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REVIEW ON ANTIBACTERIAL GEL FROM CHIA SEEDS

Miss. Pragati Ganesh Biradar[1]*, Mr. Shripad Sanjeevanrao Ahankari[2], Dr. Ganesh Tolsarwad[3]

[1]B. Pharm. Student, Swami Vivekanand College of Pharmacy, Udgir Latur District, Maharashtra, India.

[2]M. Pharm, Assistant Professor, Department of Pharmacy, Swami Vivekanand College of [3]Pharmacy, Udgir, Maharashtra, India.

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***Corresponding Author**
Miss. Pragati Ganesh Biradar
B. Pharm. Student, Swami Vivekanand College of Pharmacy, Udgir Latur District, Maharashtra, India.

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1. ABSTRACT

The rising prevalence of bacterial infections and the growing concern over antibiotic resistance have led to increased interest in natural, plant-based antibacterial agents. Chia seeds (Salvia hispanica L.) are a rich source of bioactive compounds, including phenolics, flavonoids, and mucilage, which exhibit significant antimicrobial, antioxidant, and anti-inflammatory properties. In this study, an antibacterial gel was formulated using chia seed mucilage as a natural gelling agent and the seed extract as the active antimicrobial component. The mucilage was extracted through aqueous soaking and mild heating, yielding a viscous, biocompatible gel base with favourable physicochemical properties such as pH, viscosity, homogeneity, and spread ability, making it suitable for topical application. The chia seed extract was incorporated into the gel, and its antibacterial efficacy was evaluated in vitro against pathogenic bacteria, including Staphylococcus aureus and Escherichia coli, using agar diffusion assays. The formulation demonstrated clear zones of inhibition, confirming its potent antibacterial activity. Preliminary cytotoxicity studies on mammalian skin cells indicated good biocompatibility, and antioxidant assays suggested additional benefits in reducing oxidative stress and promoting wound healing. The natural, biodegradable, and non-toxic nature of chia seed mucilage-based gels, combined with their antimicrobial potential, positions them as promising alternatives to synthetic antibacterial products in topical applications. Further research involving stability studies, formulation optimization, and in vivo testing is recommended to fully establish their therapeutic and cosmetic potential.

KEYWORDS: Chia seeds, antibacterial gel, mucilage, natural antimicrobial, bioactive compounds, topical formulation, biocompatible, wound healing.

2. INTRODUCTION

The rise of antibiotic resistance and the side effects associated with synthetic antibacterial agents have intensified the search for natural, safe, and effective alternatives for topical antimicrobial therapy. Skin infections, wounds, and superficial microbial colonization remain widespread global concerns, necessitating biocompatible treatments. Topical gels — semi-solid, polymeric matrices — provide a practical delivery system for such treatments, offering prolonged local exposure of active ingredients, ease of application, good skin adherence, and reduced systemic side effects.[1]

In recent years, plant-derived bioactive compounds have gained attention as alternative antimicrobial agents due to their chemical diversity and multi-modal mechanisms of action. Among these, Chia seeds (Salvia hispanica L.) are a promising source: besides essential nutrients, they contain polysaccharide mucilage, proteins, phenolic compounds, flavonoids, and bioactive peptides, which collectively contribute to antioxidant, anti-inflammatory, and antimicrobial properties. Research has demonstrated that extracts from Chia seeds inhibit growth of various pathogenic bacteria, including Gram-negative and Gram-positive strains, suggesting potential for medicinal and hygienic applications.[2]

Leveraging these properties, this study proposes the development of a topical antibacterial gel using Chia seed mucilage as the structural base and Chia seed extracts as the bioactive agent. The objectives are to (i) formulate a stable, skin-compatible gel matrix from natural biomaterials, (ii) incorporate Chia seed-derived antibacterial components, and (iii) evaluate the resultant formulation for physicochemical properties and in vitro antimicrobial efficacy. This approach aims to provide a sustainable, biodegradable, and low-toxicity alternative to synthetic topical antibacterials, supporting the growing demand for natural and eco-friendly therapeutic options.[1,2]

Fig. 1: Diagrammatic Representation of Chia Seeds.

3. BACKGROUND OF CHIA SEEDS

Chia (Salvia hispanica L.) is an annual herbaceous plant belonging to the mint family (Lamiaceae), native to central and southern Mexico and northern Guatemala. Historically, it was a major crop for pre-Columbian Mesoamerican civilizations such as the Aztecs and Mayas, who valued chia seeds not only as a staple food, but also for medicinal, ritualistic and general nutrition purposes.[3] The small oval seeds — ranging in colour from dark mottled to pale — were consumed whole, ground, or mixed with water to create energy-rich drinks, and the seeds' mucilage property made them useful in traditional preparations.

Nutritionally, chia seeds are a powerhouse: they are rich in polyunsaturated fatty acids (especially plant-based omega-3), proteins, dietary fiber, vitamins, minerals, and a range of bioactive phytochemicals including polyphenols and antioxidants.[4] Typical composition includes substantial oil (rich in ω-3 and ω-6 fatty acids), fibre, protein, and micronutrients — making them highly valued as both a dietary and functional food source. The high content of soluble fibre and mucilage-forming polysaccharides also contributes to their ability to absorb water and form gels, which has modern applications beyond nutrition. Given this rich nutritional and phytochemical profile along with a long history of human use, chia seeds are increasingly being explored for pharmaceutical, nutraceutical, and cosmeceutical applications.

