
Phytosterols	$\beta$ -sitosterol, campesterol, stigmasterol	Seeds	Cholesterol-lowering
Vitamins	Vitamin C, vitamin A	Pulp	Antioxidant
Minerals	K, Mg, Ca	Pulp	Electrolyte balance
Amino acids	Essential amino acids	Seeds	Nutrition, protein source

### 3.2 Flavonoids

Flavonoids form another significant class of phytochemicals in muskmelon and include compounds such as quercetin, kaempferol, isorhamnetin and apigenin derivatives. These molecules exhibit strong antioxidant, anti-inflammatory, anti-carcinogenic, antiobesity and antidiabetic activities. Flavonoids also contribute to the fruit's pigment formation, taste, aroma and defense mechanisms. They act by neutralizing reactive oxygen species, inhibiting inflammatory mediators and modulating signaling pathways such as NF- $\kappa$ B, MAPK and PI3K/Akt. Research indicates that flavonoid content varies substantially across muskmelon cultivars, with orange-fleshed varieties containing higher concentrations. Kaempferol glycosides and quercetin derivatives are particularly noteworthy for their capacity to regulate blood glucose, inhibit tumor progression and improve lipid metabolism. Apigenin compounds found in muskmelon pulp contribute to anti-inflammatory responses by reducing cytokine production and oxidative stress (Vouldoukis *et al.*, 2004). Flavonoid levels increase during early fruit development but may decline as the fruit reaches full ripeness due to metabolic conversions and enzymatic degradation. Despite this decline, ripe muskmelon remains a valuable flavonoid source, especially when consumed fresh.

### 3.3 Carotenoids and pigments

Carotenoids are among the most characteristic phytochemicals in muskmelon, responsible for the vibrant orange or yellow color of many cultivars. They are lipid-soluble antioxidants that include  $\beta$ -carotene, lutein, zeaxanthin and violaxanthin.  $\beta$ -carotene is particularly abundant in orange-fleshed muskmelon and serves as a precursor to vitamin A, essential for vision, immune function and epithelial integrity. The carotenoid profile of muskmelon varies not only by cultivar but also by environmental conditions, soil fertility and postharvest handling. The accumulation of carotenoids in muskmelon is linked to fruit maturation. During ripening, carotenoid

biosynthesis intensifies, while chlorophyll content simultaneously declines, leading to color development.  $\beta$ -carotene concentrations can vary widely among cultivars, reaching exceptionally high levels in deeply pigmented varieties. Carotenoids confer strong antioxidant activity. They help reduce oxidative damage, neutralize singlet oxygen, stabilize cell membranes and protect against chronic diseases such as cancer and macular degeneration. Processing and storage influence carotenoid stability. Exposure to heat, light and oxygen can degrade carotenoids, reducing nutritional quality (Hodges and Lester, 2006). Conversely, minimal processing techniques such as freeze-drying or cold storage help retain carotenoid levels. The presence of dietary lipids enhances carotenoid absorption in the human digestive system, suggesting that consuming muskmelon along with healthy fats may improve bioavailability.

### 3.4 Volatile and aromatic compounds

One of muskmelon's most distinguishing features is its aromatic profile, which is determined by a complex mixture of volatile compounds including esters, aldehydes, alcohols, ketones, sulfur compounds and terpenoids. These volatiles give muskmelon its characteristic fragrance and flavor, deeply influencing consumer preference and market value. The volatile composition varies dramatically among cultivars. Cantaloupe-type melons rich in esters produce sweet, fruity aromas, while honeydew types contain fewer aromatic compounds and exhibit mild fragrances. Esters such as ethyl acetate, methyl butanoate, hexyl acetate and ethyl butanoate are responsible for muskmelon's fruity, sweet aroma. Aldehydes like (E, Z)-2,6-nonadienal produce cucumber-like notes and contribute to freshness. Alcohols and terpenoids participate in floral and musky aromas, while sulfur-containing compounds provide depth to the aromatic complexity. These volatiles are produced through the lipoxygenase,  $\beta$ -oxidation and amino acid metabolism pathways. Fruit ripening plays a crucial role in volatile development. During maturation, the activity of enzymes such as alcohol acyltransferase

and lipoxygenase increases, leading to enhanced esterification and aroma production. Environmental factors such as temperature, irrigation, soil nutrition and postharvest storage significantly influence volatile retention. Refrigeration can slow volatile loss, while excessive handling, bruising and prolonged storage may diminish aromatic intensity (Gómez-García *et al.*, 2020). The volatile compounds not only contribute to sensory qualities but may also possess biological activities, including antimicrobial and antioxidant effects, improving overall fruit quality.

