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Cardioprotective Potential of Cucurbitaceae Seeds: A Systematic Review of Bioactive Profiles, Nutritional Synergy, and Therapeutic Implications for Heart Health

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ABSTRACT

This review synthesizes research on Cucurbitaceae seeds and heart health, focusing on specific types like pumpkin seeds, watermelon seeds, and cucumber seeds, to address gaps in understanding their nutritional and cardioprotective roles. The review aimed to evaluate the nutritional composition relevant to cardiovascular health, benchmark cardioprotective effects of omega-3 fatty acids and antioxidants, identify bioactive compounds, compare seed efficacy, and assess processing impacts. A systematic analysis of global studies employing biochemical profiling, clinical and animal models, and processing evaluations was conducted. Findings indicate that pumpkin seeds exhibit higher concentrations of omega-3 fatty acids, tocopherols, and phytosterols compared to watermelon and cucumber seeds, correlating with improved lipid profiles, reduced oxidative stress, and blood pressure modulation. Diverse bioactives including polyphenols, squalene, and cucurbitacins contribute synergistically to antioxidant and anti- inflammatory effects, though bioavailability data remain limited. Processing methods such as roasting and ultrasonication enhance nutrient retention and bioactive stability, yet standardized protocols are lacking. Comparative efficacy studies are scarce, particularly for watermelon and cucumber seeds, limiting comprehensive assessment. These findings collectively underscore the potential of Cucurbitaceae seeds as functional foods for cardiovascular disease prevention. Further rigorous clinical trials and standardized processing evaluations are necessary to optimize their therapeutic application and support nutraceutical development.

Keywords: *Cucurbitaceae seeds, cardiovascular disease prevention, Omega-3 fatty acids Bioactive compounds, Phytosterols, Antioxidant stability*

1. INTRODUCTION

Research on Cucurbitaceae seeds and heart health has emerged as a critical area of inquiry due to the increasing prevalence of cardiovascular diseases (CVDs) worldwide and the potential of these seeds as functional foods rich in bioactive compounds [1-2]. Over the past two decades, studies have progressively highlighted the nutritional and therapeutic properties of seeds from pumpkin, watermelon, and cucumber, emphasizing their content of polyunsaturated fatty acids (PUFAs), antioxidants, and phytosterols [3-4]. The global production of cucurbit fruits generates substantial seed by-products, which represent an underutilized resource with significant health-promoting potential [4-5]. Given the rising burden of CVDs, which account for nearly 18 million deaths annually, exploring natural dietary interventions such as Cucurbitaceae seeds is of practical and social importance [6-7].

Despite extensive research on the nutritional composition of Cucurbitaceae seeds, a specific knowledge gap persists regarding the detailed mechanisms by which their key components, such as omega-3 fatty acids and antioxidants, influence cardiovascular health [6,8-9]. While pumpkin seeds have been widely studied for their lipid profiles and antioxidant capacity, less is known about watermelon and cucumber seeds in this context [4,10-11]. Moreover, controversies exist concerning the optimal balance of omega-6 to omega-3 fatty acids in these seeds and their bioavailability, which affects their cardioprotective efficacy [12-13]. The lack of comprehensive comparative analyses and clinical evidence limits the translation of these findings into dietary recommendations [6-7]. Addressing this gap is crucial, as inadequate understanding may hinder the development of functional foods and nutraceuticals targeting heart health [2].

The conceptual framework of this review integrates the nutritional composition of Cucurbitaceae seeds—focusing on omega-3 fatty acids, antioxidants, and phytosterols—with their biological activities related to cardiovascular protection [1,3,14]. This framework posits that the synergistic effects of these bioactive compounds modulate oxidative stress, lipid metabolism, and inflammation, thereby reducing CVD risk [6-7]. Establishing these relationships provides a theoretical basis for evaluating the seeds' potential as functional food ingredients and therapeutic agents.

The purpose of this systematic review is to critically evaluate and synthesize current evidence on the nutritional components of pumpkin, watermelon, and cucumber seeds, emphasizing omega-3 fatty acids and antioxidants, and their implications for heart health [5,9]. This review aims to fill existing knowledge gaps by comparing seed types, elucidating bioactive profiles, and assessing their cardioprotective mechanisms, thereby advancing the scientific understanding and practical application of Cucurbitaceae seeds in cardiovascular nutrition [7-8].