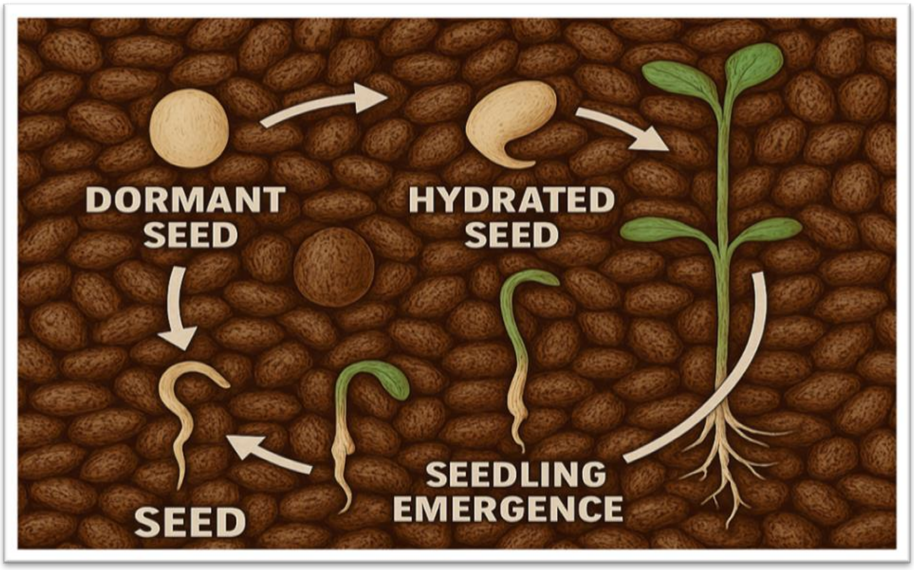

Fig. 2: Development of Chia Seeds.

4. BASIC CONSEPT OF CHIA SEEDS

4.1 ADVANTAGES

1. Natural, biocompatible gel matrix: chia mucilage is a plant-derived polysaccharide suitable as a non-toxic hydrocolloid base for topical gels.

2. Favourable rheology & spread ability: mucilage shows shear-thinning and tunable viscoelastic behaviour, giving easy application and good skin adherence.[6]

3. High water-holding / moisturizing capacity: retains water and helps maintain a moist wound/skin environment beneficial for topical use.

4. Intrinsic antioxidant activity — chia bioactives confer free-radical scavenging which may aid tissue protection and healing.[7]

5. Source of antibacterial peptides / bioactives: chia protein hydrolysates and peptide fractions have shown in-vitro antimicrobial activity against food and clinical pathogens.

6. Good cytocompatibility: chia mucilage hydrogels report low cytotoxicity in cell assays, supporting safety for topical/biomedical use.

7. Platform for controlled release / loading: mucilage can encapsulate or carry actives, enabling sustained release of antibacterial agents.[5]

4.2 Limitations and Challenges

1. Moderate intrinsic antimicrobial potency: mucilage alone often produces only modest antibacterial effects compared with conventional antimicrobials.

2. Need for supplementary actives: To obtain clinically relevant efficacy, gels often require added antibacterials or enhancers (increasing formulation complexity).

3. Extraction / yield variability: Mucilage yield and properties depend on extraction method, seed source and processing, affecting reproducibility.[5]

4. Batch-to-batch variability: Natural seed variability (geography/harvest) can change bioactive content and rheological behaviour, complicating standardization.

5. Stability & microbial contamination risk: Aqueous plant-based gels need preservation or sterilization to avoid spoilage and performance loss over shelf life.

6. Limited delivery of hydrophobic actives: Hydrophilic mucilage matrices may poorly solubilize or deliver lipophilic antibacterial compounds without additional formulation steps.[5]

7. Mechanical/physical property trade-offs: Tuning viscosity or flexibility can reduce mechanical strength or alter barrier/permeation properties.[6]

4.3 Phytochemical profile of chia seed

1. Alpha-linolenic acid (ALA, ω-3): major fatty acid in chia oil (high PUFA content).
2. Other fatty acids / lipids linoleic, oleic and small amounts of saturated fatty acids.
3. Dietary fibre & mucilage: large soluble (gel-forming) and insoluble fibre fraction (functional for gels/emulsions).[7]
4. Proteins & peptides: ~18–23% protein with bioactive peptides reported.
5. Total phenolics (polyphenols & flavonoids): chia contains multiple phenolic acids and flavonoids (rosmarinic, caffeic, chlorogenic, ferulic, gallic; flavonoids such as quercetin, kaempferol, myricetin, apigenin).[8]
6. Tocopherols / vitamin E: reported antioxidant tocopherols in the lipid fraction.

4.4 Phytochemicals in chia linked to antibacterial activity:

1. Rosmarinic acid (and salvianolic derivatives): frequent major phenolic in chia; shown in other plant studies to have antibacterial effects and is one of the main phenolics detected in chia.[8]

2. Caffeic acid and its derivatives: present in chia and known to exert bacteriostatic/bactericidal effects (membrane disruption, enzyme inhibition).

