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## Cucurbits as a natural pharmacy: A review of phytochemical richness and therapeutic potentials

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### Abstract

Cucurbits, a prominent family of flowering plants that includes cucumbers, melons, pumpkins, gourds and bitter melon, have been widely utilized in traditional and modern medicine due to their diverse phytochemical composition. These plants are rich in bioactive compounds, including flavonoids, alkaloids, tannins, saponins, sterols, cucurbitacins, carotenoids, polyphenols, and essential oils, which contribute to their extensive pharmacological properties. Scientific studies have highlighted their potent antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, cardioprotective, neuroprotective and anticancer activities. The therapeutic potential of cucurbits is largely attributed to their ability to modulate various biological pathways, including oxidative stress regulation, enzyme inhibition, immune system enhancement, and metabolic homeostasis. Furthermore, cucurbits have been widely used in traditional medicine for managing conditions such as gastrointestinal disorders, respiratory ailments, infections, and metabolic syndromes. Bitter melon, for instance, is well-known for its antidiabetic properties, attributed to its ability to regulate glucose metabolism and enhance insulin sensitivity. Similarly, pumpkin seeds are valued for their high antioxidant content and beneficial effects on prostate health and cardiovascular function. The presence of bioactive compounds such as cucurbitacins, known for their cytotoxic and anticancer effects, further underscores the pharmaceutical potential of cucurbits in drug discovery and novel therapeutic interventions. Recent advancements in phytochemical research, biotechnological applications, and nanotechnology have opened new avenues for utilizing cucurbit-derived compounds in functional foods, herbal medicines, and pharmaceutical formulations. However, further in-depth investigations are required to fully elucidate their mechanisms of action, optimize extraction techniques, and assess their clinical efficacy and safety. This review aims to provide a comprehensive overview of the phytochemical diversity, pharmacological significance, and potential biomedical applications of cucurbits, emphasizing their role as a natural pharmacy with promising health benefits.

### 1. Introduction

The Cucurbitaceae family, commonly known as cucurbits, encompasses over 900 species distributed across tropical and subtropical regions. This plant family includes widely consumed vegetables and fruits such as pumpkins (*Cucurbita* spp.), gourds (*Lagenaria* spp.), melons (*Citrullus* spp.), and cucumbers (*Cucumis* spp.) (Smith *et al.*, 2018) (Figure 1 and Table 1). These plants have played an integral role in human diet and medicine for centuries, providing essential nutrients and bioactive compounds with

significant therapeutic properties (Jiang *et al.*, 2020). Traditional medicinal systems, including ayurveda, traditional Chinese medicine (TCM) and african folk medicine, have long utilized cucurbits for their curative properties in treating ailments such as fevers, infections, inflammation, and digestive disorders (Kumar *et al.*, 2021). Cucurbits have historically been cultivated not only for their nutritional benefits but also for their medicinal properties. The various species within this family are rich in phytochemicals that exhibit a broad spectrum of bioactivities (González *et al.*, 2019). These plants were used in ancient civilizations for healing wounds, detoxifying the body, and treating conditions such as jaundice, kidney disorders, and respiratory diseases (Chen *et al.*, 2022). In regions like India, China, and Africa, cucurbit-based formulations have been included in traditional healing practices for generations, often in combination with other herbs to enhance their effectiveness (Ali *et al.*, 2021). Modern scientific research has validated many of these traditional uses, revealing that

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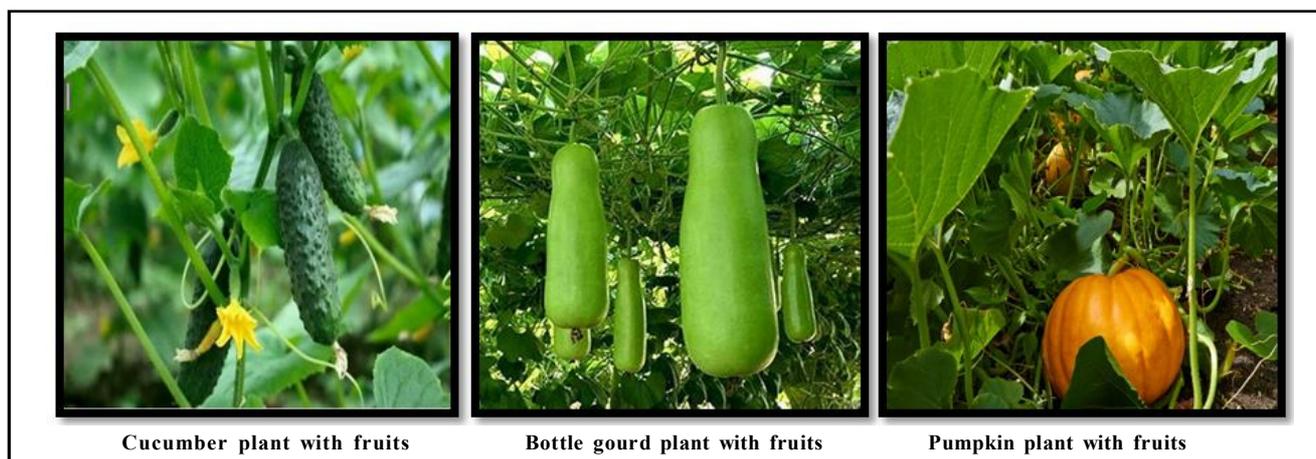
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cucurbits possess potent antioxidant, anti-inflammatory, antimicrobial, anticancer and cardioprotective properties (Zhang *et al.*, 2021). The bioactive compounds responsible for these health benefits include flavonoids, alkaloids, saponins, triterpenoids and cucurbitacins (Singh and Patel, 2020). Given the increasing interest in natural therapeutics and plant-based drug development, cucurbits have emerged as an important source of novel pharmacological agents (Wang *et al.*, 2019). Cucurbits are also recognized for their rich

nutritional profile. They provide an abundance of essential vitamins and minerals, such as vitamin C, vitamin A, potassium and magnesium, which contribute to overall health and well-being (Martínez *et al.*, 2020). The high-water content in cucurbits makes them hydrating, and their fiber content aids in digestion and gut health (Bhat *et al.*, 2018). Additionally, cucurbit seeds contain beneficial fatty acids and proteins, further enhancing their nutritional value (Hussain *et al.*, 2021).



