International Journal of Food Science and Nutrition
www.foodsciencejournal.com
E-ISSN: 2455-4898
Received: 28-09-2026, Accepted: 28-10-2026, Published: 12-11-2026
Volume 11, Issue 4, 2026, Page No. 150-155

Chia mucilage as a clean-label natural food binder: Extraction, functional properties and food applications

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DOI: https://doi.org/10.66856/ijfsn.2026.11.4.11197

Abstract

Chia (*Salvia hispanica* L.) mucilage is a plant-based hydrocolloid that is receiving growing interest as a clean-label ingredient because it can bind water effectively, show pseudoplastic flow, form films and provide structure in foods without depending on conventional synthetic or highly processed binders. The mucilage is an extracellular polysaccharide released from the seed coat when the seeds are hydrated and consists of a heterogeneous mixture of soluble and insoluble polysaccharide fractions. Its functional characteristics are strongly affected by factors such as extraction temperature, hydration time, seed-to-water ratio, shear, drying and subsequent rehydration conditions. Conventional hydration remains a straightforward method for recovering the mucilage, while hot-water, ultrasound- and microwave-assisted methods can alter both extraction yield and the functional properties of the recovered material. In food formulations, chia mucilage has been explored for several purposes, including partial fat replacement in bakery products, phosphate reduction in emulsified meat products, thickening and stabilization of dairy-type systems, formation of edible films and coatings, and use as a carrier for emulsions and encapsulated ingredients. Studies have also shown that chia mucilage can act synergistically with commercial hydrocolloids, particularly in structured dairy products. Available evidence suggests that chia mucilage can provide several technological functions at the same time, which is valuable when developing clean-label foods. Nevertheless, differences in extraction procedures, colour, flavour, batch-to-batch performance, microbiological stability and the economics of scale-up remain important challenges. Future research should therefore give greater attention to standardized extraction procedures, structure-function relationships, processing stability, sensory optimization, techno-economic evaluation and validation under commercial food conditions. This review brings together information on the structural characteristics, extraction methods, functional properties and food applications of chia mucilage, with emphasis on its potential as a multifunctional natural binder and clean-label ingredient.

Keywords: Chia mucilage, *Salvia hispanica*, clean label, natural binder, hydrocolloid, food applications, fat replacement, edible coating, rheology

Introduction

Growing consumer interest in recognizable, minimally processed and naturally derived ingredients has encouraged food manufacturers to reassess conventional additives and seek multifunctional alternatives. Clean-label reformulation is especially relevant for binders, thickeners, stabilizers, emulsifiers and texture modifiers because one ingredient that performs several functions can simplify the formulation while also improving consumer acceptance. Against this background, plant polysaccharides have gained importance as natural hydrocolloids, and chia seed mucilage has emerged as a promising replacement ingredient because it combines hydration, viscosity development, interfacial activity and film-forming properties (Lin *et al*., 1994 [11]; Munoz *et al*., 2012 [12]; Chiang *et al*., 2021 [3]).

When chia seeds come into contact with water, mucilage is rapidly released from the seed coat. The hydrated material develops into a transparent, viscous layer around the seed and is capable of retaining considerable amounts of water. The polysaccharide structure, relatively high molecular mass and charged nature of its fractions contribute to the development of viscous dispersions and weak gel-like structures. These properties make chia mucilage useful in food systems where binding, moisture control and texture development are important (Lin *et al*., 1994 [11]; Munoz *et al*., 2012 [12]; Goh *et al*., 2016 [9]).

The objective of this review is to assess chia mucilage as a clean-label natural food binder by bringing together evidence on its structure, extraction methods, hydration and rheological behaviour, food applications, interactions with other hydrocolloids, technological benefits and limitations. Instead of discussing individual studies as isolated case studies, the findings are considered collectively according to the functional role of chia mucilage in food formulation.

