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# A COMPREHENSIVE REVIEW ON *CUCURBITA PEPO* L.: PHARMACOGNOSTICAL CHARACTERIZATION, PHYTOCHEMISTRY, NUTRITIONAL COMPOSITION, TOXICITY PROFILE AND PHARMACOLOGICAL ACTIVITIES

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**Keywords:**

*Cucurbita pepo*, Cucurbitaceae, Cucurbitacins, Phytoconstituents, Pharmacological activities

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**ABSTRACT:** *Cucurbita pepo* L. (Cucurbitaceae), commonly known as pumpkin, squash, or zucchini, is an economically important food crop with a long history of traditional medicinal use and increasing scientific interest due to its diverse phytochemical composition and therapeutic potential. This review provides a comprehensive pharmacognostic overview of *C. pepo*, integrating current knowledge on its taxonomy, botanical description, macroscopic and microscopic diagnostic characteristics, powder microscopy, ethnomedicinal applications, phytochemistry, and pharmacological activities. The species is characterized by distinctive pharmacognostic features, including bicollateral vascular bundles, glandular and non-glandular trichomes, schizogenous secretory ducts, and characteristic seed testa anatomy, which are valuable for authentication and quality control. Phytochemical investigations have identified a broad spectrum of bioactive constituents, including polyunsaturated fatty acids, phytosterols (predominantly Δ7-sterols), cucurbitacins, carotenoids, tocopherols, flavonoids, phenolic acids, lignans, and other triterpenoids that collectively contribute to its biological activities. Experimental and clinical evidence demonstrates significant antioxidant, anti-inflammatory, antidiabetic, antimicrobial, hepatoprotective, antiulcer, anticancer, anthelmintic, and benign prostatic hyperplasia-relieving properties, supporting many of its traditional therapeutic applications. Despite extensive research, available information remains fragmented, with considerable variation in plant parts investigated, extraction methods, and pharmacological evaluation, limiting the standardization and clinical translation of *C. pepo*-based phytopharmaceuticals. This review consolidates the existing evidence into a unified pharmacognostic framework, highlights the relationship between phytochemical constituents and pharmacological effects, identifies current knowledge gaps, and emphasizes the need for standardized quality control parameters, comprehensive pharmacognostic profiling, and well-designed clinical studies to facilitate the development of safe, effective, and evidence-based herbal formulations derived from *C. pepo*.

**INTRODUCTION:** *Cucurbita pepo* Linn. (family Cucurbitaceae), commonly known as pumpkin, squash, or zucchini depending on the cultivar, is one of the most widely grown and consumed vegetable crops in the world. It is valued as a dietary staple and as a plant of long-standing ethnomedicinal significance.

It is thought to have been domesticated in Mesoamerica several thousand years ago, making it one of the earliest cultivated crop plants known to humans. *C. pepo's* fruit, seeds, seed oil, flowers, and leaves have been traditionally used for gastrointestinal complaints, intestinal parasites, and

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urinary disorders. The seeds and fruit pulp are recognized nutritional sources of carotenoids, tocopherols, essential fatty acids, minerals, and functional polysaccharides [1, 2]. Since then, the species has spread throughout temperate and subtropical regions of the Americas. *C. pepo* is classified as a member of the Cucurbitaceae family, which includes roughly 90-125 genera and several hundred species of significant commercial value as food crops [3, 4]. Cucurbita has five domesticated species: *C. pepo*, *C. moschata*, *C. maxima*, *C. argyrosperma*, and *C. ficifolia*. *C. pepo* is the genus' type species and one of the most morphologically diverse [3, 5]. The plant is a monoecious, fast-growing annual herb with trailing or climbing habit, angular stems reaching several meters in length, and enormous, beautiful yellow-orange unisexual blooms borne singly in the leaf axils [5, 6]. Its fruit is a unique berry variety known as a "pepo," with a strong rind surrounding a fleshy mesocarp and endocarp with numerous flattened seeds.

In recent decades, scientific interest in the species has expanded considerably beyond its culinary role, with numerous studies documenting hepatoprotective, antidiabetic, antioxidant, anticancer, antimicrobial, anti-inflammatory, antiulcer, and benign prostatic hyperplasia (BPH)-ameliorating activities, largely attributed to constituents such as cucurbitacins, cucurbitane- and multiflorane-type triterpenoids, phytosterols, carotenoids, tocopherols, and polyunsaturated fatty acids.

Despite this growing body of evidence, the existing literature on *C. pepo is* fragmented across phytochemical, nutritional, and pharmacological studies rather than consolidated within a single pharmacognostic framework, with significant variation in extract preparation, plant part used and reported potency across studies. This scattering of data impedes its translational development as a standardized phytopharmaceutical agent. In this review, we systematically synthesized data from peer-reviewed literature on *C. pepo's* botanical description and pharmacognostic characteristics, taxonomic classification, traditional uses, chemical constituents, and pharmacological activities in order to provide an integrated and up-to-date resource. The current study provides a consolidated framework for highlighting the major bioactive constituents and their underlying mechanisms across the principal pharmacological activities reported, facilitating evidence-based development of *C. pepo*-derived phytopharmaceuticals and guiding future standardization efforts.

**MATERIALS AND METHODS:** This review was conducted as a structured, non-systematic narrative synthesis of the peer-reviewed and regulatory literature available on *Cucurbita pepo* L. Relevant publications were identified through electronic searches of PubMed/MEDLINE, Scopus, Google Scholar, and ScienceDirect, supplemented by regulatory and reference sources including the European Medicines Agency (EMA) HMPC (Committee on Herbal Medicinal Products), Herbal monograph database, Kew's Plants of the World Online, and the USDA Food Data Central database, covering literature up to July 2026. Search terms included combinations of "*Cucurbita pepo*", "pumpkin", "pumpkin seed", "pharmacognosy", "phytochemistry", "cucurbitacin", "phytosterol", "nutritional composition", and specific pharmacological terms such as "antidiabetic", "antioxidant", "hepatoprotective", "anticancer", "antimicrobial", "benign prostatic hyperplasia", and "toxicity", used individually and in combination. Original research articles, review articles, regulatory monographs, and case reports published in English that reported on the botany, pharmacognostic characterization, phytochemistry, nutritional composition, pharmacological activity, or toxicity/safety profile of *C. pepo* were included. Non-English publications, articles for which the full text could not be accessed, and sources unrelated to *C. pepo* pharmacognosy or pharmacology were excluded. Titles and abstracts were first screened for relevance, followed by full-text evaluation of shortlisted articles; data extracted from each included source were organized under the thematic headings used in this review (botanical description, taxonomy, pharmacognostical and microscopic characters, phytochemistry, nutritional composition, pharmacological activities, and toxicity), and findings were qualitatively synthesized and cross-checked against multiple sources where possible to resolve inconsistencies.