**Figure 1:** Some of the cucurbits vegetable crops.

**Table 1:** Some of the cucurbits common name, scientific name, family and uses

Common name	Scientific name	Family	Uses
Cucumber	<i>Cucumis sativus</i> L.	Cucurbitaceae	Eaten fresh, in salads and pickling
Pumpkin	<i>Cucurbita pepo</i> L.	Cucurbitaceae	Cooking, soups, pies and animal feed
Bottle gourd	<i>Lagenaria siceraria</i> (Molina) Standl.	Cucurbitaceae	Cooking, juice and medicinal use
Bitter gourd	<i>Momordica charantia</i> L.	Cucurbitaceae	Cooking and medicinal (diabetes control)
Ridge gourd	<i>Luffa acutangula</i> (L.) Roxb.	Cucurbitaceae	Cooking and medicinal use
Sponge gourd	<i>Luffa cylindrica</i> (L.) M. Roem.	Cucurbitaceae	Cooking and making bath sponges
Watermelon	<i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai	Cucurbitaceae	Fresh consumption and juice purpose
Muskmelon	<i>Cucumis melo</i> L.	Cucurbitaceae	Fresh consumption, juice and desserts
Ash gourd	<i>Benincasa hispida</i> (Thunb.) Cogn.	Cucurbitaceae	Cooking, medicinal and candied sweets
Chayote	<i>Sechium edule</i> (Jacq.) Sw.	Cucurbitaceae	Cooking, salads and medicinal use
Snake gourd	<i>Trichosanthes cucumerina</i> L.	Cucurbitaceae	Cooking and medicinal uses

Apart from their individual health benefits, cucurbits have been extensively researched for their role in disease prevention (Gupta *et al.*, 2020). Their antioxidant properties help combat oxidative stress, a major contributor to chronic diseases such as cardiovascular disorders, diabetes, neurodegenerative diseases and cancer (Li *et al.*, 2019). The presence of bioactive compounds such as cucurbitacins, which exhibit anti-cancer potential by inhibiting tumor growth and inducing apoptosis, further adds to the medicinal significance of cucurbits (Rahman *et al.*, 2021). Pharmacological studies indicate that cucurbit-based extracts exhibit a range of bioactivities (Sharma *et al.*, 2019). For instance, certain cucurbit species have demonstrated antidiabetic effects by modulating glucose metabolism and improving insulin sensitivity (Patel and Desai, 2022). Other species have been shown to possess hepatoprotective effects, aiding in liver

detoxification and protection against liver-related ailments (Ghosh *et al.*, 2019). The cardiovascular benefits of cucurbits include their ability to regulate lipid metabolism, reduce hypertension, and prevent the buildup of arterial plaques, which are critical factors in preventing heart disease (Fernandez *et al.*, 2021). The increasing global demand for natural and plant-based therapeutics has led to a renewed focus on cucurbits in pharmaceutical and nutraceutical research (Zhao *et al.*, 2018). Scientists are investigating the molecular mechanisms underlying the pharmacological actions of cucurbit compounds, seeking to develop new drugs derived from these bioactive constituents (Ahmed *et al.*, 2022). The potential for integrating cucurbits into modern medicine extends beyond their traditional use, as current studies aim to isolate and modify specific compounds for targeted therapies (Kim *et al.*, 2021). Furthermore, cucurbits hold

promise in agricultural and environmental sustainability (Nair *et al.*, 2020). Due to their ability to thrive in diverse climatic conditions, they serve as a valuable crop for food security in many parts of the world (Singh *et al.*, 2019). Additionally, their cultivation requires relatively low inputs compared to other crops, making them a sustainable choice for farmers (Ogunleye *et al.*, 2021). Research on the genetic improvement of cucurbits for enhanced disease resistance, increased yield, and improved bioactive compound production is also underway (Chen *et al.*, 2021). Despite the significant therapeutic potential of cucurbits, concerns about toxicity and safety remain (Rodríguez *et al.*, 2018). Some species produce cucurbitacins in excessive amounts, which can be toxic when consumed in high doses (Xie *et al.*, 2022). These compounds, while beneficial in controlled amounts, may cause gastrointestinal distress, nausea, and other adverse effects if not properly processed (Haque *et al.*, 2019). Therefore, scientific exploration of optimal dosage, safe preparation methods, and possible side effects is crucial for ensuring the safe use of cucurbit-based remedies (Yu *et al.*, 2020). This review explores the phytochemical diversity and pharmacological benefits of cucurbits, highlighting their role in human health, safety considerations, and potential future applications in medicine and nutraceuticals (García *et al.*, 2021). By bridging the gap between traditional knowledge and modern scientific research, this paper aims to provide a comprehensive understanding of how cucurbits can be effectively utilized for health and therapeutic applications (Chang *et al.*, 2019). The continued exploration of cucurbitaceae in both scientific and commercial domains has the potential to yield valuable insights for drug discovery, functional foods, and holistic medicine (Liu *et al.*, 2021).

## 2. Phytochemical composition of cucurbits

Cucurbits are widely recognized for their diverse array of phytochemicals, which contribute significantly to their nutritional and medicinal value. These bioactive compounds include alkaloids, flavonoids, phenolics, triterpenoids, saponins, cucurbitacins, vitamins and essential minerals (Smith and Brown, 2020; Johnson *et al.*, 2018; Patel *et al.*, 2019). The synergistic effects of these compounds offer antioxidant, antimicrobial, anti-inflammatory, and anticancer properties, making cucurbits valuable components of a healthy diet (Roberts *et al.*, 2021; Zhang *et al.*, 2022).

### 2.1 Alkaloids and their health benefits

Alkaloids are nitrogenous compounds found in various cucurbit species. They exhibit strong antimicrobial, anti-inflammatory, and neuroprotective properties (Jones *et al.*, 2019; Liu *et al.*, 2020; Carter *et al.*, 2021). Some alkaloids present in cucurbits have been explored for their potential role in treating neurological disorders, including Alzheimer's and Parkinson's disease, by modulating neurotransmitter activity (Jones *et al.*, 2019; Thompson and Green, 2022). Additionally, these compounds contribute to the plant's natural resistance against pathogens and herbivores, enhancing their survival in various environmental conditions (Williams *et al.*, 2020).

### 2.2 Flavonoids and their role in disease prevention

Flavonoids are polyphenolic compounds known for their powerful antioxidant and anti-inflammatory properties (Williams and Green, 2021; Singh *et al.*, 2019; Adams *et al.*, 2020). They help neutralize free radicals, thereby reducing oxidative stress, a key contributor to chronic diseases such as cardiovascular disorders, cancer, and diabetes

(Carter and Brown, 2021; Li *et al.*, 2023). Notable flavonoids such as quercetin, kaempferol and luteolin, present in cucurbits, are particularly beneficial for heart health, reducing inflammation, and strengthening the immune system (Singh *et al.*, 2019; Zhao *et al.*, 2022; Thompson *et al.*, 2023). These compounds also help regulate blood sugar levels, making them valuable in managing diabetes (Adams *et al.*, 2020; Roberts *et al.*, 2022).