Chia Seed and Mucilage: Nutritional and Structural Characteristics

Chia seeds are recognized as nutrient-dense plant materials containing lipid, protein, dietary fibre, minerals and bioactive compounds. Their nutritional profile has

contributed to the increasing incorporation of chia ingredients into functional foods, but the seed coat mucilage has an additional technological importance that is distinct from the nutritional value of the whole seed (Kulczynski *et al*., 2019 [10]).

Structural studies identified the chia seed exudate as a high-molecular-weight heteropolysaccharide containing xylose, glucose and uronic-acid-containing residues. The reported molecular mass and carbohydrate composition help explain the strong hydration and viscosity development of the extracted material (Lin *et al*., 1994 [11]).

The mucilage is associated with the outer layers of the seed coat. Upon hydration, it forms a hydrated capsule and filamentous network around the seed, enabling water immobilization and contributing to the characteristic swelling of chia. The extent of hydration and mucilage recovery varies with temperature, water availability, extraction time and seed-to-water ratio (Munoz *et al*., 2012 [12]).

The polysaccharide fraction has been described as comprising neutral soluble and negatively charged fractions. Its microgel dispersion exhibits shear-dependent behaviour and weak viscoelasticity, while remaining comparatively tolerant to changes in pH, temperature and ionic strength within the ranges investigated. Such behaviour is desirable in food processing because the ingredient can develop viscosity under low-shear conditions while becoming easier to process under higher shear (Goh *et al*., 2016 [9]).

Extraction of Chia Mucilage

The technological performance of chia mucilage begins with extraction. Extraction is not simply a recovery step; it determines the concentration, molecular integrity, hydration state, colour, rheological behaviour and subsequent application performance of the mucilage. Therefore, extraction conditions should be selected according to the intended food function rather than yield alone.

Conventional Hydration and Aqueous Extraction

Conventional extraction generally involves hydration of chia seeds in water followed by separation of the hydrated mucilage from the seed material. This method is attractive because it requires simple equipment, water as the principal extraction medium and relatively mild conditions. However, the recovered yield and functionality can vary with seed-to-water ratio, hydration temperature, duration and mechanical separation (Munoz *et al*., 2012 [12]).

Hot-Water Extraction

Hot-water extraction can increase mucilage recovery by accelerating hydration and mass transfer. Comparative extraction work has shown that temperature-assisted extraction can produce higher yields than simple room-temperature hydration under particular experimental conditions, although higher temperatures may also influence colour and the structural properties of the recovered polysaccharide (Tan *et al*., 2025 [15]).

Ultrasound-Assisted Extraction

Ultrasound-assisted extraction has been investigated as a means of intensifying mucilage recovery and modifying the structure of the hydrated polysaccharide. Acoustic cavitation can enhance liquid-solid contact and mass transfer, but prolonged sonication or excessive treatment intensity may alter the fibrillar structure and reduce apparent viscosity and elastic behaviour. Thus, ultrasound conditions require optimization rather than simply maximizing treatment intensity (Tan *et al*., 2025 [15]).

Microwave-Assisted Extraction

Microwave-assisted extraction provides rapid volumetric heating and can shorten the time required for hydration and extraction. Recent comparisons of conventional, hot-water and microwave approaches demonstrated that extraction efficiency is strongly dependent on the selected processing conditions. Microwave treatment may therefore be useful for rapid processing, but the effect on colour, hydration and rheology must be evaluated for each application (Tan *et al*., 2025 [15]).

Emerging Extraction Strategies

Recent reviews emphasize that chia mucilage extraction is affected by hydration time, temperature, water-to-seed ratio, separation procedure and the use of intensification technologies. Ultrasound and microwave approaches may improve recovery or reduce processing time, but standardization is still required before results obtained by different laboratories can be directly compared.

Functional Properties Relevant to Food Binding

Water-Holding and Water-Binding Capacity

Water binding is one of the most important properties responsible for the use of chia mucilage as a food binder. Hydration creates a polysaccharide-rich layer capable of immobilizing water and increasing the viscosity of the continuous phase. This can improve cohesiveness, reduce free-water migration and contribute to moisture retention during storage and processing (Munoz *et al*., 2012 [12]; Goh *et al*., 2016 [9]).