### 3.5 Seed-derived bioactive compounds

Muskmelon seeds are an underutilized but highly valuable component of the fruit. Traditionally discarded during consumption, seeds are now recognized as reservoirs of essential nutrients and potent bioactive compounds. They contain 20-35% oil, rich in polyunsaturated fatty acids (PUFAs), including linoleic acid and oleic acid, known for their cardioprotective, anti-inflammatory and cholesterol-lowering effects. Seeds also contain phytosterols such as  $\beta$ -sitosterol, campesterol and stigmasterol, which help reduce cholesterol absorption and improve lipid profiles. The protein content of muskmelon seeds ranges between 20% and 30%, containing essential amino acids such as leucine, lysine and histidine. These proteins can be used in plant-based protein supplements or functional food ingredients. Seed extracts also contain vitamin E (tocopherols), phenolic compounds and flavonoids that enhance antioxidant activity. The presence of minerals such as magnesium, potassium, zinc, iron and phosphorus adds to the seeds' nutritional value. Muskmelon seed oil has shown significant antioxidant, antimicrobial and anti-inflammatory properties. Due to its desirable fatty acid composition, the oil is being explored for edible, cosmetic and pharmaceutical applications (Zulfiqar *et al.*, 2024). Additionally, defatted seed meal can be used as a high-protein ingredient in bakery products, nutraceutical capsules or dietary supplements. With a growing interest in minimizing food waste, muskmelon seeds offer substantial potential for commercial utilization.

## 4. Antioxidant properties of muskmelon

Antioxidant activity is one of the most widely studied and scientifically established biological properties of muskmelon. Oxidative stress caused by excessive production of reactive oxygen species (ROS) and reactive nitrogen species (RNS) plays a crucial role in the pathogenesis of several chronic diseases, including cardiovascular disorders, diabetes, cancer, arthritis, neurodegenerative conditions and premature aging. Fruits such as muskmelon, which are rich in natural antioxidants, provide significant protective mechanisms against oxidative damage by enhancing the body's endogenous antioxidant defense systems. The antioxidant potential of muskmelon arises primarily from its high content of phenolic compounds, flavonoids, carotenoids, vitamins (especially vitamins C and E) and seed-derived bioactives. These compounds work synergistically to scavenge free radicals, inhibit lipid peroxidation, chelate metal ions and modulate antioxidant enzyme activity.

### 4.1 *In vitro* antioxidant activity

*In vitro* studies provide compelling evidence that muskmelon exhibits strong antioxidant activity comparable to and in some cases surpassing, other commonly consumed fruits. Assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azinobis-3-ethylbenzothiazoline-6-sulfonate), FRAP (Ferric Reducing Antioxidant

Power), ORAC (Oxygen Radical Absorbance Capacity) and nitric oxide scavenging tests have consistently demonstrated the ability of muskmelon extracts to neutralize free radicals. Among the assays, the DPPH radical scavenging test often reveals moderate to high activity in muskmelon pulp extracts, while the FRAP assay indicates significant reducing power due to the presence of phenolic acids such as caffeic, ferulic, gallic and chlorogenic acids. The ABTS assay typically shows higher antioxidant capacity in rind extracts compared to pulp, highlighting the importance of rind utilization in nutraceutical applications. The high ORAC values observed in some muskmelon cultivars indicate strong peroxy radical scavenging capacity, which contributes to cellular protection against oxidative stress. Extraction method significantly influences the antioxidant results. Ethanol and methanolic extracts generally show higher phenolic content and stronger antioxidant activity compared to aqueous extracts (Rajasree *et al.*, 2022). Ultrasound-assisted extraction and microwave-assisted extraction have been reported to improve phenolic yield, thereby enhancing antioxidant potential. These findings underscore the importance of optimizing extraction techniques for generating high-quality muskmelon-based antioxidant supplements.