**Botanical Description:** *C. pepo* is an annual herbaceous vine or bush with a shallow, branching

root system originating from a well-developed taproot [2, 5]. The stems are thick, robust, angular (5-angled), setose (bristly), and can climb up to several meters in length, often root at the nodes. Multiply branching tendrils originating at the leaf axils enable the plant to climb over nearby plants [7]. The leaves are simple, borne on stout, fleshy, setose petioles up to 10 cm long, with a broadly triangular to ovate-cordate blade, 20-30 cm across, irregularly 3-5-lobed, cordate at the base, dentate at the margin, and acute at the apex. The upper and lower surfaces are rough owing to stiff trichomes distributed along the veins and petiole [5, 6].

The flowers are large, showy, and unisexual (monoecious), pentamerous, with a campanulate corolla 5.5-11 cm long and lanceolate-subulate sepals. Male flowers are borne on longer pedicels (4.5-15 cm) than female flowers (0.5-5 cm), and each flower opens for a single day, typically in the early morning [5, 8].

The fruit, botanically a "pepo," is extraordinarily variable in size, shape, and rind color/pattern (light to dark green, cream, yellow, or orange, plain or speckled). It has a rigid outer rind, cream-to-pale-orange flesh, and a robust, strongly angular, minimally expanded pedicel at the point of fruit attachment [5, 7]. The seeds are flattened, ovate to elliptical, dirty-white to cream in color, bordered/marginate, and typically 8-20 mm long, 4-12 mm wide, and 1.5-2.5 mm thick [5, 8].

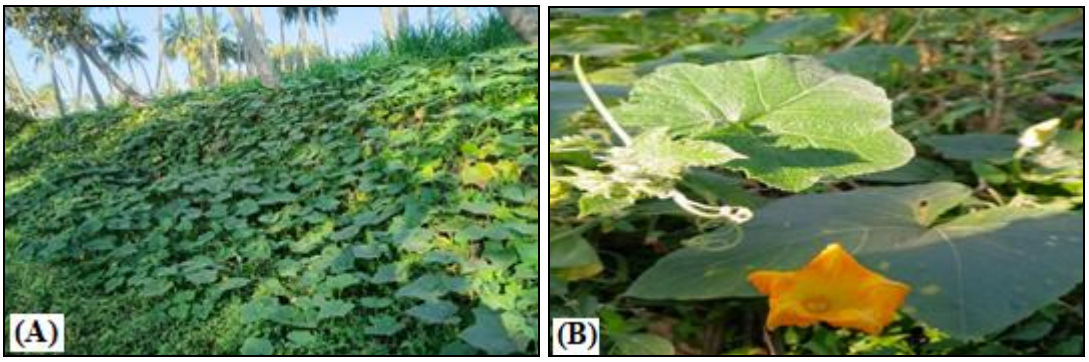


**FIG. 1: FIELD PHOTOGRAPHS OF *CUCURBITA PEPO* L.** (A) Close-up view of the lobed, cordate leaf lamina, rough pubescent leaf surface, coiled multifid tendril, and a solitary large showy yellow-orange flower, illustrating the macroscopic leaf and flower characters described above. (B) The trailing, prostrate vine growth habit of the plant forming a dense ground cover, illustrating the herbaceous climbing/trailing stem habit.

**Taxonomic Classification:** *C. pepo* is classified as follows:

| Rank | Taxon |
|---|---|
| Kingdom | Plantae |
| Clade | Tracheophytes, Angiosperms, Eudicots, Rosids |
| Order | Cucurbitales |
| Family | Cucurbitaceae |
| Genus | *Cucurbita* |
| Species | *pepo* |

Carl Linnaeus described the species in Species Plantarum (1753), and it is the type species of the genus Cucurbita [5, 9]. *C pepo* is classified into three subspecies based on allozyme variation and seed morphology: subsp*pepo*, subsp. *texana*, and subsp. *fraterna*. Subsp. pepo includes most cultivated forms, while subsp. texana and subsp. fraterna represent free-living/wild populations [9]. Molecular, morphological, and archaeobotanical evidence suggests that *C. pepo* was domesticated multiple times in eastern North America and Mexico [9, 10].

**Synonyms:** Synonyms for *C. pepo* include *Cucurbita melopepo* L., *Cucurbita ovifera* L., *Cucurbita aurantia* Willd., *Cucurbita verrucosa* L., *Cucumis pepo* (L.) Dumort., and *Citrullus variegatus* Schrad. ex M. Roem., reflecting the historical taxonomic splitting of what is now recognized as a single, highly polymorphic species [5, 8].

**Vernacular Names:** In English, *C. pepo* is known as pumpkin, summer squash, marrow, vegetable marrow, zucchini, or courgette, depending on cultivar group and regional use [5]. In South Asia, it is commonly referred to as "Kadoo" or "Kaddu" in Urdu, Saraiki, and Hindi [11, 12] and carries distinct names across the major regional languages of India, including Pucani (Tamil), Kumbalakaayi (Kannada), Kumpalam (Malayalam), Kashiphal (Marathi), Kumra (Assamese), Gummadi (Telugu), and Kumara (Bengali) [12].

Regional and vernacular names vary widely across its extensive area of cultivation.

**Traditional/Ethnomedicinal Use:** *C. pepo* fruit pulp, seeds, seed oil, flowers, and leaves are used in traditional medicine systems in Africa and Asia to treat fever, whooping cough, urinary problems, scurvy, benign prostatic hyperplasia, rheumatism, hemorrhoids, threatened miscarriage, prostate cancer, constipation, and impaired vision, among other conditions [11]. The seeds have a long-standing reputation as a natural anthelmintic, being used to remove intestinal worms in numerous folk medicine traditions [1]. Leaf extracts have been shown to have antibacterial activity against various Gram-negative pathogens including *Providencia stuartii*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Escherichia coli*, *Enterobacter aerogenes*, and *Enterobacter cloacae*. This lends scientific support to traditional applications. Several taxa in the Cucurbitaceae family, including *Cucurbita*, have been used in ethnoveterinary therapy to treat livestock ailments, highlighting the plant's dual significance in both human and animal traditional healthcare systems [13].

**Pharmacognostical Characters:** The stem of *C. pepo* is striate, fleshy, angular, and sparsely pubescent. It has prominent capitate glandular hairs, simple non-glandular bristles, and axillary tendrils [14]. Overall, the stem is rugged and bristly, with lateral branches 6-24 cm long that root freely at the nodes [2]. The leaf is a large (up to 20-30 cm across), broadly triangular to ovate-cordate lamina with a cordate base, an irregularly 3-5-lobed, dentate margin, an acute apex, and a rough-textured surface on both faces owing to the dense covering of trichomes. It is dull to dark green, odourless, and mildly mucilaginous on crushing, with a stout, fleshy, setose petiole [5, 14]. The seed is flattened-ovate to elliptical, 8-20 mm long, dirty-white to cream in color, with a smooth to finely striate testa, a noticeably bordered/marginate edge, and a faintly oily odour and bland-to-mildly-nutty taste when chewed, consistent with its high fixed-oil content [5, 15].