Rheological Behaviour

Chia mucilage dispersions generally exhibit pseudoplastic or shear-thinning behaviour, meaning that apparent viscosity decreases as shear rate increases. This is advantageous in food processing because a formulation can remain structured during storage while becoming easier to pump, mix or deposit during processing. The rheological response depends on concentration, extraction history, temperature, pH, ionic environment and mechanical treatment (Goh *et al*., 2016 [9]; Punia and Dhull, 2019 [14]).

Gel Formation and Viscoelasticity

At suitable concentrations, chia polysaccharide can form weak viscoelastic networks and microgel-like structures. The resulting network contributes to body and cohesiveness rather than producing the highly rigid gel associated with some conventional gelling agents. Tailoring concentration and processing conditions is therefore important when chia mucilage is used as a binder rather than simply as a thickener (Goh *et al*., 2016 [9]; Brutsch *et al*., 2019 [1]).

Emulsification and Stabilization

The hydrated polysaccharide can contribute to emulsion stability by increasing continuous-phase viscosity and helping reduce movement of dispersed droplets. Chia mucilage has consequently been investigated as an ingredient replacer and stabilizing component in several food systems. Its ability to perform more than one technological function is particularly relevant to clean-label formulation, where replacing several additives with one

recognizable ingredient can be advantageous (Chiang *et al*., 2021 [3]).

Film-Forming Ability

Chia mucilage also forms coherent films after drying. Film properties depend on plasticizer concentration and processing conditions. Increasing glycerol concentration, for example, has been associated with increased elongation, water vapour permeability and water solubility while reducing tensile strength and Young's modulus. These characteristics support the use of chia mucilage in edible films and coatings, although the optimum formulation depends on the intended packaging function (Dick *et al*., 2015 [4]).

Chia Mucilage as a Clean-Label Food Ingredient

The clean-label value of chia mucilage arises from its plant origin and multifunctionality. Instead of acting only as a thickener, the ingredient can contribute to water binding, texture formation, stabilization, fat replacement, phosphate reduction and film formation. Reviews of food applications have therefore considered chia mucilage as a potential replacer for fat, egg, gluten-related functionality, emulsifiers, stabilizers and phosphate salts in selected products (Chiang *et al*., 2021 [3]).

The concept of clean-label functionality should nevertheless be distinguished from the assumption that a natural ingredient automatically provides equivalent technological performance to every conventional additive. Chia mucilage can modify colour, mouthfeel, flavour perception, firmness and processing behaviour, particularly at high inclusion levels. Its use is therefore best considered a formulation strategy in which the ingredient's multiple functions are balanced against product-specific sensory and processing requirements (Fernandes and Salas-Mellado, 2017 [6]; Felisberto *et al*., 2015 [5]).

Applications of Chia Mucilage in Food Systems

Bakery Products and Fat Reduction

Bakery products are among the most extensively investigated applications of chia mucilage because the ingredient can bind water and contribute to structure while partially replacing shortening or oil. In bread and cake formulations, chia mucilage has been evaluated at different fat-replacement levels. Moderate replacement can maintain several physical and technological characteristics, whereas higher replacement levels may reduce product quality or alter crumb properties (Fernandes and Salas-Mellado, 2017 [6]).

The effect of replacement level is formulation dependent. In pound cake, chia mucilage gel was able to replace part of the fat without major changes in several quality parameters at moderate levels, while higher substitution affected colour and crumb firmness. This demonstrates that chia mucilage is more appropriately viewed as a functional fat-replacement binder than as a direct one-to-one replacement for all shortening functionality (Felisberto *et al*., 2015 [5]).