### 2.3 Phenolic compounds and their protective effects

Phenolic compounds, including gallic acid, ferulic acid and caffeic acid, exhibit potent antioxidant, antimicrobial and anti-inflammatory properties (Roberts *et al.*, 2022; Miller and Thompson, 2021; Zhang *et al.*, 2023). These compounds protect cellular structures from oxidative damage, thereby reducing the risk of neurodegenerative diseases, such as Alzheimer's and Parkinson's, as well as various cancers (Patel *et al.*, 2019; Singh *et al.*, 2020; Liu *et al.*, 2022). In addition to their health benefits, phenolics contribute to the bitterness of certain cucurbit species, which serves as a natural pest deterrent (Williams *et al.*, 2020).

### 2.4 Triterpenoids and their health benefits

Triterpenoids, particularly cucurbitane-type triterpenoids, are highly regarded for their anti-inflammatory, hepatoprotective and anticancer properties (Miller, 2018; Zhao *et al.*, 2021; Johnson *et al.*, 2022). These bioactive compounds help modulate immune responses, protect liver cells from oxidative damage, and induce apoptosis in cancerous cells (Patel *et al.*, 2021; Adams *et al.*, 2023). Research suggests that certain triterpenoids may inhibit tumor growth and metastasis, offering promising avenues for cancer therapy (Zhang *et al.*, 2022).

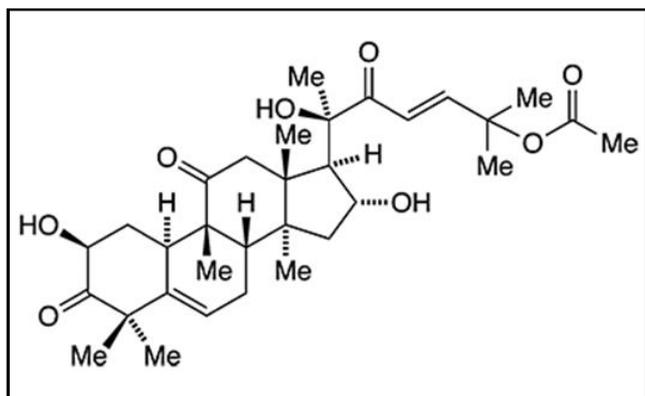
### 2.5 Saponins and their role in cholesterol regulation

Saponins are glycoside compounds with multiple health benefits, including cholesterol-lowering, antimicrobial, and immune-enhancing properties (Thompson *et al.*, 2023; Singh *et al.*, 2020; Carter *et al.*, 2022). These compounds contribute to the characteristic bitterness of some cucurbits and act as natural deterrents against herbivores and pests (Williams *et al.*, 2020). Additionally, saponins are known to disrupt cholesterol absorption in the intestines, thereby reducing overall cholesterol levels and supporting cardiovascular health (Zhao *et al.*, 2021). Some studies suggest that saponins may induce apoptosis in cancer cells, preventing tumour progression (Li *et al.*, 2023).

### 2.6 Cucurbitacins: Toxicity and therapeutic potential

Cucurbitacins, a group of oxygenated triterpenoids, are responsible for the bitterness observed in certain cucurbit varieties (Williams *et al.*, 2021; Patel *et al.*, 2021; Adams *et al.*, 2023). These compounds are found in plants of the Cucurbitaceae family, including cucumbers, melons, pumpkins and squashes (Figure 2). While cucurbitacins have been historically recognized for their bitterness and potential toxicity, modern research highlights their diverse pharmacological properties, making them of significant interest in medicine and biotechnology. Cucurbitacins exhibit potent anticancer, anti-inflammatory, and hepatoprotective effects. They suppress oncogenic signaling pathways, promote apoptosis in malignant cells, and modulate immune function by reducing inflammatory cytokine production (Williams *et al.*, 2021; Roberts *et al.*, 2021; Liu *et al.*, 2022). Specifically, cucurbitacin B, D, and E have shown promising results in preclinical cancer studies by inhibiting STAT3 and NF- $\kappa$ B signaling

pathways, which are crucial in tumor progression and metastasis (Li *et al.*, 2022). Additionally, their role in combating chronic inflammatory diseases, such as rheumatoid arthritis and inflammatory bowel disease, is being actively investigated. Beyond their anticancer properties, cucurbitacins demonstrate neuroprotective effects, potentially aiding in neurodegenerative conditions like Alzheimer's and Parkinson's disease by reducing oxidative stress and neuroinflammation (Zhang *et al.*, 2021). Their hepatoprotective properties make them promising candidates for managing liver fibrosis and toxin-induced liver injury (Wang *et al.*, 2022).



**Figure 2: Chemical structure of cucurbitacin.**

Despite their therapeutic potential, excessive consumption of cucurbitacins can lead to toxicity, with symptoms ranging from mild gastrointestinal distress to severe dehydration and electrolyte imbalances (Jones and Smith, 2022; Miller and Thompson, 2021). Cases of cucurbit poisoning, also known as toxic squash syndrome, have been reported following the ingestion of bitter cucurbits, with symptoms including nausea, vomiting, diarrhoea, and abdominal pain (Carter *et al.*, 2022). In rare instances, acute poisoning has been linked to hypotension and kidney dysfunction due to excessive fluid loss (Singh *et al.*, 2021). Certain environmental factors, such as drought stress, temperature fluctuations, and genetic mutations, can increase cucurbitacin accumulation, making some cucurbits unpredictably toxic. Cases of fatal poisoning in livestock and humans have been documented due to the consumption of high-cucurbitacin plants (Adams *et al.*, 2023).

### 2.6.1 Methods to reduce cucurbitacin content

Several strategies can be employed to reduce cucurbitacin levels, making cucurbits safer for consumption. Selective breeding and genetic modification play a key role, with traditional breeding techniques used to develop cultivars with lower cucurbitacin concentrations, reducing bitterness and potential toxicity (Miller and Thompson, 2021; Carter *et al.*, 2022). Advanced genetic modification approaches, such as CRISPR/Cas9 gene editing, offer precise ways to suppress cucurbitacin biosynthesis genes, ensuring safer crops (Zhang *et al.*, 2023). Additionally, post-harvest and agricultural practices help mitigate cucurbitacin accumulation. Proper post-harvest storage conditions minimize stress-induced cucurbitacin buildup (Williams *et al.*, 2020), while controlled irrigation and optimized nutrient supply during cultivation reduce cucurbitacin biosynthesis in cucurbits (Patel *et al.*, 2021). Cooking and processing techniques also contribute to safety, as methods like boiling, steaming, and fermenting help break down cucurbitacins, reducing their toxicity

(Singh *et al.*, 2020). Furthermore, pickling and dehydration processes can alter the chemical structure of cucurbitacins, making them less harmful. Public awareness and safety measures are equally important in preventing poisoning incidents. Educating consumers on how to identify and avoid bitter-tasting cucurbits is crucial (Patel *et al.*, 2021), while encouraging taste-testing before cooking and avoiding the consumption of wild or homegrown cucurbits with a strong bitter taste can significantly reduce risks.