3. Chlorogenic & protocatechuic acids: reported in chia and associated with antibacterial/antioxidant activity in seed extracts.[9]

4. Flavonoids (quercetin, kaempferol, myricetin, apigenin): flavonoids in chia can inhibit bacterial enzymes, disrupt cell walls and act synergistically with phenolic acids.

Fig. 3: Health Benefits of Chia Seeds.

5. CHIA SEED MUCILAGE: EXTRACTION AND GEL-FORMING PROPERTIES:

5.1 Extraction of Chia Seed Mucilage

1. Composition and Release Mechanism

Chia seed mucilage is a water-soluble polysaccharide layer located on the outer seed coat. When the seeds are exposed to water, this mucilage hydrates rapidly and swells, forming a gelatinous coating. The mucilage consists mainly of heteropolysaccharides rich in xylose, glucose, and polysaccharide gums, which contribute to its thickening properties.[10]

2. Conventional Extraction Method The most common extraction procedure involves the following steps

a) Step 1 – Hydration: Chia seeds are soaked in water using ratios that generally range from 1:8 to 1:20 (seed: water, w/v). Hydration is carried out for 2–4 hours at room temperature (25–30 °C). Agitation during soaking improves mucilage release from the seed surface.

b) Step 2 – Separation of Hydrated Mucilage: mucilage layer forms around them. This mucilage is separated by

- Filtration through muslin cloth or fine mesh
- Centrifugation to remove solid residues
- Decantation to isolate the mucilage layer
- Centrifugation (e.g., 3000–5000 rpm) is often preferred for cleaner separation.[11]

3. Drying and Recovery of Mucilage: The extracted mucilage is dried using

- **Freeze-drying (lyophilisation)**: maintains porous structure and preserves functional properties
- **Oven drying** at low temperatures (40–60 °C): higher yield but may alter viscosity
- Freeze-drying produces a lighter, more rehydration-efficient mucilage powder, preferred for food and cosmetic applications.[11]

4. Assisted Extraction Techniques: Modern extraction methods aim to increase yield and reduce processing time.

a). Ultrasound-assisted extraction (UAE): enhances cell-wall disruption and speeds mucilage.

b). Microwave-assisted extraction (MAE): improves extraction efficiency but requires careful temperature control, these advanced methods significantly increase extraction yield while preserving functional characteristics.

5.2 Gel-Forming Properties of Chia Seed Mucilage

1. Rapid Gel Formation

Upon hydration, chia mucilage forms a thick, transparent hydrogel due to strong water-binding capability. This is attributed to its polysaccharide structure, which traps water within a three-dimensional matrix.

2. Rheological Behaviour

Chia mucilage exhibits the following rheological characteristics.

a) Shear-Thinning Behaviour

The viscosity decreases when shear force is applied (e.g., stirring or pumping). This makes chia mucilage suitable for food thickening, cosmetic gels, and drug-delivery matrices.[10]

b). Viscoelastic Properties

Dynamic rheology testing shows

c). G′ (storage modulus) > G″ (loss modulus)

- Indicates solid-like, elastic behaviour typical of strong hydrogels The strength of the gel increases with concentration and extraction method.[11]

3. Water-Holding and Swelling Capacity

Chia mucilage can absorb 10–12 times its weight in water, forming highly stable gels that prevent syneresis, making it useful as

- A stabilizer in dairy products
- A thickener in beverages
- A fat replacer in bakery products.[10]

4. Concentration-Dependent Gel Strength

- Low concentrations (≤1%): produce thin sols
- Moderate concentrations (2–4%): create flowable gels
- High concentrations (>5%): form rigid, self-standing gels suitable for hydrogel formulations.

5. Rehydration Behaviour

Freeze-dried mucilage readily rehydrates to restore its original gel structure and viscosity, demonstrating excellent functional stability, this property is crucial for industrial applications in powders, supplements, and instant foods.[11]

6. METHOD OF PREPARATION OF CHIA SEED ANTIBACTERIAL GEL

1. Materials Required

a) Chia seeds (*Salvia hispanica L.*)

b) Distilled water

c) Ethanol or methanol (food grade or analytical grade)

d) Mortar & pestle or grinder

e) Filter paper / muslin cloth

f) Beakers, magnetic stirrer, hot plate

g) Centrifuge (optional but recommended)

h) Preservative (optional: sodium benzoate or natural preservative)

i) Gelling agent (if strengthening required: xanthan gum, Carbopol, or glycerol)

2. Preparation Steps

Step 1: Extraction of Chia Seed Mucilage

1. Weigh 10 g chia seeds into a beaker.
2. Add 100–150 mL distilled water (ratio 1:10 to 1:15 w/v).
3. Stir continuously for 30–45 minutes to allow mucilage to hydrate.
4. Let the mixture rest for 2 hours at room temperature (25–30 °C).
5. After swelling, a gelatinous layer forms around each seed.
6. Filter through muslin cloth or centrifuge at 4000 rpm for 10 min to separate the clear mucilage gel.
7. A thick, transparent natural gel that will serve as the gel base and stabiliser.[12]

Step 2: Preparation of Chia Seed Antibacterial Extract

1. Grind 10 g of chia seeds into coarse powder.
2. Add 100 mL of 70% ethanol or methanol.
3. Stir continuously on a magnetic stirrer for 2–3 hours at room temperature.
4. Close the container and allow 24-hour cold maceration for full extraction.
5. Filter the mixture through filter paper.
6. Evaporate the solvent using a water bath at 40–50 °C until a thick extract remains
7. This extract contains phenolic acids such as caffeic, chlorogenic, rosmarinic, protocatechuic acids, and flavonoids responsible for antibacterial activity.[9]

Step 3: Incorporation of Extract into Gel Base

1. Add 1–3% (w/w) chia seed antibacterial extract into the fresh mucilage gel base.
2. Mix using a magnetic stirrer for 20–30 minutes until fully blended.
3. Optional: Add

- Glycerol (2–3%) for smoothness
- Xanthan gum (0.3–0.5%) to strengthen the gel
- Preservative (0.1%) for stability.