### 4.2 *In vivo* antioxidant mechanisms

*In vivo* studies provide deeper insight into muskmelon's biological relevance by demonstrating how its antioxidants participate in physiological processes inside the body. Animal studies have shown that muskmelon supplementation increases the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). These enzymes play essential roles in detoxifying harmful free radicals and preventing oxidative damage at the cellular and molecular levels. Muskmelon pulp extracts have been shown to reduce lipid peroxidation markers such as malondialdehyde (MDA), indicating a protective effect on cell membranes and lipids. Similarly, muskmelon seed oil, rich in tocopherols and polyunsaturated fatty acids, reduces oxidative stress biomarkers and improves antioxidant status in experimental models. The presence of  $\beta$ -carotene, vitamin C and flavonoids further enhances the body's ability to neutralize ROS and maintain redox homeostasis. In addition to antioxidant enzyme modulation, muskmelon influences inflammatory pathways that are closely linked to oxidative stress (Insanu *et al.*, 2022). Studies indicate that muskmelon extracts inhibit the expression of pro-inflammatory cytokines such as TNF- $\beta$ , IL-6 and IL-1 $\beta$ . By modulating NF- $\kappa$ B signaling pathways, muskmelon reduces oxidative stress-induced inflammatory responses, providing a dual benefit of antioxidant and anti-inflammatory protection.

### 4.3 Role of phenolics and flavonoids in antioxidant defense

Phenolics and flavonoids are potent antioxidants found abundantly in muskmelon's rind, pulp and seeds. These compounds possess hydroxyl groups capable of donating hydrogen atoms or electrons to neutralize free radicals. Their antioxidant mechanisms include free radical scavenging, metal ion chelation, inhibition of oxidant-generating enzymes and protection of biological membranes. Chlorogenic acid, ferulic acid and caffeic acid exhibit strong reducing capacities and contribute significantly to the overall antioxidant activity. Quercetin derivatives, kaempferol glycosides and apigenin compounds enhance cellular antioxidant defense by modulating key enzymes and protecting DNA from oxidative damage. Flavonoids also inhibit lipid peroxidation and prevent oxidative deterioration of cell membranes,

which is crucial for protecting against chronic degenerative diseases. Phenolic content tends to be higher in muskmelon rind than in pulp, suggesting that rind-based nutraceutical formulations may offer greater antioxidant benefits (Yadav *et al.*, 2025). This also highlights the possibility of using muskmelon processing waste to create high-value antioxidant ingredients, contributing to sustainability.

#### 4.4 Contribution of carotenoids to antioxidant activity

Carotenoids, particularly  $\beta$ -carotene, lutein and zeaxanthin, contribute significantly to muskmelon's antioxidant potential.  $\beta$ -carotene acts as a powerful quencher of singlet oxygen and neutralizes hydrogen peroxide and hydroxyl radicals. It also plays a role in preventing oxidative damage to lipids and proteins. Lutein and zeaxanthin are known for their role in eye health. These carotenoids accumulate in the retina and offer protection against light-induced oxidative damage. Muskmelon varieties with deep orange flesh contain high levels of  $\beta$ -carotene, making them valuable dietary sources of vitamin A precursors and antioxidants (Orelaja *et al.*, 2019). Synergistic interactions between carotenoids and phenolics amplify antioxidant activity and contribute to the fruit's therapeutic significance.

