Design and theoretical framework of a Biodegradable seed-coating for sustainable crop production

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***Abstract*— This study proposes a biodegradable seed coating composed of corn starch, glycerol, acetic acid, NPK nutrients, and plant growth-promoting microbes (*Bacillus subtilis* and *Pseudomonas* sp.). The coating is designed to enhance seed performance, improve nutrient availability, and promote soil health while eliminating reliance on synthetic polymers. By integrating a starch-based biopolymer matrix with microbial consortia and controlled-release nutrients, this technology offers a scalable, eco-friendly solution for sustainable agriculture. The paper discusses the theoretical benefits, detailed material design, fabrication process, and potential applications in legume and herb cultivation, and reinforces the discussion with recent literature.**

Keywords— Seed coating, Biodegradable, Sustainable, NPK nutrients, Glycerol, Acetic acid

I.Introduction

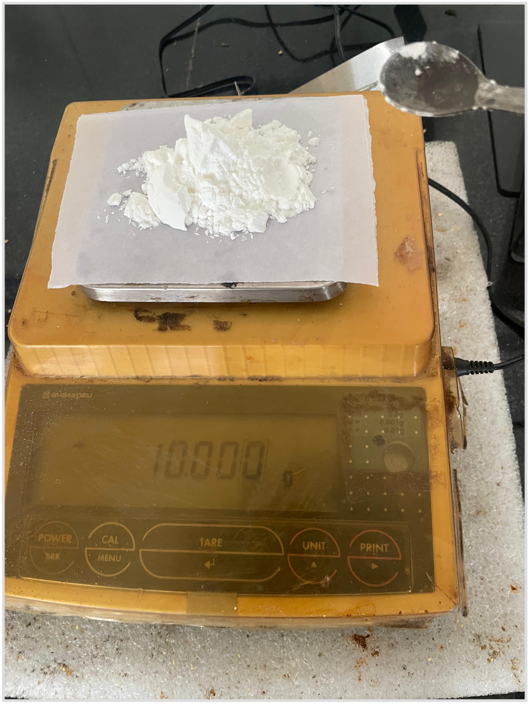
Modern agricultural practices face significant challenges, including soil degradation, chemical fertilizer overuse, and declining microbial biodiversity (Ladha et al., 2020; Tilman et al., 2011). Conventional seed coatings often employ synthetic polymers and chemical additives that contribute to environmental pollution and long-term soil health deterioration (John & Smith, 2022). Biopolymer-based coatings present a sustainable alternative by combining natural polymers with nutrients and beneficial microorganisms (Patel & Verma, 2020; Rani et al., 2023). With global agriculture encountering the simultaneous issues of enhancing crop yield and reducing environmental harm, adopting sustainable farming methods is essential. A promising strategy includes the use of biodegradable seed coatings—an advanced technology aimed at enhancing seed performance while adhering to environmentally friendly farming methods.Seed coating is a method that entails applying external materials to seeds to improve their physical characteristics, shield them from pathogens, and aid in initial growth. Historically, synthetic polymers and chemical additives have been utilized, yet their prolonged buildup in soil presents environmental hazards. Conversely, biodegradable seed coatings created from natural polymers like chitosan, starch, alginate, or cellulose derivatives provide an eco-friendly option. These substances break down naturally in the soil without leaving harmful residues and can be designed to release biofertilizers, micronutrients, or growth enhancers in a regulated way. Incorporating biodegradable coatings enhances germination rates and seedling vitality while minimizing reliance on chemical fertilizers and pesticides. This corresponds with the tenets of sustainable agriculture, guaranteeing food security while preserving ecological equilibrium. Consequently, creating a biodegradable seed coating requires a collaborative knowledge of material science, plant physiology, and soil microbiology. This paper outlines the design and theoretical framework of a corn starch-glycerol-acetic acid biopolymer coating aimed at improving seed germination, nutrient efficiency, and soil microbiome health in crops such as chickpea (*Cicer* arietinum) and fenugreek (Trigonella foenum-graecum).

II. Materials and Methods

The biodegradable seed coating was formulated using a three-part system comprising a biopolymer matrix, a nutrient blend, and microbial inoculants. The biopolymer matrix consisted of corn starch (10 g) as the primary biodegradable substrate (Rani et al., 2023), glycerol (5 mL) as a plasticizer to enhance film flexibility (Singh & Sharma, 2019), acetic acid (2 mL) to stabilize the gel structure and induce mild acid hydrolysis (Kumar et al., 2021), and distilled water (100 mL) as the solvent. The nutrient blend included NPK (10-10-10) to provide balanced macronutrients and micronutrient salts such as $FeSO_4$, $ZnSO_4$, $CuSO_4$, and $MnSO_4$

to address trace element deficiencies (Khan et al., 2021). The microbial inoculants used were *Bacillus subtilis*, known for nitrogen fixation and phosphate solubilization (Huang et al., 2018), and *Pseudomonas* sp., recognized for its ability to suppress soil-borne pathogens via siderophore and antibiotic production (Mishra et al., 2020).