4. Continue mixing until homogeneous.

Step 4: Final Gel Formation

1. Adjust viscosity according to use

- Add water → thinner gel
- Add mucilage or xanthan → thicker gel

2. Let the gel rest for 12 hours to stabilise its network.
3. Store the gel in an airtight container at 4–8 °C.
4. Quality Evaluation Parameters: pH, viscosity, antibacterial activity testing.

7. FORMULATION COMPONENTS OF CHIA SEED ANTIBACTERIAL GEL & THEIR FUNCTIONS

Chia Seed Mucilage

- Acts as the primary gelling agent.
- Provides viscosity, smooth texture, and water-holding capacity.
- Offers natural antioxidants and mild antimicrobial activity.
- (Supports natural gel structure)[10]

Distilled Water

- Serves as the solvent for mucilage extraction and gel formation.
- Ensures purity and prevents contamination.

Antibacterial Agents

- Provide active antimicrobial activity.
- Examples: tea tree oil, neem extract, eucalyptus oil, chia phenolic extract.
- Reduce microbial load and enhance product effectiveness.

Humectants (e.g., Glycerin)

- Attract and retain moisture.
- Improve gel smoothness, spreadability, and user feel.

Preservatives (e.g., Sodium Benzoate)

- Prevent microbial growth in the gel.
- Extend shelf life and stability.

Thickening Agents (Optional: Carbopol, Xanthan Gum)

- Improve viscosity and enhance gel strength.

- Provide better stability over storage.

pH Adjusting Agents (Citric Acid / NaOH)

- Maintain pH 5.5–6.0, suitable for skin compatibility.
- Prevent degradation of functional compounds.

Natural Antioxidants (Optional: Vitamin E)

- Prevent oxidation of essential oils.
- Increase product shelf-life.

8. FACTORS AFFECTING GEL FORMULATION AND STABILITY

a). Concentration of Chia Mucilage

- Higher mucilage → higher viscosity and gel strength.
- Low mucilage → thin, unstable gel.
- (Mucilage concentration influences rheology).[13]

b). Extraction Temperature

- Optimal: 60–70°C
- Higher temperature may degrade bioactive compounds.
- Lower temperature may reduce mucilage yield.

c). pH of Formulation

- Ideal pH: 5.5–6.0
- Extreme pH (>7 or <4) reduces gel stability and may cause precipitation.

d). Presence of Salts or Electrolytes

- High ionic strength breaks intermolecular interactions.
- Causes gel thinning or separation.

e). Storage Temperature

- High heat accelerates degradation and microbial growth.
- Recommended: Room temperature or refrigeration (4–8°C).

f). Type and Concentration of Antibacterial Ingredients

- Essential oils may destabilize gel if concentration is too high.
- Proper emulsification is required for uniform distribution.

g). Shear Forces During Mixing

- Excessive mixing can break polymer chains of mucilage.
- Reduces gel viscosity and stability.

h). Microbial Contamination

- Can spoil gel during storage.
- Controlled using preservatives and sterile handling.

i). Oxidation

- Essential oils and natural extracts may oxidize.
- Addition of antioxidants improves stability.

9. DETAILED MECHANISM OF ANTIBACTERIAL ACTION OF CHIA SEED CONSTITUENTS

1. Disruption of Bacterial Cell Membranes

- Phenolic acids such as rosmarinic acid, caffeic acid, and chlorogenic acid interact with the lipid bilayer of bacterial membranes.
- This leads to increased membrane permeability, leakage of cytoplasmic contents, and ultimately cell lysis.
- Long-chain fatty acids (α-linolenic acid, linoleic acid) can insert into bacterial membranes, destabilizing their structure.
- This mechanism is effective against both Gram-positive and Gram-negative bacteria.[1]

2. Inhibition of Enzyme Activity and Protein Synthesis

- Chia seed polyphenols can bind to bacterial enzymes involved in respiration, energy metabolism, and protein synthesis.
- Inhibition of these enzymes leads to reduced ATP production, impaired cellular functions, and bacterial growth suppression.[14]

3. Oxidative Stress Induction

- Chia seed flavonoids and phenolics can induce reactive oxygen species (ROS) inside bacterial cells.
- ROS damage DNA, proteins, and membrane lipids, causing oxidative stress and eventual bacterial death

4. Chelation of Essential Metal Ions

- Phenolic compounds in chia seeds can chelate metals such as iron and zinc, which are vital for bacterial enzyme function and growth.
- This results in nutrient limitation, weakening bacterial survival

5. Inhibition of Biofilm Formation

- Flavonoids in chia seeds interfere with **quorum sensing**, the bacterial communication system.
- This prevents **biofilm formation**, reducing bacterial adhesion, virulence, and resistance to antibiotics.[9]