**Microscopic Characteristics:** Comparative morphoanatomic and histochemical examinations of *C. pepo* specimens have revealed that the root, stem, and leaf all have diagnostic anatomical traits relevant for pharmacognostic identification and quality control. Some cultivars (e.g., zucchini-type) have calcium-oxalate-type crystal deposits in the root, while transverse sections of the stem reveal a sclerenchymatic pericycle and prominent schizogenous secretory (lactiferous/resin) ducts running through both the stem and leaf tissue in pumpkin-type specimens [16]. In Cucurbitaceae, vascular bundles in the stem are bicollateral, with phloem strands on both the outer and inner faces of the xylem, a defining anatomical signature of the family [6, 16]. The distribution of stored metabolites differs between cultivar types, with starch grains in zucchini-type tissue and triterpene- and steroid-rich secretory content in pumpkin-type tissue. This suggests that histochemical profiling can help distinguish *C. pepo* cultivar groups at the microscopic level [16].

At the epidermal level, glandular and non-glandular trichomes are widespread on the leaf, stem, and petiole surfaces; light, conventional, and environmental scanning electron microscopy of *C. pepo* subsp. *pepo* var. *styriaca* has at least four structurally and histochemically distinct trichome types three capitate glandular forms differing in stalk length, head size, and secretory content, and one non-glandular "columnar-digit" bristle type arising from an epidermal initial cell via an initial periclinal division [17]. In wild-type/hulled seeds, the seed coat (testa) is anatomically five-layered, comprising an outer epidermis, a subcutaneous (hypodermal) layer, a sclerenchymatous (stone-cell) layer, a parenchymatous layer, and an inner layer, with the upper four layers bearing cellulose or lignin-thickened secondary walls that confer mechanical hardness to the hull; in the naturally occurring hull-less (thin-coated) mutant phenotype, these outer four layers fail to lignify and collapse.

**Powder Microscopy:** A diagnostic powdered-drug profile of *C. pepo*, built from its component macro- and microscopic morphological characteristics, should show: The leaf, stem, and petiole epidermis is characterized by thick-walled, unicellular to multicellular non-glandular bristle trichomes, as well as capitate glandular trichomes with unicellular stalks and globular secretory heads [17]. Surface view of epidermal fragments reveals sinuous anticlinal walls.

The plant contains angular, thick-walled sclerenchymatous "stone cells" from the seed testa, ridged stem groups of collenchyma and sclerenchymatous pericyclic fibers, oil globules and aleurone-type protein grains from the fixed-oil- and protein-rich seed cotyledon/endosperm tissue, and occasional prismatic or druse-type calcium oxalate crystals in root-derived material. A fully validated, pharmacopoeial-grade quantitative powder-microscopy and physicochemical standardization profile of *C. pepo* including parameters such as stomatal number/index, vein-islet and veinlet-termination number, palisade ratio, and ash/extractive values determined specifically for this species by standard pharmacognostic protocols has not been comprehensively established in the peer-reviewed literature surveyed for this review, and represents a clear gap that original experimental pharmacognostic evaluation (such as that undertaken in the present project) is well positioned to address.

**Chemical Constituents:** *C. pepo* contains a chemically and structurally diversified phytoconstituent profile that includes fixed oils, triterpenoids, phytosterols, phenolics, lignans, fatty acids (linoleic, oleic, palmitic acid), amino acid cucurbitin, the flavonols quercetin and kaempferol, chlorogenic acid, γ-tocopherol, and squalene and a unique set of nitrogenous chemicals. The seeds are the most thoroughly studied plant portion, owing to their well-established usage in traditional and approved herbal medicine for lower urinary tract and prostatic symptoms. However, the fruit pulp, leaves, and flowers each have their own distinctive constituents [18].

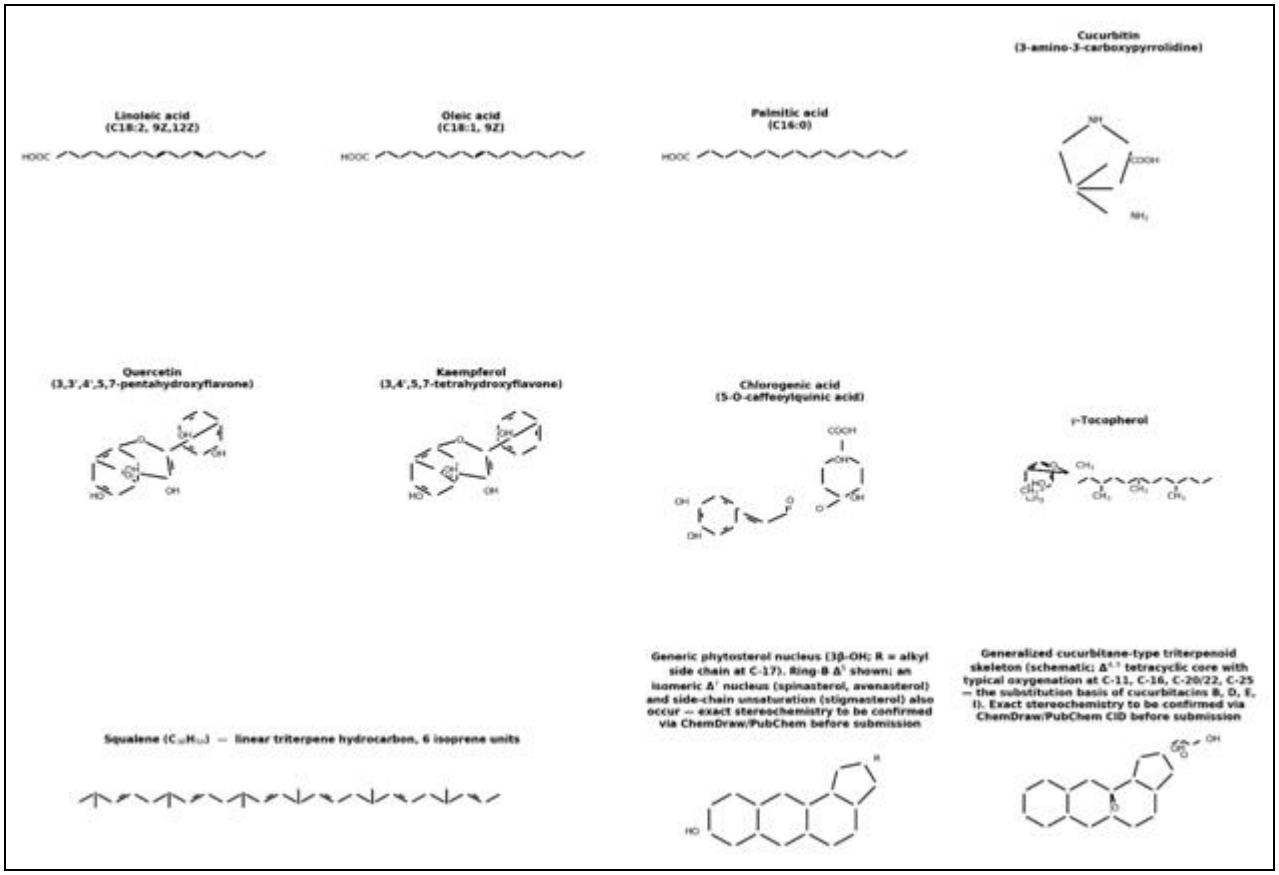


**FIG. 2: CHEMICAL STRUCURES OF SOME MAJOR PHYTOCONSTITUENTS ISOLATED FROM *C. PEPO***

**Fixed Oil and Fatty Acids:** When cold-pressed or solvent extracted, the seed kernel generates 40-50% w/w fixed (fatty) oil, making it the plant's single greatest phytochemical portion by mass. This oil is dominated by polyunsaturated omega-6 fatty acid linoleic acid (about 45-51% of total fatty acids), with significant monounsaturated oleic acid (~22-38%), and minor saturated fractions of palmitic acid (~10-13%) and stearic acid (~5-8%) [18, 19]. The oil's high polyunsaturated-to-saturated fatty acid ratio is considered nutritionally beneficial and is

hypothesized to impact its antioxidant and membrane-modulatory pharmacological effects.