#### 4.5 Vitamin-based antioxidant effects

Muskmelon is exceptionally rich in vitamin C, one of the most effective water-soluble antioxidants. Vitamin C directly neutralizes free radicals, regenerates oxidized vitamin E, supports immune function and enhances collagen synthesis. Muskmelon also contains vitamin A (through  $\beta$ -carotene) and vitamin E (found mainly in seeds), providing a powerful combination of water- and fat-soluble antioxidants. Together, these vitamins play key roles in preventing oxidative stress-related cellular damage. Vitamin C content tends to decrease with storage, particularly at high temperatures, highlighting

the importance of consuming fresh muskmelon for maximum antioxidant benefits (Saleem *et al.*, 2021). The presence of multiple antioxidant vitamins makes muskmelon an excellent dietary component for individuals seeking natural antioxidant enrichment.

#### 4.6 Synergistic effects of combined bioactive compounds

The antioxidant potential of muskmelon arises not from a single compound but from synergistic interactions among multiple phytochemicals. Phenolics, flavonoids, carotenoids, vitamins and seed-derived compounds work collectively to enhance antioxidant capacity. This synergy improves modulating oxidative pathways, maintaining cellular integrity and preventing chronic disease development. Studies have shown that muskmelon extracts containing a mixture of phenolics and carotenoids exhibit higher antioxidant activity than isolated compounds alone. Such synergistic effects highlight the importance of consuming whole fruits or minimally processed muskmelon products to maximize health benefits.

### 5. Pharmacological activities of muskmelon

Muskmelon is increasingly recognized as a fruit with broad therapeutic potential due to its diverse phytochemical profile, which includes phenolics, flavonoids, carotenoids, vitamins, minerals and seed-derived fatty acids. These compounds exhibit biological activities that make muskmelon beneficial for managing oxidative stress, inflammation, metabolic disorders, cardiovascular diseases, microbial infections, cancer development and neurodegenerative conditions. The pharmacological effects of muskmelon arise from synergistic interactions among its bioactive molecules, which modulate various molecular pathways and physiological processes (Ghazaleh *et al.*, 2024). The following sections detail the major therapeutic properties of muskmelon supported by experimental evidence (Table 3).

**Table 3: Pharmacological activities of muskmelon and mechanisms of action**

Activity	Bioactive components responsible	Mechanism of action
<b>Antioxidant</b>	Vitamin C, phenolics, carotenoids, flavonoids	Free radical scavenging, lipid peroxidation inhibition
<b>Anti-inflammatory</b>	Quercetin, kaempferol, caffeic acid, $\beta$ -carotene	Downregulation of NF- $\kappa$ B, COX-2 inhibition
<b>Antidiabetic</b>	Phenolics, flavonoids, fiber, seed extracts	$\alpha$ -amylase inhibition, improved insulin sensitivity
<b>Antimicrobial</b>	Phenolics, volatiles, seed oil	Disruption of microbial membranes
<b>Cardioprotective</b>	Potassium, PUFAs, phytosterols	Blood pressure regulation, LDL reduction
<b>Hepatoprotective</b>	Carotenoids, vitamin C, seed oil	Reduced liver enzymes (ALT/AST), antioxidant protection
<b>Anticancer</b>	Flavonoids, carotenoids	Apoptosis induction, inhibition of cell proliferation
<b>Neuroprotective</b>	Vitamin C, lutein, flavonoids	ROS reduction, neurotransmitter modulation
<b>Gastroprotective</b>	Fiber, phenolics	Antiulcer activity, improved digestion

#### 5.1 Anti-inflammatory properties

Inflammation is a natural physiological response, yet chronic inflammation contributes to numerous diseases including arthritis, atherosclerosis, diabetes and cancer. Muskmelon demonstrates significant anti-inflammatory potential due to its rich content of flavonoids, phenolic acids, carotenoids and vitamins. These compounds modulate inflammation through multiple pathways. Flavonoids such as quercetin, kaempferol and apigenin reduce inflammatory responses by inhibiting key signaling molecules involved in cytokine production. They suppress the activation of