10. EVALUATION & CHARACTERIZATION OF CHIA SEED GEL

Chia-seed gel is based on mucilage extracted from Salvia hispanica L. seeds. Its evaluation and characterization involve assessing its physicochemical, rheological, functional, and stability properties to determine suitability for food, pharmaceutical, or cosmetic applications.[17]

10.1 Physicochemical & Functional Properties

1. The mucilage derived from chia seeds is a complex heteropolysaccharide (mainly xylose, arabinose, glucose, etc.) that, upon hydration, forms a viscous, gel-like dispersion.[15]

2. Water-holding capacity (WHC) and solubility: Chia mucilage exhibits high water absorption and retention capacity (and also oil-holding), making it effective for hydration, thickening, and stabilization in gels or emulsions.

3. Thermal stability: Mucilage from some phenotypes shows thermal stability up to high temperatures (≈ 260–287 °C for the polysaccharide in some studies), indicating resilience under processing conditions.[16]

4. Hence, from a theoretical standpoint, the polysaccharide composition, hydrophilicity, and water-binding capacity make chia mucilage a strong candidate for forming stable hydrogels/gels.

10.2 Rheological / Flow Behaviour & Gel Structure

1. **Shear-thinning behaviour:** When subjected to increasing shear (stirring, spreading), viscosity decreases — beneficial for spreadability (topical use) or pourability (food gels).[15]

2. **Viscoelastic / weak-gel behaviour:** Frequency-sweep rheological analysis shows that storage modulus (G′) > loss modulus (G″) — indicating the dispersion behaves like a weak elastic gel.[16]

3. **Dependence on concentration & extraction method:** Concentration of mucilage and extraction method (cold vs hot, drying technique) significantly influence gel strength, viscosity, microstructure, and rheological properties.[17]

4. Thus, the gel-forming capability and mechanical properties of chia seed gel depend on both the inherent polysaccharide structure and processing/formulation conditions

10.3 Microstructure & Morphological / Physical Stability

1. SEM evaluation shows freeze-dried mucilage retains a fibrous/spongy network, whereas oven-dried mucilage forms more film- or sheet-like structures. This influences rehydration, gel porosity, water absorption, and stability.[17]

2. Hydrated polysaccharide chains form a 3D hydrogel network capable of trapping water and other solutes (active compounds, drugs), useful for gels, emulsions, or delivery systems.[16]

3. Applicability & Biocompatibility (Cosmetic/Pharma Use) Chia seed mucilage gels have been developed for biomedical applications (e.g., wound-healing scaffolds), showing good water retention, controlled swelling, porosity, and sustained release Mucilage demonstrates cytocompatibility (low toxicity to fibroblast cells), mucoadhesion, and photostability — important for topical, cosmetic, or pharmaceutical gels.[17]

10.4 Influence of Extraction / Processing Conditions on Gel Quality

1. Temperature, seed-to-water ratio, and drying method significantly impact yield, WHC, viscosity, and rheological properties. Optimizing these parameters is critical for reproducible, stable gels.[17]

2. Cold-extraction + freeze-drying yields mucilage that retains network structure (fibrous), showing more stable weak-gel rheology compared to hot-extraction/oven-drying where structural collapse or denaturation may occur.[15]

Fig. 5: Chia Seeds.

11. Applications of Chia Seed–Based Antibacterial Gel:

1. Wound-Healing Hydrogels – Biodegradable gels with antibacterial activity for accelerated wound closure.[18]

2. Topical Drug / Herbal Active Delivery – Controlled release of herbal or therapeutic compounds.

3. Natural Thickener / Stabilizer – Plant-based gel matrix suitable for cosmetics, food, or herbal gels.[11]

4. Encapsulation of Bioactives / Probiotics – Protects and delivers herbal actives or probiotics.

5. Edible / Topical Films & Coatings – Forms edible nutraceutical gels or topical gel patches

6. Cosmetic Formulations – Moisturizers, face gels, hair gels using plant-derived gel base.

7. Antimicrobial Surface Coatings – Can be applied as a coating to prevent bacterial growth on surfaces.[19]

8. Bioactive Delivery in Tissue Engineering – Serves as a scaffold for incorporating antibacterial or regenerative agents.

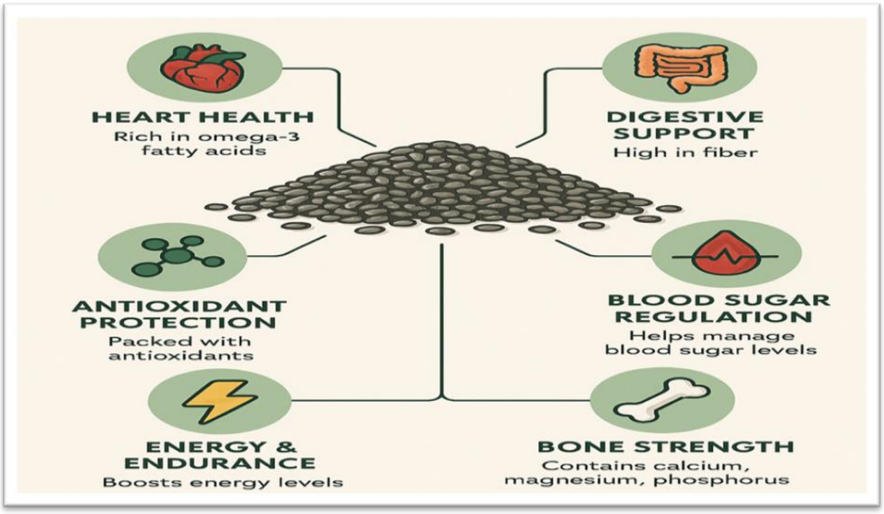

Fig. 6: Applications of Chia Seed.