A comprehensive literature search was conducted across multiple databases, including PubMed, ScienceDirect, and Google Scholar, focusing on studies published between 2000 and 2025[8-9]. Inclusion criteria encompassed research on seed composition, bioactive compounds, and cardiovascular effects, while exclusion criteria omitted studies lacking relevant biochemical or clinical data. The findings are organized to first present the nutritional profiles, followed by bioactive compound characterization, and finally, their health impacts and potential applications in functional foods and nutraceuticals [5,14].

Purpose and Scope of the Review

Statement of Purpose

The objective of this report is to examine the existing research on "Cucurbitaceae seeds and heart health, focusing on specific types like pumpkin seeds, watermelon seeds, and cucumber seeds. Explore the nutritional components such as omega-3 fatty acids and antioxidants." to synthesize current knowledge on the nutritional and bioactive profiles of these seeds and their potential cardioprotective effects. This review is important because cardiovascular diseases remain a leading cause of morbidity and mortality worldwide, and dietary interventions using functional foods like Cucurbitaceae seeds may offer accessible preventive strategies. By consolidating evidence on key nutrients such as omega-3 fatty acids, phytosterols, and antioxidants present in these seeds, the report aims to clarify their roles in cardiovascular health, identify gaps in the literature, and provide a foundation for future research and potential clinical applications.

Specific Objectives:

- To evaluate current knowledge on the nutritional composition of pumpkin, watermelon, and cucumber seeds relevant to heart health.
- Benchmarking of existing studies on the cardioprotective effects of omega-3 fatty acids and

antioxidants in Cucurbitaceae seeds.

- Identification and synthesis of bioactive compounds in Cucurbitaceae seeds that contribute to cardiovascular disease prevention.
- To compare the efficacy of different Cucurbitaceae seed types in modulating lipid profiles and oxidative stress markers.
- To deconstruct the mechanisms by which phytosterols and other seed constituents influence cardiovascular function.

Methodology of Literature Selection

Transformation of Query

We take your original research question — **"Cucurbitaceae seeds and heart health, focusing on specific types like pumpkin seeds, watermelon seeds, and cucumber seeds. Explore the nutritional components such as omega-3 fatty acids and antioxidants."**and expand it into multiple, more specific search statements. By systematically expanding a broad research question into several targeted queries, we ensure that your literature search is both **comprehensive** (you won't miss niche or jargon-specific studies) and **manageable** (each query returns a set of papers tightly aligned with a particular facet of your topic).

Below were the transformed queries we formed from the original query:

- Cucurbitaceae seeds and heart health, focusing on specific types like pumpkin seeds,

watermelon seeds, and cucumber seeds. Explore the nutritional components such as omega- 3 fatty acids and antioxidants.

- Investigate the cardiovascular health benefits of Cucurbitaceae seeds, specifically focusing on pumpkin, watermelon, and cucumber seeds, while examining their nutritional components

such as omega-3 fatty acids, phytosterols, and antioxidants.

- Investigate the health effects of phytosterols and bioactive compounds in Cucurbitaceae seeds like pumpkin, watermelon, and cucumber, with an emphasis on their role in cardiovascular health and omega-3 fatty acids.

Screening Papers

We then run each of your transformed queries with the applied Inclusion & Exclusion Criteria to retrieve a focused set of candidate papers for our always expanding database of over 270 million research papers. During this process we found 53 papers

Citation Chaining - Identifying additional relevant works

- **Backward Citation Chaining:** For each of your core papers we examine its reference list to

find earlier studies it draws upon. By tracing back through references, we ensure foundational work isn't overlooked.

- **Forward Citation Chaining:** We also identify newer papers that have cited each core paper,

tracking how the field has built on those results. This uncovers emerging debates, replication studies, and recent methodological advances

A total of 77 additional papers is found during this process

Relevance scoring and sorting

We take our assembled pool of 130 candidate papers (53 from search queries + 77 from citation chaining) and impose a relevance ranking so that the most pertinent studies rise to the top of our final papers table. We found 127 papers that were relevant to the research query. Out of 127 papers, 50 were highly relevant.

2. RESULTS

Descriptive Summary of the Studies

This section maps the research landscape of the literature on Cucurbitaceae seeds and heart health, focusing on specific types like pumpkin seeds, watermelon seeds, and cucumber seeds. Explore the nutritional components such as omega-3 fatty acids and antioxidants. The reviewed studies encompass a broad spectrum of research including nutritional profiling, bioactive compound analysis, and clinical or animal model evaluations of cardioprotective effects. Geographic diversity spans multiple regions including Asia, Europe, Africa, and the Americas, with methodologies ranging from biochemical assays to clinical trials and food processing assessments. This comparative analysis is crucial for addressing the research questions on the cardioprotective potential of Cucurbitaceae seeds, their bioactive diversity, and the influence of processing on their efficacy.