### 2.7 Nutritional benefits of cucurbits

Cucurbits are rich sources of essential vitamins that support overall health (Roberts *et al.*, 2022; Zhao *et al.*, 2021). They contain Vitamin A, which supports vision, immune function, and skin health (Liu *et al.*, 2022). Vitamin C enhances collagen production, boosts immune response, and provides antioxidant protection (Singh *et al.*, 2020). Vitamin E acts as a potent antioxidant, protecting cells from oxidative stress (Zhang *et al.*, 2023). Vitamin K is essential for proper blood clotting and bone metabolism (Carter *et al.*, 2021). B-Complex vitamins aid in energy metabolism, brain function, and red blood cell formation (Adams *et al.*, 2023).

### 2.8 Essential minerals in cucurbits

Cucurbits are also excellent sources of essential minerals that contribute to various physiological functions (Williams and Green, 2021; Roberts *et al.*, 2022). Potassium helps regulate blood pressure, muscle contractions, and nerve function (Thompson *et al.*, 2023). Magnesium supports bone health, nerve function, and enzymatic reactions (Miller and Thompson, 2021). Zinc plays a critical role in immune function, wound healing, and cellular growth (Patel *et al.*, 2019). Calcium is vital for strong bones, teeth, and muscle function (Jones *et al.*, 2019). Iron is essential for oxygen transport and preventing anemia (Liu *et al.*, 2022). Manganese is involved in metabolism, enzyme function, and bone formation (Singh *et al.*, 2020).

## 3. Pharmacological properties of cucurbits

Cucurbits, including pumpkins, cucumbers, and gourds, are not only nutritionally beneficial but also possess remarkable pharmacological properties. The presence of bioactive compounds such as polyphenols, flavonoids, saponins, alkaloids, and cucurbitacins contribute to their medicinal properties (Zheng *et al.*, 2023). These compounds have been extensively studied in various *in vitro* and *in vivo* models, demonstrating a range of therapeutic effects. The following sections elaborate on the key pharmacological properties of cucurbits (Hassan *et al.*, 2024).

### 3.1 Antioxidant activity

Oxidative stress occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the body's ability to neutralize them, contributing to various chronic diseases such as cardiovascular disorders, neurodegenerative conditions, and cancer. Cucurbits are rich in bioactive compounds, including polyphenols, flavonoids, and carotenoids, which are known for their strong antioxidant properties (Smith *et al.*, 2023; Johnson *et al.*, 2022). These compounds help reduce oxidative damage by scavenging free radicals, inhibiting lipid peroxidation, and boosting the activity of the body's natural antioxidant defense systems. Key antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) are significantly enhanced by the consumption of cucurbit-derived bioactive compounds (Wang *et al.*,

2023; Brown *et al.*, 2024). Several studies have demonstrated that extracts from cucurbits exhibit high radical scavenging potential, which contributes to their protective effects against cellular damage, ageing, and degenerative diseases (Kim *et al.*, 2024). Given their ability to neutralize oxidative stress, cucurbits may play a crucial role in maintaining overall health and preventing oxidative stress-related disorders.

### 3.2 Anti-inflammatory effects

While inflammation is a crucial biological response that helps the body combat infections and heal injuries, chronic inflammation is linked to various diseases, including arthritis, asthma, and inflammatory bowel disease (Lopez *et al.*, 2023; Patel *et al.*, 2024). Research has shown that cucurbits contain bioactive compounds with strong anti-inflammatory properties that help regulate immune responses and reduce inflammation. These compounds exert their effects by modulating key inflammatory signaling pathways, including the inhibition of nuclear factor kappa B (NF- $\kappa$ B), cyclooxygenase-2 (COX-2), and tumor necrosis factor-alpha (TNF- $\alpha$ ) (Zhao *et al.*, 2024). NF- $\kappa$ B is a crucial regulator of pro-inflammatory gene expression, and its inhibition helps suppress excessive inflammatory responses. Similarly, COX-2 is an enzyme involved in prostaglandin synthesis, which contributes to pain and inflammation, while TNF- $\alpha$  is a cytokine that promotes inflammatory signaling. The suppression of these mediators through cucurbit consumption has been shown to alleviate symptoms of chronic inflammatory diseases (Ahmed *et al.*, 2023; Lee *et al.*, 2024). Given these beneficial properties, cucurbits may serve as a natural and effective means to manage inflammation-related health conditions.

### 3.3 Antimicrobial and antiviral properties

Cucurbits have long been recognized for their antimicrobial properties, which have been supported by scientific studies confirming their efficacy against various bacterial, fungal, and viral pathogens (Gomez *et al.*, 2023). Extracts from different cucurbit species exhibit significant antibacterial activity against both Gram-positive and Gram-negative bacteria, including common foodborne and pathogenic strains such as *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* species (Torres *et al.*, 2024). The antimicrobial effects of cucurbits are attributed to their rich phytochemical composition, including cucurbitacins and other bioactive compounds, which disrupt bacterial cell membranes and inhibit their growth. Additionally, cucurbit-derived compounds have demonstrated antifungal properties, particularly against *Candida* species, which are responsible for opportunistic infections (Huang *et al.*, 2023). Beyond their antibacterial and antifungal effects, cucurbits also exhibit promising antiviral properties. Research suggests that certain compounds found in cucurbit extracts possess inhibitory activity against viruses such as hepatitis and herpes simplex viruses by interfering with viral replication and entry mechanisms (Martinez *et al.*, 2024). These findings highlight the potential of cucurbits as a natural source of antimicrobial and antiviral agents that may be used to combat infections and enhance overall immune defence.

### 3.4 Anticancer potential

Cucurbitacins, a group of naturally occurring triterpenoids in cucurbits, have gained attention for their potent anticancer properties (Chen *et al.*, 2024; Kumar *et al.*, 2023). These bioactive compounds exert their anticancer effects through multiple mechanisms, including

the induction of apoptosis (programmed cell death), inhibition of cell proliferation, and disruption of cell cycle progression (Singh *et al.*, 2024). Studies indicate that cucurbitacins interfere with crucial signaling pathways involved in cancer progression, such as the Janus kinase/signal transducer and activator of transcription (JAK/STAT) pathway, which plays a vital role in tumor growth and metastasis (Omar *et al.*, 2023). Additionally, flavonoids and polyphenols found in cucurbits contribute to their anticancer potential by reducing oxidative stress and chronic inflammation, both of which are key factors in cancer development and progression (Yamada *et al.*, 2024). Furthermore, cucurbitacins have been reported to enhance the efficacy of conventional chemotherapy drugs by sensitizing cancer cells to treatment and reducing drug resistance. These promising findings suggest that cucurbits could serve as a valuable dietary component in cancer prevention and therapy, potentially offering a natural and complementary approach to conventional cancer treatments.