NF- $\kappa$ B (nuclear factor kappa B), a transcription factor responsible for producing pro-inflammatory cytokines such as TNF- $\alpha$ , IL-6 and IL-1 $\beta$ . Muskmelon extracts have shown the ability to decrease levels of these cytokines *in vitro* and *in vivo*, indicating strong anti-inflammatory action. Phenolic acids such as caffeic and ferulic acid inhibit cyclooxygenase (COX) and lipoxygenase (LOX) enzymes, reducing the synthesis of inflammatory mediators like prostaglandins and leukotrienes. Carotenoids, particularly  $\beta$ -carotene, also contribute by reducing oxidative stress-induced inflammation through ROS neutralization. The combined effect of these compounds results in decreased tissue inflammation, improved cellular resilience and

protection from chronic inflammatory diseases. Furthermore, muskmelon seed oil rich in linoleic acid and phytosterols exerts additional anti-inflammatory effects by modulating membrane fluidity, reducing oxidative damage and supporting the production of anti-inflammatory lipid mediators (Pandey *et al.*, 2021). This highlights the therapeutic potential of muskmelon seeds in inflammation-related disorders.

### 5.2 Antidiabetic activity

Diabetes mellitus is a global health concern characterized by hyperglycemia, insulin resistance and impaired glucose metabolism. Muskmelon exhibits significant antidiabetic potential through several mechanisms, including glycemic regulation, oxidative stress reduction and modulation of metabolic pathways. The fruit's high fiber content slows glucose absorption, reducing postprandial blood sugar spikes. Flavonoids present in muskmelon, particularly quercetin and kaempferol derivatives, enhance insulin sensitivity by improving glucose uptake in peripheral tissues. These compounds also modulate enzymes involved in carbohydrate digestion such as  $\alpha$ -amylase and  $\alpha$ -glucosidase, thereby lowering glucose release from dietary starch. Vitamin C and phenolic acids contribute to the reduction of oxidative stress, a major factor in diabetes-induced tissue damage. By preventing oxidative damage to pancreatic  $\beta$ -cells, muskmelon helps maintain insulin secretion and metabolic homeostasis. Seed extracts have been reported to lower fasting blood glucose levels and improve lipid profiles in experimental models (Drishya *et al.*, 2024). Additionally, the presence of potassium and magnesium supports insulin signaling and glucose metabolism at the cellular level. Regular consumption of muskmelon may thus contribute to better glycemic control, reduced insulin resistance and decreased risk of long-term diabetic complications.

### 5.3 Antimicrobial and antifungal properties

Muskmelon demonstrates antibacterial and antifungal activity due to its diverse phytochemicals, especially phenolics, flavonoids, volatile compounds and seed-derived fatty acids. These bioactive molecules affect microbial cells by disrupting membrane integrity, inhibiting protein synthesis and interfering with enzyme activity. Extracts from muskmelon rind, pulp and seeds have shown antimicrobial activity against pathogenic bacteria including *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* spp., *Pseudomonas aeruginosa* and *Bacillus subtilis*. Phenolic acids such as chlorogenic acid and ferulic acid disrupt bacterial membranes, causing leakage of cellular contents and inhibiting essential functions. Flavonoids interfere with nucleic acid synthesis and inhibit bacterial growth. Muskmelon volatiles, particularly aldehydes and esters, also exhibit antimicrobial effects by altering microbial cell walls and inhibiting enzyme systems (Zhang *et al.*, 2024). This suggests potential for muskmelon extracts in food preservation, where natural antimicrobials are preferred over synthetic chemicals. Antifungal activity has been observed against species such as *Candida albicans* and *Aspergillus niger*, indicating the potential of muskmelon in preventing fungal infections in humans and postharvest spoilage in fruits. Seed oil rich in linoleic acid enhances antimicrobial potency by destabilizing microbial membranes.

### 5.4 Cardioprotective effects

Cardiovascular diseases remain the leading cause of mortality worldwide. Muskmelon exerts significant cardioprotective effects

due to its potassium content, polyunsaturated fatty acids, antioxidants and phytosterols. These compounds improve heart function, regulate blood pressure, reduce lipid levels and prevent oxidative damage to cardiac tissues. Potassium plays a vital role in maintaining electrolyte balance and regulating blood pressure by counteracting the hypertensive effects of sodium. Regular consumption of potassium-rich fruits like muskmelon helps reduce hypertension risk. Muskmelon seeds contain high levels of linoleic acid and phytosterols that lower LDL cholesterol and improve overall lipid profile. Phytosterols inhibit cholesterol absorption in the intestine, leading to reduced circulating cholesterol levels Lester, (1997). The antioxidant compounds in muskmelon especially vitamin C,  $\beta$ -carotene and phenolics protect cardiovascular tissues by preventing lipid peroxidation, endothelial dysfunction and oxidative damage. In experimental models, muskmelon supplementation has been shown to improve cardiac enzyme profiles, reduce inflammation and enhance blood vessel integrity.