Nutritional Composition Profiling:

Over 40 studies quantified omega-3 and omega-6 fatty acids, consistently reporting high levels of polyunsaturated fatty acids, especially linoleic and linolenic acids in pumpkin and watermelon seeds [3,12,15].

- Minerals such as magnesium, potassium, iron, and zinc were frequently reported as abundant

in pumpkin seeds, contributing to their nutritional value [3,16-17].

- Antioxidants including tocopherols (notably γ-tocopherol), carotenoids, and phytosterols

were commonly identified as key nutritional components across studies [12]Some studies highlighted variability in nutrient

content due to cultivar, geographic origin, and ecological conditions[13,17,19].

Cardioprotective Effectiveness:

- Approximately 15 studies demonstrated pumpkin seed oil or seed consumption improved

lipid profiles by lowering LDL and increasing HDL cholesterol, and reduced blood pressure in clinical or animal models [7,10,20].

- Anti-inflammatory and antioxidant effects were frequently linked to cardioprotective benefits,

with several studies showing reduction in oxidative stress markers [15,21-22].

Few studies directly compared seed types for cardiovascular outcomes, but pumpkin seeds were most studied for these effects [7,20].

- Some research suggested that phytosterols in seeds inhibit cholesterol absorption, contributing

to lipid-lowering effects [7,14].

Bioactive Compound Diversity:

Phenolic compounds, flavonoids, tocopherols, squalene, and phytosterols were consistently reported as diverse bioactives in pumpkin seeds [3,12,23].

Watermelon and cucumber seeds also contained significant bioactive profiles, though less extensively characterized [16,24].

Several studies emphasized the presence of unique compounds such as cucurbitacins and lignans with potential health benefits [1,25].

The diversity and concentration of bioactives varied by species, cultivar, and processing method [12,19,26].

Comparative Seed Efficacy:

Comparative analyses indicated pumpkin seeds generally have higher concentrations of omega-3 fatty acids, tocopherols, and phytosterols compared to watermelon and cucumber seeds [4-5,16].

Watermelon seeds were noted for high protein and oil content but less studied for direct cardiovascular effects [11,24].

Cucumber seeds were less frequently studied but showed promising nutritional profiles in some analyses [16,27].

Few studies directly compared the efficacy of these seeds on cardiovascular risk factors, indicating a research gap [4-5].

Processing Impact Assessment:

Roasting, germination, and extraction methods significantly influenced nutrient retention and bioavailability, often enhancing protein, mineral, and antioxidant levels [3,22,28].

Ultrasonication and cold-pressing extraction methods preserved antioxidant compounds better than conventional methods[23]. Processing could improve oxidative stability of seed oils, which are important for nutraceutical applications [12,15]. Some studies noted that processing might reduce certain heat-sensitive compounds,

necessitating optimization [25,28].

Critical Analysis and Synthesis

The reviewed literature on Cucurbitaceae seeds, particularly pumpkin, watermelon, and cucumber seeds, reveals a robust interest in their nutritional and cardioprotective potential, emphasizing omega-3 fatty acids, antioxidants, and phytosterols. Strengths include comprehensive profiling of bioactive compounds and promising in vitro and in vivo evidence supporting cardiovascular benefits. However, limitations arise from variability in study designs, insufficient clinical trials, and inconsistent reporting on processing effects and bioavailability. The comparative efficacy of different seed types and the mechanistic understanding of their cardioprotective actions remain underexplored, highlighting the need for standardized methodologies and more rigorous clinical investigations.

Strengths and weaknesses across reviewed studies

The evidence base is strongest for compositional profiling—multiple studies quantify PUFA profiles, tocopherols, phytosterols, and minerals using robust analytical methods (e.g., GC-MS/UPLC), supporting the seeds' potential as functional foods [3,12-13,18].

However, cross-study comparability is weakened by cultivar, geographic, and methodological heterogeneity, and cucumber seeds are markedly underrepresented [11,17,19].

Cardioprotective signals (lipid profile improvement, blood pressure modulation, oxidative stress reduction) are reported most consistently for pumpkin seed oil/products, with far fewer controlled human data overall [7,22]. Mechanistic explanations

are often plausible but not fully resolved, and translation to watermelon/cucumber remains limited [6,8,11,24,29].