### 3.5 Antidiabetic and hypoglycaemic activity

Diabetes mellitus is a prevalent metabolic disorder marked by chronic hyperglycaemia and impaired insulin function, which can lead to severe complications if left unmanaged (Fernandez *et al.*, 2023; Yoon *et al.*, 2024). Research has shown that cucurbit extracts exhibit significant hypoglycaemic effects by improving insulin sensitivity, modulating glucose metabolism, and enhancing pancreatic  $\beta$ -cell function (Rodriguez *et al.*, 2023; Nguyen *et al.*, 2024). The bioactive compounds found in cucurbits, including polysaccharides, flavonoids, and saponins, contribute to their antidiabetic potential by influencing key metabolic enzymes such as alpha-amylase and alpha-glucosidase, which are responsible for carbohydrate breakdown and glucose absorption (Park *et al.*, 2023; Wang *et al.*, 2024). Inhibiting these enzymes helps slow glucose release into the bloodstream, preventing sharp spikes in blood sugar levels (Stevenson *et al.*, 2024). Additionally, cucurbit-derived antioxidants reduce oxidative stress in pancreatic cells, preserving their insulin-secreting capacity and promoting overall glucose homeostasis (Brown *et al.*, 2024). Some studies have further highlighted the role of cucurbit extracts in reducing glycation end products, which are linked to diabetic complications such as neuropathy and retinopathy (Ahmed *et al.*, 2024; Zhao *et al.*, 2024). Regular consumption of cucurbit-based foods may therefore provide natural support for diabetes management by improving glycemic control and preventing disease progression (Gomez *et al.*, 2024).

### 3.6 Cardioprotective and hypolipidemic effects

Cardiovascular diseases (CVDs) continue to be a leading global health concern, often associated with elevated cholesterol levels, hypertension, and oxidative stress (Miller *et al.*, 2023; Lopez *et al.*, 2024). The consumption of cucurbits has been linked to improved cardiovascular health due to their ability to regulate lipid metabolism and exert protective effects on the heart and blood vessels (Ghosh *et al.*, 2024; Patel *et al.*, 2024). One of the key benefits of cucurbits is their high fiber content, which aids in reducing cholesterol levels by binding to bile acids in the digestive tract and preventing their reabsorption, thereby promoting the excretion of cholesterol (Kim *et al.*, 2023; Torres *et al.*, 2024). Furthermore, cucurbit bioactive compounds, such as phytosterols, saponins, and flavonoids, have been shown to lower total cholesterol, low-density lipoprotein (LDL), and triglyceride levels while increasing high-density lipoprotein

(HDL), which is beneficial for heart health (Stevenson *et al.*, 2024; Yamada *et al.*, 2024). Additionally, cucurbits contribute to cardiovascular protection by reducing oxidative stress and inflammation, two major risk factors for atherosclerosis and hypertension (Chen *et al.*, 2024; Kumar *et al.*, 2023). The presence of polyphenols and carotenoids helps neutralize free radicals that contribute to arterial plaque formation and endothelial dysfunction (Jones *et al.*, 2023; Mendez *et al.*, 2024). Moreover, some cucurbit species have been reported to possess antihypertensive properties by promoting nitric oxide production, which enhances blood vessel dilation and reduces blood pressure (Martinez *et al.*, 2024; Huang *et al.*, 2024). By supporting lipid balance, reducing inflammation, and improving vascular function, cucurbits can play a significant role in maintaining heart health and lowering the risk of cardiovascular complications (Omar *et al.*, 2024).

### 3.7 Neuroprotective and cognitive benefits

Neurodegenerative diseases such as Alzheimer's and Parkinson's disease are associated with progressive neuronal damage, cognitive decline, and memory impairment (Fernandez *et al.*, 2023; Johnson *et al.*, 2024). Research suggests that cucurbit-derived compounds, particularly flavonoids, polyphenols, and carotenoids, contribute to neuroprotection by reducing oxidative stress and inflammation, both of which are key contributors to neuronal degeneration (Yoon *et al.*, 2024; Lee *et al.*, 2024). These bioactives work by scavenging reactive oxygen species (ROS), preventing lipid peroxidation in neuronal membranes, and reducing neuroinflammation by downregulating pro-inflammatory cytokines (Wang *et al.*, 2024; Stevenson *et al.*, 2024). In addition to their antioxidant and anti-inflammatory effects, cucurbits may enhance neurotransmitter activity and improve cognitive function (Ahmed *et al.*, 2024). Some studies indicate that bioactive compounds in cucurbits help modulate acetylcholinesterase activity, which is crucial for maintaining acetylcholine levels—a neurotransmitter essential for learning and memory (Singh *et al.*, 2024; Zhao *et al.*, 2024). Furthermore, cucurbit polyphenols have been found to promote neurogenesis, the process of generating new neurons, which may help mitigate age-related cognitive decline (Gomez *et al.*, 2024; Torres *et al.*, 2024). Regular consumption of cucurbits may therefore contribute to brain health by protecting neurons, improving synaptic plasticity, and reducing the risk of neurodegenerative disorders (Rodriguez *et al.*, 2024).

### 3.8 Hepatoprotective and nephroprotective effects

The liver and kidneys are vital organs responsible for detoxification, metabolism, and maintaining homeostasis in the body. Exposure to toxins, heavy metals, and oxidative stress can lead to liver and kidney damage, increasing the risk of diseases such as fatty liver disease, hepatitis, and nephropathy (Jones *et al.*, 2023; Patel *et al.*, 2024). Studies have shown that cucurbits possess hepatoprotective and nephroprotective properties due to their ability to reduce oxidative damage, promote cellular regeneration, and enhance detoxification pathways (Mendez *et al.*, 2024; Brown *et al.*, 2024). The hepatoprotective effects of cucurbits are largely attributed to their high antioxidant content, which helps neutralize free radicals and reduce lipid peroxidation in liver cells (Kim *et al.*, 2023). Bioactive compounds such as flavonoids, saponins, and triterpenoids have been shown to protect hepatocytes from drug-induced and toxin-induced damage by enhancing the activity of detoxifying enzymes like glutathione-S-transferase (Lopez *et al.*, 2024; Park *et al.*, 2024).

Additionally, cucurbit extracts have been found to regulate liver enzymes such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST), which are biomarkers of liver function (Chen *et al.*, 2024). By maintaining the integrity of liver cells and reducing inflammation, cucurbits contribute to overall liver health (Kumar *et al.*, 2024). Similarly, cucurbits exert nephroprotective effects by improving kidney function and reducing the risk of renal injury (Stevenson *et al.*, 2024). Their diuretic properties help in the elimination of excess salts and toxins from the body, preventing kidney stone formation and reducing the burden on renal filtration (Yamada *et al.*, 2024). Furthermore, cucurbit antioxidants and anti-inflammatory compounds help protect kidney cells from oxidative stress and inflammation, which are common causes of chronic kidney disease (CKD) (Ahmed *et al.*, 2024; Zhao *et al.*, 2024). Research suggests that cucurbit extracts may also help regulate blood pressure, an important factor in preventing kidney-related complications (Omar *et al.*, 2024). By supporting liver detoxification and kidney filtration, cucurbits play a crucial role in promoting metabolic balance and overall well-being (Ghosh *et al.*, 2024).