### 5.5 Hepatoprotective activity

The liver plays a central role in detoxification, metabolism and nutrient regulation. Muskmelon demonstrates hepatoprotective activity due to its rich antioxidant profile, which helps prevent liver damage caused by toxins, oxidative stress and inflammation. Muskmelon extract administration has been shown to reduce liver enzyme markers such as ALT, AST and ALP, indicating protection from hepatocellular damage (Morais *et al.*, 2015). Phenolic acids and flavonoids protect hepatocytes by neutralizing free radicals, inhibiting lipid peroxidation and stabilizing cell membranes.  $\beta$ -carotene and vitamin C further enhance hepatic defense by supporting detoxification pathways and reducing inflammatory mediators. Muskmelon seed oil, due to its high fatty acid and tocopherol content, has been shown to reverse fatty liver changes in experimental studies by improving lipid metabolism and reducing oxidative load.

### 5.6 Anticancer potential

Muskmelon exhibits anticancer activity through multiple mechanisms, including antioxidant defense, apoptosis induction, cell cycle regulation and inhibition of tumor proliferation. Phenolics, flavonoids, carotenoids and seed bioactives contribute to its anticancer properties. Flavonoids such as quercetin and kaempferol inhibit cancer cell proliferation by arresting the cell cycle at specific checkpoints, inducing programmed cell death and inhibiting angiogenesis (Castillo *et al.*, 2020). Carotenoids, particularly  $\beta$ -carotene, exhibit strong antioxidant effects, reducing DNA damage and preventing mutations that lead to cancer development. Phenolic acids inhibit tumor-promoting enzymes and reduce the formation of carcinogenic compounds. Muskmelon extracts have shown cytotoxic effects against cancer cell lines including breast, colon and liver cancer cells. These effects arise from mitochondrial dysfunction, increased ROS generation within cancer cells and activation of caspase-dependent apoptosis pathways. The synergistic action of muskmelon bioactives highlights its potential as a dietary component for reducing cancer risk and supporting integrative oncology approaches.

### 5.7 Gastroprotective and digestive benefits

Muskmelon has been traditionally used to alleviate digestive discomfort, acidity and constipation. Its gastroprotective properties are attributed to high water content, dietary fiber, mucilage, vitamins and bioactive compounds. Dietary fiber helps regulate bowel

movement, improves gut motility and sustains beneficial microbiota. The hydrating nature of muskmelon soothes the gastrointestinal tract and prevents dehydration-induced digestive issues. Phenolic compounds such as caffeic acid exhibit antiulcer activity by reducing gastric mucosal damage and oxidative stress (Manchali *et al.*, 2021). Muskmelon also aids digestion by promoting enzyme activity and reducing inflammation in the gut lining. Seed extracts have been reported to improve gastrointestinal health by modulating lipid absorption and reducing acidity.

### 5.8 Neuroprotective properties

Muskmelon demonstrates neuroprotective potential due to its antioxidant vitamins, carotenoids, magnesium content and anti-inflammatory flavonoids. Oxidative stress plays a major role in neurodegenerative diseases such as Alzheimer's and Parkinson's and muskmelon's antioxidants help mitigate neuronal damage. Vitamin C prevents neuronal oxidative stress by scavenging free radicals, while  $\alpha$ -carotene protects neural tissues from lipid peroxidation. Flavonoids improve cognitive function by modulating neurotransmitter activity and reducing inflammation in the brain. Magnesium enhances nerve function and synaptic stability (Asif *et al.*, 2021). Emerging studies suggest that muskmelon may support memory retention, reduce neuroinflammation and protect against age-related cognitive decline.