Bioactive diversity is well characterized (phenolics, flavonoids, tocopherols, sterols, squalene and related compounds), but human bioavailability/metabolism and the stability of these compounds across processing pipelines are inconsistently addressed [12,14-15,21,23,28,30-31].

Finally, while valorization and nutraceutical applications are frequently proposed, standardization (cultivar selection, extraction/processing protocols) and stronger clinical validation remain key barriers to implementation [5,14,27,32-34].

Thematic Review of Literature

Research on Cucurbitaceae seeds, particularly pumpkin, watermelon, and cucumber seeds, consistently highlights their rich nutritional profile and potential cardiovascular benefits. Key bioactive components such as omega-3 and omega-6 fatty acids, antioxidants including tocopherols and polyphenols, and phytosterols are commonly noted for their cardioprotective effects. Studies also explore the influence of processing and geographic factors on the bioavailability and efficacy of these nutrients. Emerging evidence underscores the seeds' roles in modulating lipid profiles, oxidative stress, and inflammation, suggesting their promising applications as functional foods or nutraceuticals in cardiovascular health management.

Thematic synthesis of literature

The most frequent themes were nutritional composition and bioactive profiling (38/50 papers), emphasizing high protein, PUFA (linoleic/linolenic acids), tocopherols, phytosterols, carotenoids, and minerals—with substantial variability by species, cultivar, and geography [2-3,10,12-13,15-18,26].

Cardioprotective effects and mechanisms were also common (29/50 papers), typically framed around lipid-lowering, antihypertensive, antioxidant, and anti-inflammatory pathways; evidence again concentrates on pumpkin seed oil/products [3,7,10,14-15,21-22,35].

Additional recurring themes included antioxidant capacity/oxidative stability (27/50), processing and geographic variability (18/50), functional food/nutraceutical applications (15/50), phytosterols and lipid metabolism (14/50), and comparative seed-type analysis (12/50) [4,11,16,36].

Less frequent but important themes were broader CVD prevention/management potential (11/50), phytochemical diversity beyond fatty acids (9/50), and bioavailability/safety considerations (7/50), highlighting clear translation gaps [1,9,30-31].

Chronological Review of Literature

Research on Cucurbitaceae seeds and their impact on heart health has evolved significantly over the last two decades. Early studies primarily focused on the basic nutritional composition and functional properties of pumpkin, watermelon, and cucumber seeds, highlighting their rich content of polyunsaturated fatty acids and antioxidants. Over time, investigations expanded to characterize specific bioactive compounds, their mechanistic roles in cardiovascular protection, and the effects of processing on nutrient bioavailability. Recent research emphasizes cultivar differences, extraction technologies, and the potential clinical benefits, including lipid profile modulation and antioxidant effects, positioning these seeds as promising functional foods for cardiovascular health.

Chronological evolution of literature

2001–2010 studies established baseline seed composition (protein, lipid, minerals) and functional properties, identifying essential fatty acids and tocopherols and assessing seed flours for food use.

Between 2011–2015, work moved toward detailed lipid fraction characterization (fatty acids, tocopherols, carotenoids, phytosterols) and physicochemical properties of seed oils, with early nutraceutical framing and by-product valorization.

From 2016–2019, emphasis expanded to nutraceutical potential and biological effects (antioxidant, anti-inflammatory, and cardiometabolic relevance), often linking omega-3/omega-6 balance, phytosterols, and polyphenols to lipid modulation and oxidative stress.

During 2020–2021, studies increasingly evaluated processing effects (roasting, germination, extraction) and broadened beyond lipids to protein extracts and multi-component formulations, while still relying heavily on preclinical designs.

In 2022–2025, research became more integrative: cultivar-specific variability, advanced extraction/preservation methods, oxidative stability, and emerging clinical relevance were foregrounded alongside sustainable product development and circular economy applications.Agreement and Divergence Across Studies

Most studies consistently highlight those pumpkin seeds, along with watermelon and cucumber seeds, are rich sources of bioactive compounds including omega-3 and omega-6 fatty acids, antioxidants like tocopherols, phenolics, and phytosterols, which contribute to cardiovascular health benefits. There is broad agreement on the cardioprotective effects of these seeds through lipid profile improvement, anti-inflammatory, and antioxidant mechanisms. However, some divergence arises regarding the extent of bioactive compound concentration variations across species, cultivars, and geographical origins, as

well as the impact of processing methods on nutrient retention and efficacy. These differences are often attributable to variations in study designs, seed varieties, extraction and processing methods, and the focus on different seed parts or products (oil, flour, whole seed).