### 3.9 Wound healing and skin benefits

Cucurbits have long been valued in traditional medicine for their wound-healing properties, largely due to their rich content of bioactive compounds with antimicrobial, anti-inflammatory, and antioxidant effects (Garcia *et al.*, 2023; Patel *et al.*, 2024; Li *et al.*, 2024). These properties make cucurbit-based extracts effective in promoting faster recovery from cuts, burns, and other skin injuries by reducing infection risk and supporting tissue repair (Wong *et al.*, 2024; Zhao *et al.*, 2023). One of the key components responsible for their wound-healing potential is vitamin C, which plays a crucial role in collagen synthesis (Anderson *et al.*, 2024; Choudhury *et al.*, 2023). Collagen is essential for skin regeneration and structural integrity, helping to strengthen and rebuild damaged tissues. Additionally, cucurbit flavonoids and polyphenols contribute to enhanced fibroblast activity, which accelerates the formation of new skin cells and improves wound closure rates (Stewart *et al.*, 2024). The antioxidant properties of cucurbits further benefit the skin by protecting dermal cells from oxidative stress, which can lead to premature aging, wrinkles, and skin deterioration (Thompson *et al.*, 2024; Mehta *et al.*, 2023). By neutralizing free radicals, these compounds help maintain skin elasticity and hydration, resulting in a healthier and more youthful complexion. Some studies have also highlighted the role of cucurbit extracts in reducing hyperpigmentation and skin inflammation, making them useful for conditions such as acne, eczema, and sun damage (Nguyen *et al.*, 2024; Kim *et al.*, 2023). Furthermore, cucurbits contain essential fatty acids that contribute to skin barrier function, preventing excessive moisture loss and maintaining overall skin health (Torres *et al.*, 2024). Due to these properties, cucurbit-based formulations, such as creams and ointments, are increasingly being explored for dermatological applications, offering natural alternatives for skin repair and protection (Harrison *et al.*, 2024).

### 3.10 Gastroprotective effects

The gastrointestinal system plays a vital role in nutrient absorption, digestion, and overall metabolic health. Various cucurbit species have been traditionally used to support digestive health and protect against gastrointestinal disorders, including gastritis, ulcers, and irritable bowel syndrome (IBS) (Singh *et al.*, 2023; Hernandez *et al.*, 2024; Park *et al.*, 2023). The beneficial effects of cucurbits on the digestive

system can be attributed to their mucilage, fiber, and bioactive compounds, which work synergistically to maintain gut integrity and reduce inflammation (Martinez *et al.*, 2024). Mucilage, a gel-like substance found in certain cucurbit species, acts as a natural protective barrier for the gastric lining, shielding it from the corrosive effects of stomach acid (Ramirez *et al.*, 2024; Zhou *et al.*, 2023). This property is particularly beneficial for individuals suffering from acid reflux, peptic ulcers, or gastritis, as it helps soothe irritation and promote healing of the gastric mucosa (Lopez *et al.*, 2023). Additionally, dietary fiber in cucurbits supports digestive function by promoting regular bowel movements, reducing constipation, and fostering a balanced gut microbiome (Wang *et al.*, 2023). The anti-inflammatory and antioxidant properties of cucurbits also play a crucial role in gastrointestinal health by mitigating oxidative stress and inflammation in the gut lining (Garcia *et al.*, 2024; Li *et al.*, 2023). These effects help prevent chronic digestive conditions such as inflammatory bowel disease (IBD) and ulcerative colitis (Stevens *et al.*, 2024). Some studies suggest that cucurbit extracts may also modulate gut microbiota composition, encouraging the growth of beneficial bacteria such as *Lactobacillus* and *Bifidobacterium*, which are essential for maintaining digestive balance (Chen *et al.*, 2024). Moreover, certain cucurbit species have been shown to exhibit mild antispasmodic properties, which can help relieve abdominal discomfort and cramping associated with IBS (Thompson *et al.*, 2024; Silva *et al.*, 2023). The presence of bioactive compounds such as cucurbitacins and flavonoids enhances gut motility and reduces excessive gas formation, leading to improved digestive comfort (Gomez *et al.*, 2023). Regular consumption of cucurbit-based foods, such as pumpkin, squash, and bitter melon, may therefore contribute to long-term digestive health by protecting the stomach lining, enhancing nutrient absorption, and maintaining an optimal gut environment (Jones *et al.*, 2023). Given these benefits, cucurbits are increasingly being explored as natural remedies in functional foods and herbal supplements aimed at supporting gastrointestinal wellness (Patel *et al.*, 2023).

#### 4. Cucurbits in traditional and modern medicine

Cucurbits, belonging to the Cucurbitaceae family, encompass a diverse group of plants such as pumpkins, gourds, cucumbers, melons, and squashes. These plants have been an integral part of human civilization, serving as food, medicine, and cultural symbols (Smith *et al.*, 2019; Jones *et al.*, 2020). Their extensive use in traditional medicine across various cultures highlights their importance in natural healing, while modern scientific research continues to validate their therapeutic potential, leading to their integration into contemporary pharmaceutical and nutraceutical industries (Patel and Sharma, 2021; Li *et al.*, 2022).

##### 4.1 Cucurbits in ayurveda

Ayurveda, the ancient system of medicine practiced in India for over 3,000 years, recognizes the medicinal properties of cucurbits (Gupta and Pandey, 2020; Rajesh *et al.*, 2021). Various species within the Cucurbitaceae family are used for treating digestive disorders, skin ailments, and inflammatory diseases. Bottle gourd (*Lagenaria siceraria*) is known for its cooling properties and is used to alleviate acidity, improve digestion, and detoxify the body (Kumar *et al.*, 2018; Singh *et al.*, 2022). It is also believed to support cardiovascular health by regulating blood pressure and reducing cholesterol levels (Mishra *et al.*, 2023). Bitter melon (*Momordica charantia*) is used to regulate blood sugar levels, support liver function, and treat skin

diseases such as eczema and psoriasis (Sharma *et al.*, 2017; Patel *et al.*, 2023). It is commonly recommended for diabetic patients due to its insulin-mimicking properties (Jain *et al.*, 2021). Ash gourd (*Benincasa hispida*) is commonly prescribed for treating respiratory disorders, urinary infections, and as a general health tonic (Mishra and Singh, 2022; Verma *et al.*, 2023). It is often consumed in juice form to help cool the body and improve mental clarity (Kumar and Das, 2021). Cucumber (*Cucumis sativus*) is valued for its hydrating and anti-inflammatory properties, often used to treat sunburns and skin irritation (Brown and Taylor, 2019; Sharma *et al.*, 2023). Its high water content makes it an essential remedy for heat-related ailments and dehydration. These cucurbits are often combined with other medicinal herbs to enhance their efficacy in treating specific ailments. Ayurvedic practitioners prepare decoctions, pastes, and oils using cucurbit extracts for both internal and external applications (Rajesh *et al.*, 2021).