**Tocopherols, Carotenoids, and Squalene:** The unsaponifiable fraction of seed oil contains the majority of plant's lipophilic micronutrient and antioxidant content. Carotenoid pigments, such as β-carotene, lutein and zeaxanthin, are found in both seed oil and the orange-fleshed fruit pulp of pumpkin-type cultivars. These pigments contribute pro-vitamin-A and antioxidant activity [18, 20]. Tocopherols, primarily γ-tocopherol, with lesser amounts of α-tocopherol, contribute to the oil's vitamin E antioxidant activity [18, 19]. The seed oil contains squalene, a linear $C_{30}$ triterpene hydrocarbon and biosynthetic precursor of the sterol pathway, with quantities ranging from around 583 to 747 mg per 100 g of seeds [1]. Squalene has established antioxidant and chemoprotective properties independent of its role as a phytosterol precursor.

**Phytosterols:** The phytosterol (unsaponifiable sterol) portion of *C. pepo* seed oil has specific chemotaxonomic and pharmacological properties. *C. pepo* seed oil is primarily composed of Δ7-sterols, accounting for 91-94% of total phytosterol content [23]. In contrast, most vegetable oils contain Δ5-sterols (e.g., β-sitosterol, stigmasterol, and campesterol). The principal Δ7-sterols are Δ7,22,25-stigmastatrienol (the most abundant single sterol in most cultivars), spinasterol (stigmasta-7,22-dien-3β-ol; 18-23 g/100 g of total sterol, and together with β-sitosterol accounting for 41-54 g/100 g), Δ7-avenasterol (stigmasta-7,24(28)-dien-3β-ol), Δ7-stigmastenol, and Δ7,25-stigmastadienol, alongside smaller quantities of the corresponding Δ5-sterols and their 24-ethyl-Δ7-steryl glucoside conjugates [18, 23]. Regulatory herbal medicine assessments, such as the European Medicines Agency's HMPC (Committee of Herbal Medicinal Products) monograph on *Cucurbita pepo* semen, attribute the seed's traditional use for benign prostatic hyperplasia and other lower urinary tract symptoms to its unusual Δ7-sterol dominance. This sterol is thought to interfere with androgen-receptor signaling and 5α-reductase activity in prostatic tissue.

**Cucurbitacins and Other Triterpenoids:** Beyond the sterol fraction, *C. pepo*, like other Cucurbitaceae, produces a variety of highly oxygenated tetracyclic triterpenoids of the cucurbitane type known as cucurbitacins. Cucurbitacins B, D, E, and I, as well as cucurbitane glycosides L and K 2-O-β-D-glucopyranoside, and related multiflorane-type derivatives 7-epizucchini factor A and 24-dihydrocucurbitacin D [18, 42] have been reported. Cucurbitacins have a 19-(10→9β)-abeo-10α-lanost-5-ene tetracyclic skeleton with Δ4,5 (or Δ5) unsaturation and oxygenation sites at C-11 (ketone), C-16 and C-20 (hydroxyl), C-22 (ketone), and C-25 (hydroxyl or acyloxy). Cucurbitacins are derived from the same 2,3-oxidosqualene cyclization pathway as phytosterols, diverging at the cyclization step to form cucurbitadienol rather than the lanosterol/ cycloartenol precursors of conventional phytosterols, with subsequent oxidation carried out by a cluster of cytochrome-P450 and acyltransferase genes that in cultivated *C. pepo* is organized across two chromosomal loci a bitter-tasting biosynthetic pathway that is understood to function primarily as a chemical anti-herbivore defense in wild and feral Cucurbita populations.

**Flavonoids, Phenolic Acids, And Phenolic Glycosides:** *C. pepo* leaves and seeds contain a variety of flavonoid O-glycosides, such as isoquercitrin (quercetin 3-O-glucoside), astragalin (kaempferol 3-O-glucoside), rutin, nicotiflorin, narcissin, and isorhamnetin 3-O-glucoside, as well as free aglycones quercetin and kaempferol [18]. These flavonols have the same C6-C3-C6 flavone skeleton but differ in the degree of B-ring hydroxylation (quercetin has a catechol-type 3′,4′-dihydroxy B-ring whereas kaempferol has a single 4′-hydroxy substitution), a structural difference that is known to influence relative antioxidant potency more broadly. The fruit and seed contain phenolic acids, including chlorogenic acid (5-O-caffeoylquinic acid) and free caffeic acid, as well as cucurbitosides (A-M), which are unique to the seed [18].

**Lignans:** *C. pepo* seed extracts include the furofuran- and dibenzylbutane-type lignans secoisolariciresinol, lariciresinol, and pinoresinol. Cultivar-comparison studies show that these lignans are primarily found in the seed coat and hydrophilic seed fractions [69]. As phytoestrogenic diphenolic chemicals, lignans of this class are of

pharmacological interest for their hormone-modulatory and antioxidant activity, similar to their better-studied role in other lignan-rich seeds such as flaxseed.

**Cucurbitin and other Nitrogenous Constituents:** Cucurbitin (3-amino-3-carboxypyrrolidine; structure) is a taxonomically diagnostic non-protein amino acid that is consistently found in *C. pepo* seed extracts and has long been considered a marker compound underlying the traditional anthelmintic use of the seed, based on the theory that it paralyzes the musculature of intestinal cestodes and nematodes without the neurotoxicity of some synthetic anthelmintics. A variety of other nitrogenous small molecules, such as the alkaloid trigonelline, nicotinic acid, the inhibitory neurotransmitter γ-aminobutyric acid (GABA), p-aminobenzoic acid, the essential amino acid L-tryptophan, and the purine nucleosides adenosine and guanosine are present in the seed along with cucurbitin [1, 69].

**Polysaccharides, Proteins and Lectins:** The seed also offers a significant supply of minerals, storage protein, and water-soluble, non-starch polysaccharides, some of which have been studied separately for their immunomodulatory and hypoglycemic bioactivity. Cucurbitaceae phloem exudate lectins (CPELs), carbohydrate-binding proteins isolated from *C. pepo*'s phloem sap that show clear antimicrobial and anticancer activity in preliminary studies, are of emerging interest. These findings extend the species' pharmacological relevance beyond its more thoroughly studied small molecule constituents [21]. Taken together, these constituents summarized by chemical class in **Table 1**, provide the phytochemical basis for the broad pharmacological spectrum of *C. pepo* discussed in the sections that follow.