12. Opportunities in Herbal Gel Development

1. Plant-Based Antibacterial Gels – Combine chia mucilage with herbal extracts (antibacterial, anti-inflammatory, antioxidant).[11]

2. Sustained-Release Herbal Formulations – Use pH- or stimuli-responsive chia gels for controlled herbal delivery.[18]

3. Functional Food / Nutraceutical Gels – Incorporate probiotics or herbal bioactives in chia-based gel systems.

4. Eco-Friendly Cosmetic Gels – Biodegradable, non-toxic gels for skin and hair applications.

5. Herbal Wound Dressings – Develop chia mucilage hydrogels loaded with herbal antibacterials for wound care.

6. Topical Patches / Gel Films – Chia mucilage provides a stable gel or film matrix for delivering herbal actives.

7. Natural Moisturizing Gels – Use chia mucilage for hydration and skin barrier enhancement in herbal formulations.

8. Bioactive-Enhanced Cosmetic or Therapeutic Gels – Integrate antioxidants, anti-inflammatory, or antibacterial plant compounds for multi-functional herbal gels.[19]

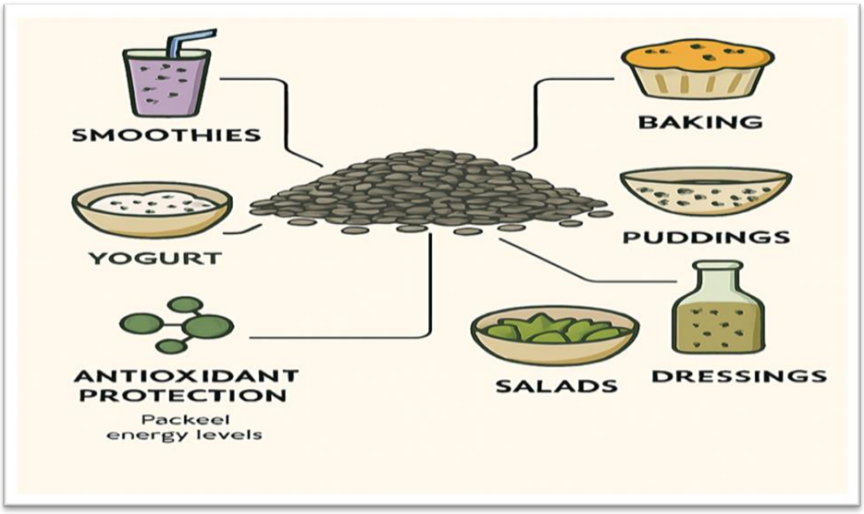

Fig. No: 6 Mechanistic Uses of Chia seeds.

13. Challenges in Plant-Based Antibacterial Gel Formulations

1. Variability of Plant Extracts – Chemical composition and antibacterial potency can vary due to species, climate, harvest, and extraction method.[20]

2. Stability of Bioactive Compounds – Phytochemicals may degrade under light, heat, oxygen, or pH changes, reducing efficacy.

3. Compatibility with Gel Matrix / Excipients – Interactions with gel polymers can alter viscosity, texture, and release profile.[21]

4. Microbial Contamination – High water content gels are prone to bacterial or fungal growth; natural preservatives may be less effective.

5. Poor Bioavailability / Limited Penetration – Many phytochemicals have low skin absorption or uneven release from gel matrices.

6. Sensory & Storage Issues – Odor, colour changes, phase separation, or viscosity loss can reduce user acceptability.[22]

7. Regulatory & Standardization Challenges – Lack of standardized protocols and clinical validation can limit product approval and commercialization.

8. Scale-Up & Manufacturing Difficulties – Lab-scale extraction and gel formation methods may not translate efficiently to industrial production.[21]