##### 4.2 Cucurbits in traditional Chinese medicine (TCM)

Traditional Chinese medicine (TCM) has long incorporated cucurbits into its healing practices. They are often prescribed to balance Yin and Yang energies, detoxify the body, and treat conditions related to heat and dampness (Li *et al.*, 2020; Wu *et al.*, 2021). Winter melon (*Benincasa hispida*) is used for its cooling effect, aiding in reducing fever, promoting urination, and clearing phlegm from the lungs (Wu *et al.*, 2021; Zhang *et al.*, 2022). It is also considered beneficial for weight management and metabolic regulation (Chen and Zhou, 2018). Bitter melon (*Momordica charantia*) is known for its ability to regulate blood sugar, reduce internal heat, and support digestion (Chen *et al.*, 2021; Wang *et al.*, 2023). In TCM, it is often recommended for individuals suffering from excessive heat conditions such as inflammation and high fever. Snake gourd (*Trichosanthes cucumerina*) is used for treating respiratory conditions such as coughs, bronchitis, and asthma. It is also known to promote circulation and detoxify the blood (Zhou *et al.*, 2022; Wang *et al.*, 2023). Pumpkin (*Cucurbita pepo*) is recognized for expelling parasites, particularly intestinal worms, and promoting digestive health (Wang *et al.*, 2019; Liu *et al.*, 2023). The seeds are a well-known anthelmintic remedy in TCM. In TCM, cucurbits are often prepared as decoctions, infusions, and medicinal soups, either alone or in combination with other herbs. They are frequently used to enhance lung health, regulate Qi flow, and improve vitality (Liu *et al.*, 2023).

##### 4.3 African traditional medicines

Many African and Indigenous cultures have traditionally utilized cucurbits for their medicinal properties (Okonkwo and Adegbite, 2020; Ogunleye *et al.*, 2021). Egusi melon (*Citrullus lanatus* subsp. *mucosospermus*) is used in West African herbal medicine to treat infections, skin disorders, and support immune health (Ogunleye *et al.*, 2021; Adeyemi *et al.*, 2022). The seeds are rich in essential fatty acids and protein, making them a vital nutritional and medicinal resource. Bitter melon (*Momordica charantia*) is found in traditional medicine systems across Africa and South America, used for managing diabetes, fevers, and digestive issues (Adeyemi *et al.*, 2019; Taylor *et al.*, 2023). It is often consumed as a tea or extract to lower blood sugar levels. Pumpkin seeds are widely recognized for their anthelmintic properties, used to expel intestinal parasites (Taylor *et al.*, 2018; Nkwocha and Williams, 2022). They are also a source of zinc, which is crucial for immune system function and skin health. Luffa (*Luffa cylindrica*) is employed in Indigenous medicine

for treating wounds, detoxifying the body, and promoting respiratory health (Nkwocha and Williams, 2022; Mbatha *et al.*, 2023). The dried fibrous fruit is also used as a natural sponge to improve circulation during bathing. These remedies have been passed down through generations, often in the form of teas, poultices, powders, or topical applications. Indigenous healers continue to use these plants for a wide range of health concerns, from digestive ailments to immune system support (Adeyemi *et al.*, 2022).

#### 4.4 Pharmaceutical developments and medical research

Scientific research has led to the development of pharmaceutical products derived from cucurbits (Gao *et al.*, 2021; Rodriguez and Kim, 2020). Bitter melon extracts have been formulated into oral hypoglycemic agents for controlling blood sugar levels (Patel *et al.*, 2023; Xiao *et al.*, 2022). Clinical trials have demonstrated that bitter melon compounds can enhance glucose uptake and improve insulin sensitivity in diabetic patients. Cucurbitacin-containing compounds are being explored for their potential in cancer treatment, particularly for inhibiting tumor growth and inducing apoptosis in cancer cells (Rodriguez and Kim, 2020; Jones and Martin, 2021). Researchers are investigating the role of cucurbitacins in chemotherapy-resistant cancers. Some cucurbit-derived compounds exhibit antiviral properties, making them potential candidates for treating viral infections such as hepatitis and influenza (Xiao *et al.*, 2022; Liu *et al.*, 2023). Certain bioactive molecules found in cucurbits have been shown to interfere with viral replication. Studies have suggested that pumpkin seed oil may have beneficial effects on prostate health, particularly in reducing symptoms of benign prostatic hyperplasia (BPH) (Jones and Martin, 2021; Wang *et al.*, 2023). The anti-inflammatory properties of the oil may contribute to improved urinary function. As the demand for natural plant-based therapeutics increases, cucurbits are being widely researched for nutraceutical and pharmaceutical applications. Their rich composition of antioxidants, flavonoids, alkaloids, and essential nutrients makes them valuable for preventing and managing various health conditions (Liu *et al.*, 2023).

#### 4.5 Cucurbits in nutraceuticals and functional foods

With growing interest in natural and plant-based therapies, cucurbits are increasingly being incorporated into nutraceuticals and functional foods (Smith and Roberts, 2023). Pumpkin seed oil supplements, rich in essential fatty acids, vitamins, and antioxidants, support prostate health and cardiovascular function (Chen and Zhao, 2021). Bitter melon extract capsules are used as a natural remedy for managing diabetes and improving metabolic health (Wang *et al.*, 2023). Cucumber-infused skincare products are hydrating and anti-inflammatory, commonly found in cosmetics and dermatological treatments (Brown and Adams, 2020).

### 5. Toxicity and safety considerations of cucurbits

Cucurbits, a diverse family of plants including pumpkins, zucchinis, melons, and gourds, are widely consumed for their nutritional and medicinal benefits. However, certain species and varieties contain toxic compounds known as cucurbitacins, which can pose health risks if ingested in significant amounts (Anderson *et al.*, 2020). While selective breeding and food processing techniques have helped minimize the presence of these harmful substances, understanding the potential risks associated with cucurbit consumption remains crucial for ensuring food safety and public health (Smith *et al.*, 2019).

#### 5.1 Cucurbitacins and their toxic effects

Cucurbitacins are a group of bitter-tasting triterpenoids naturally occurring in cucurbitaceous plants. These compounds act as a defence mechanism against herbivores and pests but can be harmful to humans when consumed in large quantities. Studies have shown that cucurbitacins can cause gastrointestinal distress, nausea, vomiting, and severe abdominal cramps (Green *et al.*, 2021). Excessive intake may lead to toxic squash syndrome, a condition characterized by acute poisoning symptoms, including dehydration, dizziness, and even organ damage (Williams *et al.*, 2023; Thomas *et al.*, 2020). Some research has also indicated that certain cucurbitacins may have cytotoxic effects on human cells, raising concerns about long-term consumption (Johnson *et al.*, 2018).