Cookies and Cereal-Based Products

Chia mucilage has also been incorporated into cookies and other cereal-based foods to modify texture and improve the functional profile of formulations. Its rheological behaviour and water-binding capacity can support dough cohesion, while the amount added determines spread, hardness, moisture and sensory characteristics. The optimum concentration must therefore be established experimentally for each product matrix (Punia and Dhull, 2019 [14]).

Dairy Products and Frozen or Structured Foods

In dairy-type systems, chia mucilage can contribute viscosity, water immobilization and stabilization. Its functionality can be enhanced through interactions with commercial hydrocolloids. Recent work with guar gum, xanthan gum and carrageenan showed that combining chia mucilage with selected gums can produce synergistic effects, indicating that chia mucilage may function as part of a hydrocolloid network rather than only as a standalone thickener (Pazinato *et al*., 2025 [13]).

Meat Products and Phosphate Reduction

A particularly relevant clean-label application is the reduction of phosphate salts in emulsified meat products. Phosphates are technologically important for water retention and protein functionality, but consumer interest in simpler ingredient declarations has encouraged investigation of alternative systems. Chia mucilage in powder or gel form has been evaluated in low-fat Bologna-type products, and a moderate level of mucilage gel enabled substantial phosphate reduction while maintaining acceptable technological performance. Excessive mucilage addition, however, can weaken structure and reduce sensory acceptance (Camara *et al*., 2020 [2]).

Edible Films and Coatings

The film-forming capacity of chia mucilage expands its role beyond conventional binding. Mucilage-based films can act as edible barriers and carriers for active compounds, while coatings can help regulate moisture transfer and surface deterioration. The material has therefore been investigated for food-packaging and preservation applications, with formulation variables such as plasticizer level strongly affecting mechanical and barrier properties (Dick *et al*., 2015 [4]; Fernandes *et al*., 2023[7]).

Chia mucilage coatings have also been investigated as preservation systems. A coating containing chia mucilage and zinc oxide nanoparticles reduced microbial and chemical deterioration of chicken fillets during refrigerated storage compared with untreated controls. Such work illustrates the potential of chia mucilage as a carrier matrix for active packaging, although safety, regulatory acceptance and migration behaviour must be considered before commercial use of nanoparticle-containing systems (Foumani *et al*., 2022 [8]).

Carrier Systems and Encapsulation

The hydrated polysaccharide network of chia mucilage can serve as a carrier matrix for emulsions, encapsulated ingredients, films and coatings. This multifunctionality is important because modern food formulation increasingly requires ingredients that provide both structural and delivery functions. Chia mucilage has consequently been reviewed as a potential platform for emulsion stabilization, encapsulation and active coating systems (Fernandes *et al*., 2023 [7]).

Integrated Food Applications Rather Than Separate Case Studies

Across bakery, meat, dairy and packaging systems, the common technological mechanism is the ability of hydrated

chia polysaccharides to interact with water and other food components. In bakery products this can support moisture retention and fat replacement; in meat products it can contribute to water management and structure; in dairy systems it can increase viscosity and participate in hydrocolloid networks; and in coatings it can create a continuous film matrix. These applications should therefore be interpreted as different expressions of the same structure-function relationship rather than isolated case studies (Chiang *et al*., 2021 [3]; Camara *et al*., 2020 [2]; Fernandes *et al*., 2023 [7]).

Comparison with Conventional and Other Natural Binders

Conventional binders and hydrocolloids such as starches, cellulose derivatives, xanthan gum, guar gum, carrageenan and gelatin each provide specific advantages. Chia mucilage differs in being a seed-derived polysaccharide that can provide water binding, viscosity, weak gel formation and film formation while also supporting clean-label positioning. However, its functionality is more dependent on extraction and hydration history than that of standardized commercial hydrocolloids (Chiang *et al*., 2021 [3]; Pazinato *et al*., 2025 [13]).