Agreement and divergence across studies

Nutritional composition—broad agreement that cucurbit seeds contain substantial PUFA (linoleic and α-linolenic acids), tocopherols (notably γ-tocopherol), phytosterols, squalene, and key minerals [3,10,12,16,18,33]. Divergence largely reflects cultivar, ecology, and region, as well as analytical and extraction variability [11-13,17,24].

Cardioprotective effectiveness—agreement that pumpkin seed oil/products can improve lipid fractions and reduce blood pressure/oxidative stress in some animal and limited human studies [7,22], but divergence arises from variable dosages, intervention durations, and the scarcity of comparable evidence for watermelon/cucumber [11,24].

Bioactive diversity—agreement that seeds contain diverse phenolics, flavonoids, tocopherols, sterols, and related phytochemicals with demonstrable antioxidant activity in standard assays; divergence stems from extraction method differences and seed/part variability [12,18,23,31,33,37].

Comparative seed efficacy—consensus that pumpkin is both the most studied and often richest in selected bioactives, but there is little head-to-head evidence for cardiovascular outcomes across seed types [4-5,11-12,24,36].

Processing impact—agreement that roasting/germination and extraction choices can materially change nutrient retention and oxidative stability; divergence persists because processing is rarely evaluated against clinical endpoints and is less studied for watermelon/cucumber [3,12,23-24,28].

Theoretical and Practical Implications

Theoretical Implications

- The reviewed literature consolidates the understanding that Cucurbitaceae seeds, particularly pumpkin, watermelon, and cucumber seeds, are rich sources of bioactive compounds such as omega-3 and omega-6 fatty acids, phytosterols, tocopherols, and antioxidants, which collectively contribute to cardioprotective effects. This supports existing theories on the role of polyunsaturated fatty acids and antioxidants in cardiovascular health by demonstrating their presence and functional potential in these seeds [7,12,15].
- The evidence highlights the multifaceted mechanisms by which these seeds may influence cardiovascular function, including lipid profile modulation, oxidative stress reduction, and anti-inflammatory effects. The presence of phytosterols that inhibit cholesterol absorption

and tocopherols that act as antioxidants align with biochemical pathways known to mitigate atherosclerosis and hypertension [6-7,14].

- Variability in bioactive compound content due to factors such as seed variety, geographical origin, and processing methods introduces complexity in standardizing the cardioprotective efficacy of Cucurbitaceae seeds. This challenges the assumption of uniformity in functional

food components and underscores the need for cultivar-specific and region-specific

investigations [17,19,28].

- The identification of additional bioactive constituents such as squalene, lignans, and

cucurbitacins expands the theoretical framework of seed-derived nutraceuticals beyond classical antioxidants and fatty acids, suggesting broader pharmacological potentials

including anti-inflammatory and neuroprotective effects [1,21,30].

- The literature also points to gaps in understanding pharmacokinetics and bioavailability

of these compounds, indicating that while in vitro and animal studies support cardiovascular benefits, human clinical evidence remains limited and requires further elucidation to confirm mechanisms and effective dosages [8-9,38].

Practical Implications

- The demonstrated cardioprotective properties of Cucurbitaceae seeds, especially pumpkin

seed oil, suggest their potential incorporation into functional foods, dietary supplements, and nutraceutical formulations aimed at managing dyslipidemia, hypertension, and oxidative

stress-related cardiovascular conditions [7,14-15].

- Processing methods such as roasting, germination, and advanced extraction techniques (e.g., ultrasonication-assisted

extraction) have been shown to enhance the nutritional profile and bioavailability of key compounds, offering practical pathways to optimize seed-based products for maximum health benefits [12,23,28].

The variability in seed composition due to ecological and varietal differences necessitates the

development of standardized cultivation and processing protocols to ensure consistent quality and efficacy of seed-derived products in the food and pharmaceutical

industries [13,17,19].

The valorization of Cucurbitaceae seed by-products aligns with sustainable industry practices by reducing agricultural waste and creating value-added products, which can stimulate economic growth in agri-food sectors and support circular economy initiatives[5,18,34]. Clinical evidence supporting the safety and efficacy of pumpkin seed oil in improving lipid profiles and blood pressure underscores its potential for integration into public health strategies and dietary guidelines aimed at cardiovascular disease prevention[7] [6,14].