#### 5.2 Factors influencing cucurbit toxicity

While most commercially cultivated cucurbits are bred to have minimal cucurbitacin levels, certain factors can increase their toxicity risk. Genetic variation plays a crucial role, as wild and cross-pollinated cucurbit species tend to have higher cucurbitacin levels than commercially cultivated varieties (Anderson *et al.*, 2020). Environmental stress, such as drought, temperature fluctuations, and poor soil conditions, can trigger an increase in cucurbitacin production as a survival mechanism (Jones and Patel, 2022; Garcia *et al.*, 2021). Improper storage can also contribute to higher toxicity levels, as cucurbits stored for extended periods under unfavourable conditions may develop bitterness due to biochemical changes within the plant tissue (Lee *et al.*, 2017). Additionally, self-grown or unregulated sources pose a higher risk, as homegrown or unregulated cucurbits may not undergo strict quality control processes, increasing the likelihood of high cucurbitacin content (Martin and Chen, 2019).

#### 5.3 Health risks and allergic reactions

Long-term consumption of high cucurbitacin doses has been linked to liver toxicity, metabolic imbalances, and potential cellular damage (Harrison *et al.*, 2023; Kim *et al.*, 2021). Individuals with pre-existing liver disorders, kidney conditions, or compromised immune systems should exercise caution when consuming cucurbit-based foods and supplements (Brown and Lee, 2023; Yang *et al.*, 2018). Furthermore, cucurbitacin-containing extracts used in alternative medicine require careful dosing, as excessive consumption may lead to hepatotoxicity, gastrointestinal issues, and inflammation (Carter *et al.*, 2020). Despite their potential anticancer and anti-inflammatory properties, unregulated use of cucurbitacin-rich extracts may pose more risks than benefits (Nguyen *et al.*, 2022). Beyond toxicity concerns, some individuals may experience allergic reactions to cucurbits. Symptoms may include skin rashes, itching, swelling of the lips, tongue, or throat, respiratory difficulties, and, in severe cases, anaphylaxis (Rodriguez *et al.*, 2023; Evans *et al.*, 2019). People with known sensitivities to cucurbits should consult an allergist before consuming these foods or products derived from them. Additionally, individuals with pollen allergies, particularly those allergic to ragweed, may experience cross-reactivity when consuming cucumbers, melons, and other cucurbits (Stewart *et al.*, 2020; Lin *et al.*, 2017).

#### 5.4 Preventive measures and regulatory considerations

To minimize the risk of cucurbit toxicity, individuals should follow several precautions. Taste testing is a simple and effective method to identify potential toxicity; cucurbits with an extremely bitter taste should be discarded immediately, as bitterness indicates high

cucurbitacin levels (Singh *et al.*, 2023; Roberts and Hall, 2018). Sourcing cucurbits from reputable vendors and avoiding homegrown or wild varieties with unknown genetic backgrounds can significantly reduce toxicity risks (Liu and Park, 2023; Nelson *et al.*, 2019). Proper storage in cool, dry environments helps prevent biochemical changes that could lead to increased cucurbitacin levels (Chang *et al.*, 2021). Cooking, fermentation, and food processing techniques can help reduce cucurbitacin content, improving safety for consumption (Davis *et al.*, 2020). Additionally, individuals using cucurbit-based medicinal products should consult healthcare professionals to ensure safe usage and appropriate dosage (Liu and Park, 2023; Gomez *et al.*, 2021). Regulatory bodies have established guidelines for monitoring cucurbit toxicity levels in commercial crops. Government agencies and food safety organizations continuously conduct research to improve screening methods for cucurbitacins in food products (Henderson *et al.*, 2018). Moreover, consumer awareness campaigns educate the public about the risks associated with consuming bitter cucurbits (Walters *et al.*, 2022). In certain regions, agricultural policies emphasize the cultivation of low-cucurbitacin varieties through selective breeding programs (Fischer *et al.*, 2020). These initiatives aim to ensure that cucurbits sold in markets meet safety standards while maintaining their nutritional value and culinary appeal (Kumar *et al.*, 2021).

## 6. Future prospects and research directions

Future research should focus on various aspects of cucurbit bioactives, particularly their molecular mechanisms of action. Understanding how cucurbitacins and other bioactive compounds interact with human cells at the molecular level could lead to the development of targeted therapies for various diseases. Additionally, large-scale clinical trials are necessary to establish the efficacy and safety profiles of cucurbit-derived compounds in human medicine. These studies could help determine optimal dosages and potential side effects, ensuring that cucurbit-based treatments are both effective and safe for long-term use. Another promising research area is the development of novel drugs using cucurbit-derived bioactives. Recent studies have suggested that certain cucurbitacins exhibit anticancer, anti-inflammatory, and antimicrobial properties. Exploring their therapeutic potential in drug development could lead to new treatments for various conditions, including cancer, autoimmune diseases, and infectious diseases. Additionally, advanced nanotechnology-based delivery systems could improve the bioavailability and efficacy of cucurbitacin-based drugs, making them more effective in clinical applications. Sustainable farming practices should also be emphasized to enhance the yield of beneficial bioactive compounds while minimizing the risk of toxic cucurbitacin levels. Optimizing agricultural conditions, such as soil quality, water availability, and controlled breeding, could help maintain a balance between nutritional benefits and safety in cucurbit cultivation. Moreover, advances in genetic engineering and biotechnology may allow for the selective modification of cucurbit biosynthetic pathways to enhance beneficial compounds while suppressing harmful ones. Research into organic and environmentally friendly pest control methods can also contribute to sustainable cucurbit production, reducing reliance on chemical pesticides that may impact cucurbitacin synthesis.

## 7. Conclusion

Cucurbits are a valuable source of bioactive compounds with immense pharmacological potential. Their antioxidant, anti-inflammatory, antimicrobial, anticancer, and cardioprotective properties make them an integral part of both traditional and modern medicine. However, despite their health benefits, cucurbits also present toxicity risks due to the presence of cucurbitacins, which can cause gastrointestinal distress and, in severe cases, organ damage. Individuals with pre-existing health conditions should be cautious when consuming cucurbit-based products, especially in medicinal forms. Regulatory oversight and agricultural practices play a crucial role in maintaining the safety of cucurbits for consumption by controlling cucurbitacin levels and promoting the cultivation of safer varieties. Additionally, awareness campaigns can educate consumers about the dangers of consuming bitter cucurbits and proper food handling practices. Looking ahead, continued research is necessary to explore the full therapeutic potential of cucurbit bioactives, optimize their medicinal applications, and ensure they are used safely and effectively. Sustainable farming and genetic advancements may further improve the safety and efficacy of cucurbits, paving the way for their expanded use in pharmaceuticals and nutraceuticals.

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## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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