**TABLE 1: MAJOR CHEMICAL CONSTITUENTS REPORTED FROM *CUCURBITA PEPO***

| Chemical Constituent(s) | Chemical Class | Principal Plant Part |
|---|---|---|
| Linoleic acid, oleic acid, palmitic acid, stearic acid | Fatty acids | Seed (fixed oil) |
| γ-Tocopherol, α-tocopherol | Tocopherols | Seed oil |
| β-Carotene, lutein, zeaxanthin | Carotenoids | Seed oil, fruit pulp |
| Spinasterol, avenasterol (Δ7-sterols); sitosterol, stigmasterol, campesterol (Δ5-sterols); clerosterol, isofucosterol, codisterol | Phytosterols | Seed oil |
| Squalene | Triterpene hydrocarbon | Seed oil |
| Cucurbitacin B, D, E, I; cucurbitacin L/K 2-*O*-β-D-glucopyranoside; 7-epizucchini factor A; 24-dihydrocucurbitacin D | Cucurbitane/multiflorane triterpenoids (cucurbitacin) | Fruit, seed |
| Isoquercitrin, astragalin, rutin, nicotiflorin, narcissin, isorhamnetin 3-*O*-glucoside, quercetin, kaempferol | Flavonoids | Leaf, seed |
| Chlorogenic acid, caffeic acid | Phenolic acids | Fruit, seed |
| Cucurbitosides A–M | Phenolic glycosides | Seed |
| Secoisolariciresinol, lariciresinol, pinoresinol | Lignans | Seed (coat) |
| Cucurbitin (3-amino-3-carboxypyrrolidine) | Non-protein amino acid | Seed |
| Trigonelline, nicotinic acid, GABA, *p*-aminobenzoic acid, L-tryptophan, adenosine, guanosine | Nitrogenous compounds/nucleosides | Seed |
| Water-soluble polysaccharides, storage proteins | Polysaccharides/proteins | Seed |
| Cucurbitaceae phloem exudate lectins (CPELs) | Lectins (proteins) | Phloem sap |

**Nutritional Profile:** In addition to its secondary-metabolite phytochemical properties, *C. pepo* holds nutritional value on its own, and its role as a food crop supports its long-standing use in traditional medicine as a dietary supplement. The fruit pulp (flesh) and seeds exhibit significant differences in their basic nutritional components, highlighting their distinct functions as a low-calorie, water-laden vegetable and a high-calorie source rich in oil and protein, respectively.

**Fruit Pulp:** Raw pumpkin flesh is typically low in calories and fat, with a high water content, aligning with its role as a low-calorie vegetable in diets. According to USDA compositional data for raw pumpkin fruit (see **Table 2**), it contains roughly 92 g of water, 26 kcal of energy, 6.5 g of carbohydrates (of which 2.8 g are sugars), 0.5 g of dietary fiber, 0.1 g of fat, and 1 g of protein per 100 g. The pulp is particularly rich in provitamin-A carotenoids, predominantly β-carotene, along with lutein and zeaxanthin, which significantly contribute to its antioxidant and provitamin-A benefits, in addition to moderate amounts of vitamin C, various B vitamins, and potassium.

Independent evaluations of pumpkin pulp from different regional varieties show generally similar yet more varied results such as total ash ranging from 3.5% to 16.0%, crude fiber from 1.2% to 14.6%, crude protein from 1.7% to 34.1%, crude fat from 0.8% to 40.0%, and carbohydrates from 2.8% to 72.7%.

These wide variations are attributed to factors like cultivar, ripeness, growing conditions, and whether the pulp is analyzed fresh or dried, highlighting the necessity for standardized reporting when assessing pumpkin pulp as a nutraceutical ingredient. Additionally, the pulp contains notable levels of anti-nutritional components phytates, oxalates, and tannins usually found at nutritionally insignificant levels but important to consider in any standardization or safety evaluation.

**Seeds:** The seed serves as a nutrient-rich component of the plant, being high in calories and rich in proteins and oils, which aligns with its function as a nutrient reserve for the embryo and its prevalent application in phytopharmaceutical products. Numerous regional studies indicate that dried *C. pepo* seeds typically contain about 27–43% crude fat (oil), 17–35% crude protein, 1–16% crude fiber, 3–6% ash, and low moisture levels (1–9%). The energy content is around 560–565 kcal per 100 g, highlighting the significant oil and protein levels.

Mineral analyses consistently show that potassium and phosphorus are the predominant minerals, along with notable amounts of magnesium, calcium, iron, and zinc, as well as trace quantities of manganese, sodium, and copper. This pattern has been reported reliably across various independent studies from different cultivation areas. The combination of high-quality proteins, unsaturated fats, essential dietary minerals (especially magnesium and zinc), and the aforementioned phytochemicals has led to a growing acknowledgment of pumpkin seeds as a functional food and valuable nutraceutical ingredient, in addition to their established use as a standardized herbal extract for urological applications.

**TABLE 2: NUTRITIONAL COMPOSITION OF RAW *CUCURBITA PEPO* FRUIT PULP (PER 100 G EDIBLE PORTION)**

| Component | Amount | Component | Amount |
|---|---|---|---|
| Water | 91.6 g | Vitamin B6 | 0.061 mg |
| Energy | 26 kcal (109 kJ) | Folate (B9) | 16 µg |
| Carbohydrate | 6.5 g | Vitamin C | 9 mg |
| Sugars | 2.76 g | Vitamin E | 0.44 mg |
| Dietary fibre | 0.5 g | Vitamin K | 1.1 µg |
| Fat | 0.1 g | Calcium | 21 mg |
| Protein | 1 g | Iron | 0.8 mg |
| Vitamin A equivalent (β-carotene, lutein/zeaxanthin) | 426 µg (3100 µg β-carotene; 1500 µg lutein/zeaxanthin) | Magnesium | 12 mg |
| Thiamine (B1) | 0.05 mg | Manganese | 0.125 mg |
| Riboflavin (B2) | 0.11 mg | Phosphorus | 44 mg |
| Niacin (B3) | 0.6 mg | Potassium | 340 mg |
| Pantothenic acid (B5) | 0.298 mg | Zinc | 0.32 mg |

Source: USDA National Nutrient Database, as compiled for raw pumpkin [20].

**TABLE 3: REPRESENTATIVE PROXIMATE AND MINERAL COMPOSITION OF *CUCURBITA PEPO* SEEDS (DRIED, PER 100 G)**

| Proximate Parameter | Representative Range | Mineral | Representative Range (mg/100 g) |
|---|---|---|---|
| Moisture | 1–9% | Potassium | 200–1290 |
| Crude protein | 17–35% | Phosphorus | 100–1040 |
| Crude fat/oil | 27–43% | Magnesium | 34–693 |
| Crude fibre | 1–16% | Calcium | 14–141 |
| Total ash | 3–6% | Iron | 1.2–88 |
| Available carbohydrate | 1–28% | Zinc | 1.2–11.5 |
| Energy value | ~560–565 kcal/100 g | Manganese, sodium, copper | Minor/trace amounts |

Compiled from independent regional proximate studies [22, 25]; wide ranges reflect differences in cultivar, growing region, hulled vs. hull-less seed type, and analytical protocol, and are not directly comparable without reference to the specific study conditions.