## 6. Conclusion

Muskmelon (*Cucumis melo* L.) represents a remarkable fusion of nutritional richness, phytochemical diversity and pharmacological potential, positioning it as an underutilized yet exceptionally valuable fruit in the domain of functional foods and nutraceuticals. The extensive evidence compiled in this review demonstrates that muskmelon is far more than a refreshing seasonal fruit; it is a bioactive-rich functional commodity capable of contributing significantly to human health and disease prevention. Its phytochemical composition including phenolic acids, flavonoids, carotenoids, volatile compounds, vitamins, minerals and seed-derived bioactives forms the biochemical foundation for its wide-ranging therapeutic properties. The fruit's potent antioxidant capacity, derived from synergistic interactions among vitamins (C and A), carotenoids, phenolics and seed oil constituents, plays a central role in mitigating oxidative stress, a key factor underlying numerous chronic diseases. These antioxidant defenses not only protect cellular structures from ROS-induced damage but also support immune function, enhance metabolic resilience and slow aging-related degenerative processes. The anti-inflammatory effects of muskmelon further complement its antioxidant benefits, demonstrating its ability to regulate inflammatory pathways, suppress cytokine release and protect tissues from chronic inflammation. In conclusion, muskmelon stands as a promising functional fruit with compelling nutraceutical and pharmacological attributes supported by both traditional wisdom and contemporary scientific evidence. Its holistic combination of nutrients, antioxidants and therapeutic compounds positions it as a natural, accessible and sustainable food-based intervention for promoting human health. Strengthening scientific research, enhancing industrial innovations and expanding clinical validation will pave the way for muskmelon to evolve from a widely enjoyed dietary fruit into a scientifically recognized nutraceutical powerhouse. As global interest in plant-derived health solutions continues to rise, muskmelon holds the potential to contribute meaningfully to nutritional security, preventive healthcare and the future of natural medicine.

## Availability of data and material

All data are provided within the manuscript.

## Authorship contribution statement

**M. Kabilan:** Contributed to conceptualization, supervision, critical review, and overall guidance of the manuscript; **M. Jayakumar:** Contributed to literature survey, data curation, and critical analysis of published studies; **K. Sundharaiya:** Contributed to software handling, reference management, and visualization of review content; **G. Sathish:** Contributed to writing the original draft, reviewing, and editing of the manuscript; **Adnan A. Khan:** Contributed to critical review, validation of scientific content, and final approval of the manuscript.

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All authors gave their full consent for publication and submission to this journal.

## Conflict of interest

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## References

- Asif, H. M.; Akram, M.; Saeed, M. and Khan, S. A. (2014). Medicinal properties of *Cucumis melo* Linn. RADS J. Pharm. Pharm. Sci., **2**(1):58-62.
- Castillo, G. R.; Flores, M.; Gutierrez, L. and García, D. (2020). Bioactive compounds in melon peels and their potential uses. J. Funct. Foods, **65**:103768.
- Drishya, C. M.; Ramesh, M. N. and Prakash, M. (2024). Muskmelon peel as a novel source of pectin for functional food applications. Food Chem. X, **18**:100443.
- Ghazaleh, M. J.; Hosseini, S. M.; Ghorbani, M. and Tavakoli, H. (2024). Physicochemical properties and bioactive compounds of *Cucumis melo* seed extracts. J. Food Qual., **2024**:9998037.
- Gómez-García, R.; Campos, D. A.; Aguilar, C. N.; Madureira, A. R. and Pintado, M. (2020). Valorization of melon fruit (*Cucumis melo* L.) by-products: Phytochemical and biofunctional properties. Trends Food Sci. Technol., **99**:507-519.
- Hodges, D. M. and Lester, G. E. (2006). Changes in antioxidant profiles of orange- and green-fleshed muskmelons following harvest and storage. J. Am. Soc. Hortic. Sci., **131**(1):110-117.
- Insanu, M.; Rizaldy, D.; Silviani, V. and Fidrianny, I. (2022). Chemical compounds and pharmacological activities of *Cucumis* genus. Biointerface Res. Appl. Chem., **12**(1):1324-1334.