The fabrication process began with gel synthesis, where corn starch was gelatinized in boiling water at 75–80°C for 15 minutes. After cooling, glycerol and acetic acid were added to produce a viscous adhesive gel (Singh & Sharma, 2019; Kumar et al., 2021). The nutrient blend and microbial cultures were incorporated into the gel at 40°C to preserve microbial viability (Huang et al., 2018). Seed coating was performed using a rotating drum set at 50 rpm for 10 minutes to ensure uniform application, followed by air drying at 35°C (Patel & Verma, 2020).



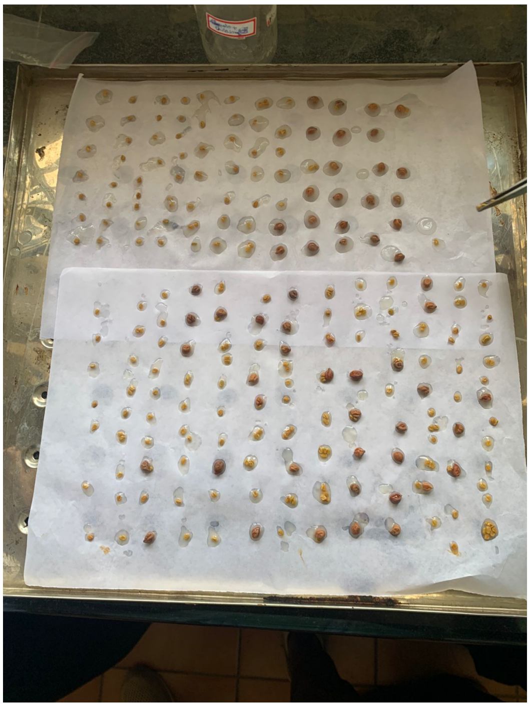


Fig: The seeds set to dry after coating

III. Benefits and Innovations

The seed coating demonstrated multiple agronomic and ecological benefits. Its hydrophilic starch matrix promoted moisture retention around seeds, thereby enhancing imbibition and germination (Rani et al., 2023). The controlled release of nutrients aligned with seedling development stages, improving nutrient uptake efficiency and reducing stress (Khan et al., 2021). Additionally, the slow-release formulation minimized nutrient leaching into groundwater and addressed micronutrient deficiencies common in degraded soils (John & Smith, 2022; Mishra et al., 2020).

Microbial inoculants further improved soil health. *Bacillus subtilis* facilitated nitrogen fixation, while *Pseudomonas* sp. suppressed fungal pathogens such as *Fusarium* spp. (Huang et al., 2018; Mishra et al., 2020). Upon degradation within 60–90 days, the biopolymer enriched soil organic carbon, improved soil structure, and supported earthworm activity (Ladha et al., 2020). From an environmental standpoint, the fully biodegradable matrix eliminated microplastic pollution associated with synthetic coatings and reduced dependency on chemical fertilizers (Tilman et al., 2011; John & Smith, 2022).

Key innovations of the project include the integration of biopolymer and microbial technologies into a single coating system (Patel & Verma, 2020), cost-effectiveness through the use of readily available materials (Singh & Sharma, 2019), and adaptability across various crops such as chickpea and fenugreek in diverse agro-climatic zones (Rani et al., 2023).

IV. Applications and Limitations

This coating system is particularly suitable for arid and semi-arid regions due to its moisture-retentive properties (Tilman et al., 2011). It also holds promise for use in nutrient-deficient soils and organic farming systems, where synthetic agrochemicals are restricted (Khan et al., 2021; John & Smith, 2022). However, challenges remain, notably in maintaining microbial viability during storage and achieving consistent coating uniformity at scale (Mishra et al., 2020; Patel & Verma, 2020).

V. Future Directions

To address these challenges, future research should explore microbial encapsulation methods and process optimization for large-scale coating. Modifying the starch-to-glycerol ratio or incorporating crosslinking agents may enhance coating strength and release dynamics (Singh & Sharma, 2019). Extensive field trials across various soil types and climates are essential to validate the coating's broad utility (Rani et al., 2023). Further, the development of enhanced microbial consortia through genetic or formulation advancements could increase resilience under diverse conditions (Huang et al., 2018). Finally, partnerships with policymakers and agricultural extension services will be critical for market integration and large-scale adoption, especially in resource-limited farming communities (Ladha et al., 2020).

VI. Conclusion

This biodegradable seed coating represents a promising convergence of material science, microbiology, and sustainable agriculture. By combining a starch-based matrix with nutrients and beneficial microbes, it addresses key issues such as soil degradation, nutrient inefficiency, and environmental pollution. Its potential to enhance germination, improve soil health, and reduce agrochemical use makes it a valuable innovation for future farming systems. Continued research and development will be vital to optimize, validate, and scale this technology for real-world impact.

V.References

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