**Toxicity and Safety Analysis:**

**Preclinical Acute Oral Toxicity:** Acute oral toxicity studies of *C. pepo* seed extracts consistently indicate a wide margin of safety. Using Lorke's up-and-down method in female Wistar rats, n-hexane, dichloromethane, and 70% aqueous ethanol extracts of *C. pepo* seed each produced no mortality, morbidity, or overt signs of toxicity at oral doses up to 5000 mg/kg, the highest dose tested, indicating an $LD_{50}$ in excess of this value for all three extract types regardless of polarity [63].

This favourable acute toxicity profile is broadly consistent with sub-acute toxicity data reported for Charmagaz seed oil, a traditional Cucurbitaceae seed blend that includes pumpkin alongside cucumber, watermelon, and muskmelon seed, which likewise showed no evidence of toxicity at doses up to 5000 mg/kg over 28 days and an *in-vitro* cell viability inhibition rate below 50%, although this finding should be interpreted cautiously as it reflects a multi-seed blend rather than *C. pepo* in isolation [61].

**Reproductive and Developmental Safety:** Reproductive toxicity findings are encouraging and suggest an organ-protective profile rather than a damaging one in several ways. When given daily for 21 days to female Wistar rats, n-hexane, dichloromethane, and aqueous ethanol extracts of *C. pepo* seed at doses derived from the EMA/HMPC-recommended human dose range (equivalent to 143–429 mg/kg) did not significantly affect any reproductive outcome measure, including fetal weight, fetal crown-rump length, litter size, or the number of implantation and resorption sites, and the pups did not exhibit any gross pathology [63].

Instead, ethanolic C. pepo seed extract has been demonstrated to be protective against reproductive toxicity caused by other agents in male rats, reducing the impairment of sperm characteristics, biochemical parameters, and epididymal histology caused by cyclophosphamide [64] and similarly shielding testicular tissue from damage caused by *Azadirachta indica* (neem) extract [65]. In line with this, seed extract pretreatment also protected against acute uranyl-acetate-induced testicular oxidative damage in the antioxidant study previously discussed in this review.

**Clinical Safety and Regulatory Evaluation:** The Committee on Herbal Medicinal Products (HMPC) of the European Medicines Agency conducted a formal safety and efficacy assessment of *C. pepo* semen (pumpkin seed), which supports its use for the relief of lower urinary tract symptoms associated with BPH(Benign Prostatic Hyperplasia) or overactive bladder after serious underlying conditions have been ruled out and recommends a traditional-use adult oral dose in the range of 10–30 g of seed per day [62]. An established and seemingly stable safety record for standardized seed preparations led to the conclusion that no revision of the current monograph was necessary, according to a subsequent HMPC addendum that reviewed newly available literature and found no new pharmacovigilance alerts pertaining to the use of *Cucurbita* seeds [28]. In contrast to the comparator Tamsulosin, which caused dizziness, headache, retrograde ejaculation, and skin reactions in a minority of patients, pumpkin seed oil did not cause any drug-related side effects over a three-month period. This is supported by the clinical trial evidence discussed under Pharmacological Activities above. Additionally, the 24-month noninterventional study found sustained symptom improvement without impairment of sexual function. Clinical trials of C. pepo formulations have reported few adverse reactions overall, according to broader clinical safety reviews.

**Allergenicity:** Despite the widespread dietary consumption of *C. pepo* fruit and seed, IgE-mediated hypersensitivity reactions have been documented, though they appear to be uncommon relative to the scale of consumption. Reported reactions to pumpkin seed range from oral allergy syndrome to, in rare case reports, anaphylaxis [66, 67] and IgE-mediated allergy specifically to zucchini-type fruit has also been reported, including oral allergy syndrome, nausea, diarrhoea, and pruritus [29].

A profiling pan allergen has been identified in *C. pepo* seed, and cross-reactivity has been demonstrated with melon seed, cashew nut, birch pollen, and other Cucurbitaceae fruits (watermelon, cucumber), consistent with a panallergen-mediated mechanism common to botanically related and pollen-associated food allergens [68].

Separately, contact urticaria and angioedema have been reported after handling of raw *Cucurbita* peel/rind during food preparation, again with an IgE-based mechanism demonstrated in at least one case, whereas the corresponding cooked product was tolerated without symptoms indicating that at least some of this contact-type reactivity is heat-labile [66].

**Other Safety Considerations:** A small number of additional, mechanistically distinct safety signals have been reported for *Cucurbita* preparations, none of which involve the plant's principal phytochemical or pharmacological actions discussed elsewhere in this review. Methaemoglobinaemia, attributable to the naturally occurring nitrate content of the vegetable rather than to any of its characteristic phytoconstituents, has been reported in infants given zucchini soup for constipation, underscoring that infant feeding of concentrated cucurbit purees warrants the same nitrate-related caution applied to other nitrate-accumulating vegetables [29]. The seeds and leaves additionally contain measurable but generally low levels of anti-nutritional factors phytates, oxalates, tannins, and trace cyanogenic compounds as already noted under Nutritional Composition, which are considered nutritionally insignificant at normal dietary intakes but are worth monitoring in any standardized extract intended for pharmaceutical use [24, 29]. Taken together, the acute, sub-acute, reproductive, clinical, and post-marketing pharmacovigilance evidence converge on a favourable overall safety profile for *C. pepo* seed preparations at traditional and studied therapeutic doses, with allergenicity in susceptible individuals and nitrate-related infant feeding caution representing the principal safety considerations meriting continued clinical vigilance.

**Pharmacological Activities:**

**Effect on Benign Prostatic Hyperplasia (BPH) and Lower Urinary Tract Symptoms:** This is the most clinically developed pharmacological application of *C. pepo* and the one with the strongest evidence from human trials. This maturity is reflected in a dedicated narrative review specifically addressing the plant's role in managing BPH-related lower urinary tract symptoms [32]. A single-blind randomized clinical trial in men aged ≥50 years with BPH compared 360 mg of pumpkin seed oil taken twice daily against 0.4 mg of tamsulosin taken nightly over three months. The study assessed the International Prostate Symptom Score (IPSS), BPH-related quality of life, prostate-specific antigen, post-void residual volume, and maximum urine flow. Pumpkin seed oil significantly relieved BPH symptoms with no reported drug-related side effects, although it was less effective than tamsulosin. In contrast, the tamsulosin group experienced dizziness, headache, retrograde ejaculation, and skin reactions in a minority of patients [33].