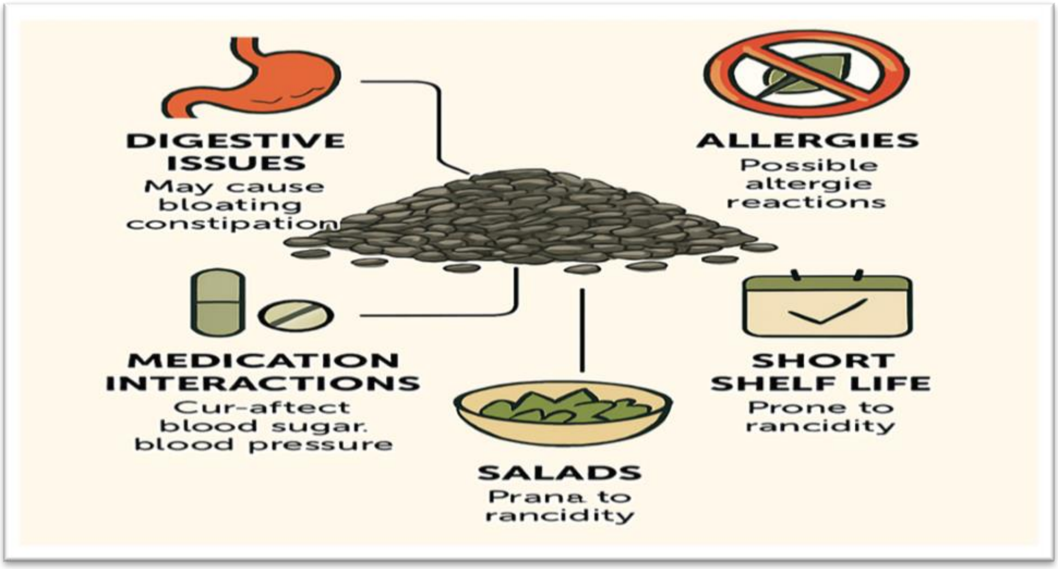

Fig. No: 7 Challenges of Chia Seeds.

14. Future Perspectives of Chia Seeds:

1. **Scale-up and Industrial Production of Chia Mucilage Gels** – Eco-friendly and optimized extraction techniques (e.g., cold extraction, freeze-drying) can produce large quantities of mucilage without losing gel-forming or bioactive properties, enabling commercial production of antibacterial gels.[23]

2. **Development of Smart / Stimuli-Responsive Gel Systems** – Chia mucilage can be chemically modified (e.g., grafting with monomers) to create hydrogels responsive to pH or other environmental triggers, suitable for controlled, targeted release of antibacterial or therapeutic agents.

3. **Composite / Hybrid Gels with Enhanced Antimicrobial & Healing Properties** – Combining chia mucilage gel with antimicrobial agents (e.g., nanoparticles, herbal extracts) can yield hydrogels with enhanced antibacterial, antifungal, and wound-healing effects.

4. **Biomedical Applications** – Biocompatibility, water retention, and gel-forming properties make chia-based gels suitable for wound dressings, hydrogel scaffolds, and antimicrobial hydrogels for tissue repair.[25]

5. **Cosmetic and Skin-Care Products** – Natural origin, biocompatibility, and favorable rheology make chia mucilage gels attractive for clean-label skin gels, moisturizers, or antibacterial cosmetics.[23]

6. **Food / Nutraceutical Applications** – Edible chia mucilage gels can be used as functional food gels, nutraceuticals, or edible coatings with antimicrobial or antioxidant properties.[24]

7. **Use as Natural Delivery Matrix for Probiotics or Bioactive Compounds** – Chia mucilage gels can encapsulate bioactives or probiotics, enabling probiotic gels or sustained-release herbal formulations.

8. **Need for Standardization, Stability Studies & Regulatory Validation** – Long-term stability, reproducibility, safety (cytotoxicity, irritation), and regulatory compliance must be addressed for commercial or therapeutic use.[25]

Fig. No: 8 Mechanistic Representation of Antibacterial Gel from Chia Seeds.

15. CONCLUSION

Chia-seed derived antibacterial gel shows considerable potential as a natural antimicrobial formulation due to the presence of bioactive compounds such as phenolics, peptides, and mucilage, which can inhibit the growth of various bacterial pathogens by disrupting cell membranes and interfering with microbial processes. The gel, prepared from chia seed extracts or mucilage, provides a biocompatible and sustainable option for applications requiring mild antibacterial action, including topical skin care, wound management, and natural preservative systems. Its ability to form a stable, hydrophilic gel matrix supports controlled release of active compounds, enhancing antimicrobial efficacy. However, while laboratory studies indicate promising in vitro activity, real-world effectiveness depends on factors such as concentration, stability, formulation methods, and the type of microorganisms targeted. Variability in active compound content and potential degradation under environmental or physiological conditions may affect consistent performance. Therefore, chia seed antibacterial gel represents a promising, eco-friendly, and multifunctional natural antimicrobial agent, yet further research including in vivo studies and clinical assessments is needed to optimize formulations, ensure stability, and establish standardized protocols for practical applications in healthcare, cosmetics, and food safety.

16. REFERENCES

1. Saleh H. E., Chiad J. S., & Shawkat S. M. (2022). *Extraction, Characterization, and Evaluation the Activity of Chia Seed (Salvia hispanica L.) as an Antibacterial for the Treatment of Gingivitis. Iraqi Journal of Industrial Research, 9*(3): 110–118. Available at: https://ijoir.gov.iq/ijoir/index.php/jou/article/view/216
2. Aguilar-Toalá J. E., Deering A. J., Liceaga A. M. (2020). *New Insights into the Antimicrobial Properties of Hydrolysates and Peptide Fractions Derived from Chia Seed (Salvia hispanica L.). Probiotics and Antimicrobial Proteins, 12*(4): 1571–1581. Available at: https://pubmed.ncbi.nlm.nih.gov/32385579/
3. Chia (Salvia hispanica): Nutraceutical Properties and Therapeutic Applications. *MDPI*. https://www.mdpi.com/814334MDPI+1
4. Chia Seeds (Salvia hispanica L.): An Overview — Phytochemical Profile, Isolation Methods, and Application. *MDPI*. https://www.mdpi.com/1420-3049/25/1/11 MDPI
5. Tavares, L. S., et al. Cold extraction method of chia (Salvia hispanica L.) seed mucilage — extraction, yield and rheological analysis. *Food Hydrocolloids / PMC*. 2017. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5785370/.
6. Sacco, P., et al. Insights into mechanical behavior and biological properties of chia seed mucilage hydrogels. *Gels (MDPI)*. 2021. PubMed: https://pubmed.ncbi.nlm.nih.gov/33923998/
7. Hrnčič MK et al., *Chia Seeds (Salvia hispanica L.) — an overview (composition & bioactive compounds)*. PubMed Central (2019). URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC6994964/
8. Oliveira-Alves SC et al., *Characterization of phenolic compounds in chia (Salvia hispanica L.)* — phenolic profiling (rosmarinic, caffeic and salvianolic derivatives). (ScienceDirect, 2017). URL: https://www.sciencedirect.com/science/article/pii/S0308814617305629
9. Tuncil YE et al., *Total phenolic contents, antioxidant and antibacterial activities of chia seeds (Salvia hispanica L.) having different coat color* (comparative/functional study; antibacterial assays). PDF (2019). URL: https://dergipark.org.tr/tr/download/article-file/765038