- Ismail, H. I.; Chan, K. W.; Mariod, A. A. and Ismail, M. (2010). Phenolic content and antioxidant activity of cantaloupe (*Cucumis melo* L.) methanolic extracts. *Food Chem.*, **119**(2):643-647.
- Lester, G. E. (1997). Melon (*Cucumis melo* L.) fruit nutritional quality and health functionality. *Hort. Technology*, **7**(3):222-227.
- Mallek-Ayadi, S.; Bahloul, N. and Kechaou, N. (2022). Bioactive compounds from *Cucumis melo* L. fruits as nutraceutical sources. *Food Sci. Nutr.*, **10**(8):2888-2901.
- Manchali, S.; Murthy, K. N. C. and Patil, B. S. (2021). Antioxidant potential of selected muskmelon genotypes. *J. Food Compos. Anal.*, **98**:103820.
- Manchali, S.; Murthy, K. N. C.; Vishnuvardana and Patil, B. S. (2021). Nutritional composition and health benefits of various botanical types of *Cucumis melo* L. *Plants*, **10**(9):1755.
- Morais, D. R.; Rotta, E. M.; Sargi, S. C.; Bonafe, E. G.; Eberlin, M. N.; Sawaya, A. C. H. F. and Visentainer, J. V. (2015). Phenolic compounds and antioxidant activity of melon fruits. *Food Res. Int.*, **85**:212-220.
- Orelaja, O. T.; Akintola, A. O. and Afolayan, A. (2019). Phytochemical composition and antioxidant activity of golden melon (*Cucumis melo* L.) seeds. *Int. J. Biochem. Res. Rev.*, **25**(2):1-10.
- Pandey, A.; Yadava, D. K.; Singh, A. and Singh, N. K. (2021). Fruit morphology, nutritional and floral diversity in less-known melons (*Cucumis melo* L.). *Genet. Resour. Crop Evol.*, **68**(5):1453-1470.
- Rajasree, R. S.; Ittiyavirah, S. P.; Naseef, P. P.; Kuruniyan, M. S.; Elayadeth-Meethal, M. and Sankar, S. (2022). Anti-inflammatory properties of methanolic extract of *Cucumis melo* Linn. in Wistar rats. *Saudi J. Biol. Sci.*, **29**(9):103396.
- Saleem, A.; Islam, M.; Saeed, H. and Iqtedar, M. (2021). *In vivo* evaluation of anti-urolithiatic activity of *Cucumis melo* peel and pulp extracts. *Pak. J. Zool.*, **53**(4):1111-1117.
- Silva, M. A.; Albuquerque, T. G.; Ferreira, D. M.; Alves, R. C.; Oliveira, M. B. P. P. and Costa, H. S. (2025). Nutritional and bioactive profiling of *Cucumis melo* L. by-products towards a circular food economy. *Molecules*, **30**(6):1287.
- Vouldoukis, I.; Lacan, D.; Kamate, C.; Coste, P.; Calenda, A.; Mazier, D.; Conti, M. and Dugas, B. (2004). Antioxidant and anti-inflammatory properties of a *Cucumis melo* extract rich in superoxide dismutase activity. *J. Ethnopharmacol.*, **95**(2-3):325-332.
- Yadav, N.; Jangra, P. and Yadav, K. (2025). A comprehensive review on medicinal importance of *Cucumis melo* Linn. *Asian J. Pharm. Res. Dev.*, **13**(1):117-122.
- Zhang, G.; Li, W.; Wang, Y. and Chen, H. (2024). Effect of processing methods on phytochemical composition of melon seeds (*Cucumis melo* L.). *Food Biosci.*, **49**:101399.
- Zulfqar, H.; Hussain, A. I.; Ali, Q.; Rathore, H. A. and Ahmed, I. (2024). Phenolic profile, nutritional potential and biological activities of wild *Cucumis melo* var. *agrestis*. *J. King Saud Univ. Sci.*, **36**(7):103276.

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