A separate 24-month noninterventional study similarly reported sustained improvement in IPSS with a standardized *C. pepo* seed extract, without impairment of sexual function [26]. A systematic review and meta-analysis of the clinical literature have been conducted specifically to quantify the pooled effectiveness of *C. pepo* preparations for BPH symptom relief, reflecting the relative maturity of this indication compared with the plant's other pharmacological uses [27]. Mechanistically, pumpkin seed extract has been shown to inhibit the growth of both hyperplastic and cancerous prostate cell lines in vitro, independently of classical steroid hormone receptor pathways. This points to a receptor-independent antiproliferative action that may complement the Δ7-sterol/androgen-signaling mechanism proposed in the phytochemistry literature [35]. This mechanism is directly supported at the preclinical level: pumpkin seed oil significantly inhibited testosterone-induced prostatic hyperplasia in Sprague-Dawley rats, reducing prostate weight and epithelial cell height relative to testosterone-only controls [30].

An *In-vitro* study of a standardized pumpkin-seed-derived Δ7-sterol, extract, and oil preparation demonstrated direct inhibition of both isoforms of 5α-reductase, along with binding to the androgen receptor, providing a specific molecular basis for the antiandrogenic, DHT-lowering effect proposed throughout the clinical and phytochemical literature [31]. A more recent chemical and morphometric evaluation similarly found that dietary pumpkin seed significantly reduced prostate-specific antigen levels, ventral prostate weight, and improved testicular histology in a BPH rat model, particularly

at higher seed concentrations, further corroborating the plant's efficacy in the mild-to-moderate stage of the condition [12].

**Antidiabetic Activity:** Both leaf and seed preparations of *C. pepo* have demonstrated antidiabetic activity through complementary *in-vitro* enzyme-inhibition and *in-vivo* mechanisms. An ethyl acetate leaf extract exhibited carbohydrate-digestive enzyme inhibitory activity with an $IC_{50}$ of 24.99 ± 0.07 µg/mL against α-amylase (compared with 19.45 ± 0.19 µg/mL for the standard drug acarbose) and an $IC_{50}$ of 22.29 ± 0.27 µg/mL against α-glucosidase (compared with 16.70 ± 0.99 µg/mL for acarbose), indicating a potency approaching that of a clinically used agent for both key carbohydrate-hydrolysing enzymes [38]. *In-vivo*, the tocopherol-rich fraction of raw *C. pepo* seed extract improved glycaemic, insulinaemic, and lipid profiles and reduced lipid peroxidation in a poloxamer-407-induced type 2 diabetic rat model, with accompanying computational docking against protein-tyrosine phosphatase 1B (PTP-1B) and peroxisome proliferator-activated receptor targets used to support a plausible molecular mechanism for the observed *in-vivo* effects [36]. These findings are consistent with the plant's long-standing traditional use as a hypoglycaemic remedy noted earlier in this review.

**Antioxidant Activity:** Free-radical scavenging activity has been demonstrated across leaf, fruit, and seed preparations of *C. pepo* using standard *in-vitro* assays. An ethyl acetate leaf extract showed DPPH radical scavenging with an $IC_{50}$ of 49.31 ± 0.21 µg/mL and ABTS radical scavenging with an $IC_{50}$ of 48.67 ± 0.27 µg/mL, correlating with a total phenolic content of 32.6 ± 0.17 mg gallic acid equivalents/g and total flavonoid content of 80.5 ± 0.02 mg rutin equivalents/g[38]. A separately reported ethanolic extract of the leaves and stems showed comparable DPPH scavenging ($IC_{50}$ 30 µg/mL relative to 8 µg/mL for ascorbic acid), with a total phenolic content of 17.49 mg gallic acid equivalents/g and total flavonoid content of 25.43 mg quercetin equivalents/g of dried plant material [13], while a survey of multiple solvent extracts of the leaves found the ethyl acetate fraction highest in flavonoid content and the n-butanol fraction highest in total phenolics, both displaying strong DPPH scavenging [34]. Squash fruit pulp and seeds collected in Egypt likewise showed measurable DPPH scavenging ($SC_{50}$ of 643.09 µg/mL for fruit and 576.19 µg/mL for seed methanolic extracts) with a positive correlation observed between total phenolic/flavonoid content and antioxidant capacity in both plant parts [39], and microwave- and ultrasound-assisted aqueous extraction of the seeds has been explored as a green-chemistry approach to further optimize antioxidant yield and phenolic recovery [40]. Fruit extracts prepared in chloroform, methanol, and other solvents were similarly evaluated for enzymatic and non-enzymatic antioxidant activity alongside anti-inflammatory testing, with phytochemical screening confirming the presence of flavonoids, tannins, triterpenoids, and saponin glycosides as likely contributors; the methanolic fruit extract additionally showed measurable levels of non-enzymatic antioxidants including ascorbate, reduced glutathione, tocopherol, carotenoids and lycopene [37]. *In-vivo*, an ethanolic seed extract significantly reduced serum corticosterone, oxidative markers, and inflammatory cytokines while upregulating antioxidant enzyme levels in a chronic unpredictable mild stress rat model of depression, with corresponding protection against stress-induced adrenal histopathological changes and apoptosis [41] and a related study demonstrated that pumpkin seed extract pretreatment protected against acute uranyl-acetate-induced oxidative reproductive toxicity in male rats [43].

**Anti-inflammatory Activity:** Consistent with its antioxidant profile, *C. pepo* fruit and seed extracts have shown anti-inflammatory activity in both *in-vitro* and *in-vivo* models.

Preliminary phytochemical and antioxidant/anti-inflammatory assays on *C. pepo* fruit extracts were undertaken specifically to evaluate their potential as an alternative to conventional anti-inflammatory drugs, given the adverse-effect burden associated with long-term NSAID use; using standard *in vitro* surrogate models of inflammation, the methanolic fruit extract produced a dose-dependent stabilization of red blood cell membranes and a corresponding reduction in heat-induced haemolysis, protein denaturation, and proteinase activity at concentrations of 150 and 300 µg/mL, effects that are commonly used to model the

membrane-stabilizing and anti-inflammatory potential of plant extracts *in-vitro* [37]. In an excisional wound-healing model in depressed rats, both oral and topical administration of *C. pepo* fruit extract significantly reduced pro-inflammatory cytokine gene expression and depressive-like behaviour and produced complete wound re-epithelialization with reduced inflammatory cell infiltration and increased collagen deposition, with the combined oral-plus-topical treatment group showing the most pronounced effect [47]. The chronic-stress adrenal study described above similarly documented a reduction in TNF-α and IL-6 alongside the antioxidant effects of seed extract treatment [41].

**Hepatoprotective Activity:** Contrary to the position taken in earlier drafts of this review, dedicated hepatoprotective studies specific to *C. pepo* are in fact available in the literature, in addition to the general attribution of hepatoprotection to the species in secondary review sources [1]. A pumpkin seed protein isolate significantly normalized plasma liver enzyme activities in carbon-tetrachloride ($CCl_4$)-induced liver injury in protein-malnourished rats, supporting a specific hepatoprotective role for the seed's protein fraction independent of its lipid/phytosterol constituents [52].