10. Capitani MI, Nolasco SM, Tomás MC. "Rheological properties of aqueous dispersions of chia (Salvia hispanica L.) mucilage." *Od Hydrocolloids*, 2013. URL: https://www.sciencedirect.com/science/article/pii/S0268005X12001740
11. Brütsch L, et al. "Chia Seed Mucilage – A Vegan Thickener: Rheology, Viscoelasticity and Functional Properties." *Food & Function*, 2019. URL: https://pubs.rsc.org/en/content/articlehtml/2019/fo/c8fo00173a
12. Muñoz LA, Cobos A, Diaz O, Aguilera JM. "Chia seeds: Microstructure, mucilage extraction and functional components." *Journal of Food Science and Technology*, 2013. (Provides validated mucilage extraction methods and functional gel properties.) URL: https://pubmed.ncbi.nlm.nih.gov/24426016/
13. Ucar, B., Karakaya, S., & Gülseren, I. (2022). "Extraction and characterization of mucilage from chia seeds." *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2022.107512
14. Reyes-Caudillo, E., Tecante, A., & Valdivia-López, M. Á. (2008). "Dietary fibre content and antioxidant activity of phenolic compounds in chia (Salvia hispanica L.) seeds." *Food Chemistry*, 107(2), 656–663. URL: https://doi.org/10.1016/j.foodchem.2007.12.056
15. PMC — "Cold extraction method of chia seed mucilage (Salvia hispanica L.): effect on yield and rheological behavior." URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC5785370/
16. Martínez-Cruz, O., et al. (2021). "Physicochemical and functional properties of soluble fiber extracted from two phenotypes of chia (Salvia hispanica L.) seeds." *Journal of Food Composition and Analysis.* URL: https://www.sciencedirect.com/science/article/abs/pii/S0889157521003380
17. Carbohydrate Polymer Technologies and Applications (2024). "Chia (Salvia hispanica L.) seed mucilage-based antimicrobial hydrogel scaffold for wound healing: In vitro-in vivo characterization."URL:https://www.sciencedirect.com/science/article/pii/S2666893924000124
18. Mahajan P., Nangare S. N., Patil A. Y., et al. "Chia (Salvia hispanica L.) seed mucilage-based antimicrobial hydrogel scaffold for wound healing: In vitro–in vivo

characterization." *Carbohydrate Polymer Technologies and Applications*, 2024. URL: https://doi.org/10.1016/j.carpta.2024.100432.

19. Khatoon M., Ali A., Hussain M. A., et al. "A chia (Salvia hispanica L.) seed mucilage–based glucoxylan-grafted-acrylic acid hydrogel: a smart material for pH-responsive drug delivery systems." *Materials Advances*, 2025. URL: https://doi.org/10.1039/D5MA00046G
20. Shrestha S., et al. "Challenges and opportunities in herbal gel formulations: standardization and efficacy issues." *PMC*, 2010. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC12682302/?utm_source=chatgpt.com
21. Rathi S., et al. "Stability and compatibility issues in plant-based topical gels." *PMC*, 2010.URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11855317/?utm_source=chatgpt.com
22. Chatterjee S., et al. "Microbial contamination and preservative challenges in natural gel formulations." *IJPS*, 2023. URL: https://www.ijpsjournal.com/assetsbackoffice/uploads/article/document-20231223133951.pdf?utm_source=chatgpt.com
23. Insights into Mechanical Behavior and Biological Properties of Chia Seed Mucilage Hydrogels — *Gels* (MDPI, 2021). URL: https://doi.org/10.3390/gels7020047 (pubmed.ncbi.nlm.nih.gov)
24. A chia (Salvia hispanica L.) seed mucilage-based glucoxylan-grafted-acrylic acid hydrogel: a pH-responsive drug delivery system — *Materials Advances*, 2025. URL: https://doi.org/10.1039/D5MA00046G (pubs.rsc.org)
25. Chia seed mucilage-based antimicrobial hydrogel scaffold for wound healing: in vitro–in vivo characterization — *Carbohydrate Polymer Technologies and Applications*, 2024. URL: https://doi.org/10.1016/j.carpta.2024.100432 (sciencedirect.com)