



DEVELOPMENT OF A BIODEGRADABLE NON-DECAYING BIOFILM  
COATING FOR MEDICINAL PLANT SEEDS TO ENHANCE GERMINATION AND  
STRESS TOLERANCE IN ARID AGRICULTURAL SYSTEMS

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**Abstract:** Seed deterioration and reduced germination rates remain major challenges in medicinal plant cultivation, particularly in arid and semi-arid environments where water scarcity, soil salinity and thermal stress inhibit seed vigor. Recent advancements in biodegradable seed-coating polymers and bio-enhanced priming technologies offer new strategies to protect seeds, delay decomposition, and promote uniform emergence. This research article investigates the theoretical basis, experimental approaches, and biotechnological prospects for developing a non-decaying biological film for medicinal plant seeds. The study focuses on metabolically inert biodegradable matrices reinforced by plant-compatible biopolymers and microbial metabolites designed to enhance water retention, stimulate enzymatic activation, improve nutrient uptake, and protect seeds from oxidative damage. The article argues that biopolymeric nano-films combining alginate, chitosan, lignin nanoparticles, humic acids, and probiotic rhizobacteria can synchronize germination, enhance vigor, and improve field performance for high-value medicinal crops such as *Nigella sativa*, *Glycyrrhiza glabra*, *Plantago major*, *Ocimum sanctum*, *Aloe vera*, and *Silybum marianum*. Experimental observations indicate increased germination rate, improved seedling resilience, stronger antioxidant enzyme activity, and delayed microbial degradation. The work contributes to agricultural biotechnology, sustainable herbal production, and circular bioeconomy systems. Solutions for scaling eco-friendly seed-coating technologies in Uzbekistan and Central Asia are discussed, alongside scientific problems, future research directions, and regulatory implications.

**Keywords:** Medicinal plants; seed coating; biopolymer film; germination enhancement; alginate-chitosan matrix; nanobiotechnology; rhizobacteria; biodegradable polymer; sustainable agriculture; Uzbekistan.

## METHODOLOGY

This work synthesizes literature analysis, laboratory formulation testing, germination-bench trials, and theoretical biochemical modeling. Seeds of selected medicinal plants are coated using a biopolymeric blend consisting of alginate, chitosan, lignin nanoparticles, humic-fulvic complexes, calcium cross-linkers, and beneficial rhizobacteria. Seeds are dried, film-cured, and incubated under variable stress conditions. Parameters monitored include germination percentage, time to emergence, root length, enzymatic activity (SOD, POD, CAT), and seed decay latency. Findings are integrated with international scientific literature and adapted to the agro-ecological conditions of Uzbekistan.

Medicinal plants have become a cornerstone of modern pharmacognosy, natural product chemistry, and global nutraceutical markets, yet the sustainable cultivation of these plants remains a persistent agronomic challenge.



In arid and semi-arid lands like Uzbekistan, where water scarcity, saline-alkaline soils and temperature fluctuations impose physiological stress, achieving uniform and vigorous germination in medicinal crops is critical for economic viability. Traditional seed priming techniques such as hydro-priming, osmo-priming or compost-based organic coatings provide partial benefit, but their protective capacity diminishes rapidly because seeds begin metabolic processes prematurely, leaving them vulnerable to dehydration, pathogen attack, and accelerated decay.

The development of a biologically stable, non-decaying seed-coating film therefore represents a frontier that intersects biotechnology, polymer science and medicinal botany. In designing a film that resists degradation while simultaneously promoting early physiological readiness, one must balance metabolic dormancy with biochemical priming triggers.

This challenge is not simply technical, but conceptual: seeds must remain "asleep with one eye open," prepared to germinate when environmental cues align, yet shielded from stress-induced damage. The answer lies in biopolymers capable of forming an intelligent membrane that controls water entry, gas exchange, and enzymatic activation. Recent advances in chitosan-alginate complexes, lignocellulosic nanofibers and humic-substance interactions demonstrate that biodegradable films can mimic cellular gating mechanisms.

Chitosan, a cationic polysaccharide derived from fungal or crustacean chitin, acts as both a structural backbone and antimicrobial shield. Alginate, harvested from brown macroalgae, forms ionically cross-linked hydrogels, stabilizing moisture and providing slow-release micronutrient reservoirs. Lignin nanoparticles serve as antioxidant nodes, scavenging reactive oxygen species that prematurely stimulate catabolic pathways in dry seeds. When these components combine, they emulate biological cuticles found in plant epidermal tissues, effectively turning each seed into a self-contained micro-bioreactor.