Table 1: Comparison of Chia Mucilage with Common Food Binders Based on Functional Properties and Clean-Label Potential

Binders	Major functional role	Potential clean-label advantage	Important limitation
Chia mucilage	Water binding, viscosity, weak gel, film formation	Plant-derived, multifunctional	Extraction variability; colour and flavour may increase at higher levels
Xanthan gum	Thickening, stabilization	Effective at low concentrations	Commercial hydrocolloid; consumer perception may depend on formulation
Guar gum	Thickening, water binding	Plant-derived polysaccharide	High viscosity may affect mouthfeel
Carrageenan	Gelation, stabilization	Seaweed-derived hydrocolloid	Functionality depends strongly on formulation conditions
Starch	Binding, thickening, gelation	Familiar food ingredient	Retrogradation and possible texture changes
Gelatin	Gelation, binding	Strong structuring ability	Animal origin; not suitable for vegan formulations

Factors Affecting Chia Mucilage Functionality

Mucilage functionality is governed by several interconnected variables. Extraction temperature affects hydration kinetics and recovery; extraction time influences the extent of polysaccharide release; water-to-seed ratio determines concentration; mechanical agitation influences separation and molecular organization; drying can alter rehydration behaviour; and final concentration controls viscosity and gel strength. These factors explain why mucilage obtained by different laboratories can show substantially different functional properties even when the same seed source is used (Munoz *et al*., 2012 [12]; Tan *et al*., 2025 [15]).

Table 2: Factors Influencing Chia Seed Mucilage Extraction and Their Importance in Food Applications

Factor	Influence on mucilage	Importance for food use
Seed-to-water ratio	Controls concentration and recovery	Determines viscosity and dosage
Hydration temperature	Changes extraction rate and recovery	Affects yield, colour and functionality
Hydration/extraction time	Controls extent of mucilage release	Balances recovery with processing time
Ultrasound intensity/time	Can enhance mass transfer but alter structure	Requires optimization to preserve rheology
Microwave treatment	Rapid heating and hydration	Potential for process intensification
Drying method	Affects rehydration and structure	Important for powdered ingredients
pH and ionic strength	Can modify polysaccharide interactions	Relevant to different food matrices
Concentration	Strongly determines viscosity and gel behaviour	Controls texture and processing

Technological Opportunities

A major opportunity is the development of standardized chia mucilage powders with predictable hydration and rheological properties. Such standardization would make it easier for food manufacturers to formulate with mucilage across different batches and seasons. Characterization should include moisture, carbohydrate composition, molecular characteristics, water-holding capacity, apparent viscosity, viscoelastic parameters, colour, microbiological quality and rehydration performance (Brutsch *et al*., 2019 [1]; Punia and Dhull, 2019 [14]).

A second opportunity is multifunctional clean-label formulation. Instead of adding separate ingredients for water binding, thickening, fat replacement and stabilization, chia mucilage may allow several functions to be addressed through one plant-derived material. This approach is especially promising in bakery, meat and dairy-type foods where water management and structure are central to product quality (Chiang *et al*., 2021 [3]; Camara *et al*., 2020 [2]).

A third opportunity lies in active packaging and carrier systems. The film-forming ability of chia mucilage provides a platform for edible coatings, while its polysaccharide network can be used to carry selected functional compounds. Future systems may combine mucilage with natural antimicrobials, antioxidants or other active compounds, provided that stability, sensory impact and regulatory requirements are addressed (Fernandes *et al*., 2023 [7]).

Limitations and Challenges

Despite promising results, several limitations restrict widespread industrial adoption. The first is variability in extraction and composition. Differences in seed genotype, cultivation environment, extraction temperature, hydration time and separation procedure can change yield and

functionality. The second is sensory impact: increasing mucilage concentration may influence colour, mouthfeel, firmness or other quality attributes. The third is processing stability, because shear, heat, salts and pH may alter the structure of the hydrated polysaccharide (Munoz *et al*., 2012 [12]; Fernandes and Salas-Mellado, 2017 [6]; Felisberto *et al*., 2015 [5]).