A combined flax-and-pumpkin-seed mixture rich in omega-3/omega-6 fatty acids produced hypolipidaemic and hepatoprotective effects in hypercholesterolaemic rats [53] and pumpkin seed oil alone has separately been shown to exert antioxidant and hepatoprotective effects against $CCl_4$-intoxicated liver injury [54] and to ameliorate chronic-alcohol-induced hepatotoxicity and oxidative stress in albino rats [55], together indicating that both the protein and lipid/oil fractions of the seed independently contribute to hepatoprotective activity across at least two distinct hepatotoxin models ($CCl_4$ and chronic ethanol). Nonetheless, compared with the antidiabetic, antioxidant, and BPH indications, these hepatoprotective studies remain comparatively fewer in number and more heterogeneous in extract type and dosing, and continued dose-ranging investigation with standardized extracts ideally correlating biochemical (ALT/AST/ALP) and histopathological endpoints with the specific phytochemical fraction responsible would further strengthen this evidence base.

**Anticancer/Cytotoxic Effect:** Several *C. pepo*-derived fractions and isolated chemicals have been shown to have cytotoxic effect against a variety of cancer cell lines. While purine-containing cucurbitane triterpenoids, such as cucurbitacin B and related dihydrocucurbitacin derivatives, have been isolated and structurally characterized directly from *C. pepo* cv. dayangua seed material, [42] cucurbitaglycosides A and B, which were isolated from the ethanolic extract of air-dried *C. pepo* fruit, demonstrated weak but detectable *in-vitro* cytotoxicity against HeLa cervical carcinoma cells [1]. Separately, a hydro-alcoholic extract of *C. pepo* leaves showed measurable cytotoxicity against HepG2 hepatocellular carcinoma ($IC_{50}$ 132.6 µg/mL) and CT26 colon carcinoma ($IC_{50}$ 167.2 µg/mL) cell lines, with markedly lower potency against normal CHO and fibroblast cell lines, indicating a degree of selective cytotoxicity toward malignant cells relative to normal tissue [44] In the context of applied nanotechnology, pumpkin seed oil-loaded chitosan nanoparticles demonstrated cytotoxic and apoptotic effects against SCC-25 tongue squamous cell carcinoma cells [46], silver nanoparticles biosynthesized using a hydroethanolic extract of *C. pepo* fruit induced dose-dependent apoptosis and reduced viability of MCF-7 breast cancer cells *in-vitro* [45], and copper oxide nanoparticles biosynthesized using pumpkin seed extract showed cytotoxic effects against additional cancer cell lines [49], illustrating the extract's utility as a green-synthesis platform for nanoparticle-enhanced anticancer delivery in addition to its direct phytochemical bioactivity.

**Antimicrobial and Antifungal Action:** *C. pepo* formulations have been shown to have antimicrobial action against a variety of Gram-positive and Gram-negative infections in seed, leaf, and oil extracts. The antioxidant, antimicrobial, and antifungal potential of *C. pepo* var. *fastigata* seed extracts has been assessed;[50] the phytochemical profile of the seed, which is rich in *against Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli*, according to a thorough analysis of aqueous, methanolic, and chloroform seed extracts with maximum inhibition zones of 12.0 mm and 10.0 mm respectively against *P.*

*aeruginosa* and minimum inhibitory concentrations of 18–24 mg/mL, while the aqueous extract showed no measurable activity against *E. coli* or *S. aureus*, indicating that antibacterial potency in this species is strongly solvent-polarity-dependent [57]. In a dedicated evaluation of *C. pepo* seed oil against *S. aureus*, ethanolic extract produced clear dose-dependent inhibition zones ranging from 10.0 ± 0.36 mm at 10 mg/mL to 23.0 ± 0.91 mm at 100 mg/mL, with a minimum inhibitory concentration of 0.625 mg/mL [56], and a comparative study of extracted seed oils found *C. pepo* oil produced a larger zone of inhibition against *S. aureus* than *Brassica nigra* (black mustard) oil under identical Kirby-Bauer disc-diffusion conditions, with both oils showing comparable activity against *E. coli* [58].

Acetone extracts of *C. pepo* leaves have similarly shown inhibitory activity against *E. coli*, with immature leaves showing stronger antibacterial effect than ripe leaves in a comparative study alongside *Lagenaria siceraria* leaves [59], and a broader survey of seed extract antimicrobial efficacy using multiple solvent systems has been reported by the International Society for Horticultural Science [60].

Consistent with this body of evidence, the biosynthesized copper oxide nanoparticles described above additionally showed significant antibacterial activity against *Bacillus subtilis*, with an inhibition zone diameter of 2.8 cm at a concentration of 4 ppm, considerably enhancing the antibacterial potency of the extract when formulated as a nanoparticle system [49].

**Anthelmintic Activity:** The traditional use of *C. pepo* seed as an anthelmintic remedy has received experimental support from both *in-vitro* and *in-vivo* studies. Seed preparations have shown anthelmintic potential against the dwarf tapeworm *Hymenolepis nana*, reducing worm viability in a dose-dependent manner [48], while a combined *in-vitro*/*in-vivo* evaluation of pumpkin seed extract composition and anthelmintic activity found that an ethanolic extract significantly reduced faecal egg counts and adult worm burden in mice infected with the gastrointestinal nematode *Heligmosomoides bakeri*, with the greatest effect observed at the highest tested dose, supporting further development of pumpkin seed extract as a cost-effective, plant-derived alternative for gastrointestinal nematode control [51]. These *in-vivo* anthelmintic findings are consistent with the proposed mechanism of the marker compound cucurbitin described in the Chemical Constituents section above.

**Other Reported Activities:** Beyond the major activities described above, *C. pepo* preparations have also been investigated for antidepressant-like and neuroendocrine-modulating effects in chronic-stress rodent models (see antioxidant/anti-inflammatory activity above) [41], for protection against acute reproductive oxidative toxicity [43], and for antiulcer activity, which is noted repeatedly alongside the other principal pharmacological activities in the general review literature on this species [1], though dedicated, dose-ranging primary studies specific to *C. pepo* for this particular indication were not identified in comparable depth to the BPH, antidiabetic, antioxidant, or hepatoprotective literature during this review.

**CONCLUSION:** In conclusion, *Cucurbita pepo* L. represents a significant intersection of culinary and medicinal value, with a robust pharmacognostical profile that underscores its therapeutic potential. Pharmacologically, the plant has demonstrated notable antidiabetic and antioxidant activity through enzyme inhibition and free-radical scavenging; hepatoprotective effects against $CCl_4$- and alcohol-induced liver injury; anticancer/cytotoxic activity across multiple cell lines, including *via* nanoparticle-based delivery; and broad-spectrum antimicrobial and anthelmintic effects consistent with its traditional use. Among these, its role in managing benign prostatic hyperplasia and related conditions remains the most clinically validated. Addressing the identified gaps in pharmacognostical standardization and expanding clinical research will be essential to harness its full capabilities as a reliable source of phytopharmaceuticals, thereby enhancing its role in contemporary healthcare.

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## CONFLICT OF INTEREST: Nil

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