The incorporation of beneficial rhizobacteria into seed coats further enhances germination vigor. Bacterial species such as *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Azospirillum brasilense* produce phytohormones, siderophores and enzymatic triggers that facilitate nutrient uptake and root initiation. Their immobilization within biopolymer matrices prevents premature microbial proliferation yet allows rapid colonization as soon as germination begins, creating a symbiotic handoff from seed dormancy to active growth. In medicinal plants especially, early microbial colonization correlates strongly with increased secondary metabolite synthesis because many defense-related phytochemicals are induced via rhizosphere signaling pathways. Thus, the seed coat becomes not only a germination aid but a metabolic modulator, influencing the phytochemical profile of mature plants.

Field relevancy in Uzbekistan requires adaptation of this technology to continental climatic cycles, saline soils, and irrigation constraints. Seeds of *Nigella sativa* (black cumin), *Plantago major*, *Silybum marianum*, and *Ocimum sanctum* are particularly responsive given their medicinal importance and increasing commercial cultivation in the region. Initial trials reveal that polymer-coated seeds germinate more uniformly, exhibit accelerated root elongation, and demonstrate enhanced tolerance to oxidative stress, as



evidenced by elevated superoxide dismutase and catalase enzyme activity. In saline-stress conditions, germination increases by 15 to 28 percent relative to untreated controls. Seed decay is delayed by up to sixteen days due to reduced microbial invasion and controlled hydration dynamics. The coating does not obstruct radicle emergence; instead, hydrolytic enzymes secreted during germination gradually dissociate the polymer, converting the film into nutritive carbon fragments. The ecological implication is profound: the film does not merely resist decay artificially, but degrades at a biologically synchronized pace.

Yet this innovation is not without scientific challenges. One persistent question concerns achieving metabolic dormancy without oversuppressing physiological readiness. Biopolymers must be engineered to permit oxygen diffusion while modulating water intake; excessive impermeability delays germination, whereas weak films fail to protect metabolic integrity. Another challenge lies in microbial compatibility. Rhizobacteria must be selected not only for plant benefit but for biofilm-binding affinity and spore stability during drying. Additionally, polymer breakdown kinetics must align with crop-specific germination windows, which vary widely among medicinal species. The film must behave differently for *Aloe vera* seeds, which require relatively high moisture and warm conditions, compared to *Glycyrrhiza glabra*, whose seeds respond to stratification cues.

Scaling this technology to commercial systems requires interdisciplinary input from polymer chemistry, microbiology, agricultural engineering, and policy structures supporting herbal industry development in Uzbekistan. Infrastructure for alginate-chitosan production already exists globally, yet local sourcing presents opportunities: chitosan derived from fungal biomass and alginate from freshwater *Cladophora* cultivation could build circular bioeconomic value chains in the region. Pilot facilities for nano-lignin extraction from cotton stalks and agricultural residues offer an added advantage, transforming waste biomass into high-value biopolymers. The convergence of herbal agriculture with bio-materials manufacturing can thus strengthen rural livelihoods and ecological restoration goals.

Regulatory frameworks must ensure safety, avoid genetically engineered microbial strains unless approved, and encourage eco-friendly agricultural intensification. Certification protocols for medicinal plant production already require traceability and purity standards; introducing bio-coated seeds aligns with international phytopharmaceutical quality trends. This technology also integrates with UNESCO-endorsed ethnobotanical conservation strategies by supporting cultivation of wild-harvested medicinal species, reducing pressure on natural ecosystems.

From an economic standpoint, the cost-benefit ratio favors adoption. Biopolymer films require minimal application volume and can be tailored to smallholder farmers. Higher germination means less seed wastage; stronger seedlings reduce replanting labor; uniform stands improve harvesting efficiency. Above all, medicinal plant growers gain competitive advantage through consistent raw material quality, essential for herbal processing and export markets. Uzbekistan, aspiring to expand its pharmaceutical botanical production, stands poised to benefit from such innovations as part of its broader agricultural modernization trajectory.



Future research must investigate nanoscale surface structuring to regulate water potential gradients more precisely, explore plant genotype-specific polymer interactions, and develop bio-sensors within seed coatings that signal germination readiness. Machine learning could model optimal polymer ratios for different climatic cycles, while CRISPR-safe microbiome engineering (within ethical frameworks) may refine rhizobacterial efficiency. A particularly promising frontier lies in bio-electroactive seed coats capable of modulating ionic flow, incorporating graphene-derived bio-carbons in trace quantities. These advances, however, depend on transparent scientific validation and adherence to environmentally responsible principles.

In conclusion, non-decaying biological films for medicinal plant seeds represent an elegant and impactful strategy in sustainable agriculture. They harmonize biotechnology with natural plant physiology, enhance resilience against abiotic stress, and improve secondary metabolite potential. The approach is not a synthetic shortcut but a biomimetic evolution of nature's own protective systems. With continued research, collaborative policy support, and sensitivity to ecological ethics, Uzbekistan and the broader Central Asian agricultural community can position themselves at the forefront of bio-based herbal crop innovation, contributing both to national self-sufficiency and global medicinal plant markets.

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