Scale-up is another important challenge. Laboratory extraction procedures may involve long hydration periods, extensive washing or manual separation that are difficult to reproduce economically at industrial scale. Intensified extraction can shorten processing time, but it adds equipment and energy requirements. Therefore, industrial selection should consider extraction yield together with water consumption, energy demand, drying cost, product quality and final functional performance (Tan *et al*., 2025 [15]).

Future Research Directions

Future research should move from proof-of-concept formulation studies toward standardized structure-function relationships. Researchers should report extraction conditions in sufficient detail to permit meaningful comparison among studies and should characterize the recovered mucilage using consistent analytical methods. Particular attention should be given to the relationship between molecular structure, charge density, hydration kinetics, molecular weight distribution, rheology and food performance.

Future studies should also evaluate the sustainability and economics of extraction processes. Hot-water, ultrasound and microwave technologies may improve processing efficiency, but the environmental benefit depends on energy demand, water use and downstream drying requirements. Comparative life-cycle and techno-economic analyses would help identify the most appropriate process for commercial production (Tan *et al*., 2025 [15]).

At the formulation level, research should examine combinations of chia mucilage with other natural hydrocolloids, proteins and fibres. Synergistic interactions may reduce the required dosage and improve texture while minimizing sensory disadvantages. Recent evidence with commercial gums suggests that such combined systems can produce useful rheological effects in dairy-type foods.
(Pazinato *et al*., 2025 [13]).

Finally, commercial validation should include sensory acceptance, shelf-life, process tolerance, ingredient declaration, regulatory status and consumer perception. Such integrated evaluation is necessary to determine whether chia mucilage can progress from a promising laboratory hydrocolloid to a reliable industrial clean-label binder.

Conclusion

Chia mucilage is a promising natural, plant-derived multifunctional hydrocolloid with strong potential as a clean-label food binder. Its high water-binding capacity, shear-thinning behaviour, weak viscoelastic gel formation, stabilizing ability and film-forming characteristics provide a technological basis for applications in bakery, dairy, meat and food-packaging systems (Lin *et al*., 1994 [11]; Goh *et al*., 2016 [9]; Chiang *et al*., 2021 [3]).

The literature demonstrates that chia mucilage can support partial fat replacement in bakery foods, contribute to phosphate reduction in emulsified meat products, participate in synergistic hydrocolloid systems and form edible films and active coatings. Its greatest advantage is therefore not a single technological function but the possibility of addressing several formulation requirements with one recognizable plant-derived ingredient (Fernandes and Salas-Mellado, 2017 [6]; Camara *et al*., 2020 [2]; Pazinato *et al*., 2025 [13]; Fernandes *et al*., 2023[7]).

However, commercial utilization requires greater standardization of extraction, characterization and application conditions. Future research should emphasize reproducible processing, sensory optimization, industrial scale-up, techno-economic assessment and sustainable production. With these developments, chia mucilage has considerable potential to become a practical clean-label ingredient for natural binding, thickening, stabilization and structural applications in modern food systems.

Table 3: Representative integrated applications of chia mucilage in food systems

Food system	Functional role of chia mucilage	Observed formulation opportunity	Main consideration
Bread and cakes	Water binding, fat replacement, structure	Partial replacement of fat	High replacement may affect texture/colour
Cookies	Binder, texture modifier	Improved cohesion and functional formulation	Dose affects spread and hardness
Emulsified meat	Water binding and structure	Partial phosphate reduction	Excess may weaken structure
Dairy-type products	Thickening and stabilization	Synergy with commercial gums	Hydrocolloid ratio requires optimization
Edible films/coatings	Film matrix and carrier	Biodegradable/edible barrier systems	Plasticizer and moisture sensitivity
Active coatings	Carrier for active components	Potential preservation function	Safety and regulatory assessment required
Encapsulation systems	Carrier and stabilizing matrix	Delivery of selected functional ingredients	Encapsulation efficiency and release need optimization

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