The incorporation of Cucurbitaceae seeds into novel food products such as energy bars and spreads offers practical solutions for enhancing nutrient intake among specific populations, including athletes and individuals at risk of cardiovascular diseases, thereby broadening consumer access to heart-healthy functional foods [27,39].

3. LIMITATIONS OF LITERATURE

Geographic bias limits generalizability because many studies focus on specific regions/cultivars [13,17,19]. Clinical evidence remains limited—most studies are in vitro/animal or small human trials, reducing translational certainty [6-7,9]. Processing effects are understudied, especially regarding bioavailability and cardioprotective efficacy after roasting/germination/extraction [3,12,28]. The literature is skewed toward pumpkin seeds; watermelon and especially cucumber seeds are underrepresented for cardiovascular outcomes [11,24]. Bioactive profiling is incomplete/inconsistent across studies, limiting synthesis of synergistic effects [16,18,23]. Long-term studies and dose–response data are scarce, constraining safety and dietary guidance [7,22]. Variation in extraction methods complicates cross-study comparison and reproducibility, particularly for seed oils [12,24,33].

Gaps and Future Research Directions

High-priority gaps include (1) large, well-controlled human trials assessing lipid fractions, blood pressure and cardiovascular endpoints; (2) head-to-head comparisons across pumpkin, watermelon and cucumber seeds; (3) pharmacokinetic/bioavailability studies for key bioactives (phytosterols, tocopherols, polyphenols); and (4) long-term safety and dose–response evaluations.

Medium-priority gaps include mechanistic studies (cellular/molecular targets), standardized cultivation/harvesting protocols to manage cultivar/geographic variability, systematic evaluation of processing technologies against bioactive stability and efficacy, focused studies on cucumber seeds, integration of seed by-products into functional foods, and research on synergistic/antagonistic interactions among seed phytochemicals.

Overall Synthesis and Conclusion

The body of literature collectively indicates that seeds from the Cucurbitaceae family, particularly pumpkin, watermelon, and cucumber seeds, are nutrient-dense functional foods rich in bioactive compounds that contribute to cardiovascular health. Among these, pumpkin seeds have received the most extensive scientific attention, consistently demonstrating high concentrations of polyunsaturated fatty acids, especially omega-3 and omega-6 fatty acids, alongside antioxidants such as tocopherols, carotenoids, phytosterols, and polyphenols. Watermelon and cucumber seeds also present promising nutritional profiles, notably high in protein and unsaturated fats, though they remain underexplored in direct cardiovascular health research. The nutritional composition of these seeds varies notably with species, cultivar, geographic origin, and ecological conditions, underscoring the complexity in standardizing their health effects.

Research collectively supports the cardioprotective potential of these seeds, primarily through lipid profile modulation, antioxidant activity, and anti-inflammatory effects. Clinical and preclinical studies on pumpkin seed oil and extracts reveal improvements in lipid markers—such as reductions in LDL cholesterol and blood pressure and increases in HDL cholesterol—alongside decreased oxidative stress, which are central to cardiovascular disease prevention. Phytosterols and other bioactives present in seeds appear to play critical mechanistic roles by inhibiting cholesterol absorption and neutralizing free radicals. However, direct comparative efficacy studies among the different seed types are limited, and watermelon and cucumber seeds lack robust clinical evidence for cardiovascular outcomes, representing a notable gap.

Processing techniques, including roasting, germination, ultrasonication, and cold pressing, significantly influence the bioavailability and stability of key nutrients and bioactives. While certain methods enhance protein content, mineral availability, and antioxidant retention, others may degrade heat-sensitive compounds, highlighting the need for optimized processing protocols to maximize cardioprotective benefits. Despite advances in characterizing the chemical composition

and in vitro properties of Cucurbitaceae seeds, there is a scarcity of well-designed longitudinal human trials and mechanistic studies that definitively establish causality and elucidate molecular pathways.

Overall, the literature suggests that Cucurbitaceae seeds, especially pumpkin seeds, hold substantial promise as accessible, functional food ingredients for cardiovascular disease prevention through their rich omega-3 fatty acid and antioxidant content. Nonetheless, further research is warranted to clarify the comparative effectiveness of different seed types, standardize processing methods for enhanced bioactive delivery, and conduct rigorous clinical trials to validate their health claims and inform practical dietary recommendations

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