Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 01 (JAN-FEB, 2026)
Available online at http://www.agriarticles.com

Seed Coating and Pelleting Technologies for Precision Agriculture

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The focus of precision farming is on the optimal use of resources, the establishment of uniform crops, and the productivity of variable-field environments. Technological interventions that use seeds are now important in aiding the realization of these goals and seed coating, and seed pelletizing have become significant in this regard. Such methods entail seed treatment with protective, nutritional, or functional materials that enhance ease of sowing, germination, and early seedling development. Seed coating provides thin coatings of active substances, including pesticides, nutrients, bio-stimulants, and beneficial microorganisms, whereas pelleting changes seed size, shape, and weight to enable precise planting. The two methods will lead to better seed management, reduced input waste, precise application of agrochemicals, and uniformity in crops. The recent developments combine polymers, bioactive compounds, microbial inoculants, and nanomaterials to enhance seed treatment with the objective of sustainability. This paper is a critical review of the concepts, materials, processes, advantages, issues and prospective of seed coating and pelletizing processes under precision agriculture.

Keywords: Seed Enhancement, Precision Farming, Seed Coating, Seed Pelleting, Targeted Input Delivery, Sustainable Agriculture

Introduction

Precision agriculture is the site-specific management of crops in order to maximize their productivity and reduce the impact on the environment. Evenly spaced seeds, anticipated development, and co-ordinated plant production are pre-requisites of the precision-based systems. Seeds, as the main biological precursor, provide an easy and viable platform for delivering technologies to boost early crop performance. Pelletizing and seed coating have become significant pre-sowing interventions, contributing to the accuracy of planting, reducing variations in seed rates, and enhancing the efficiency of inputs (Pedrini *et al.*, 2017). The phenomenon of seed coating is the deposition of thin layers of functional substances on the surface of seeds with no serious change in seed size and geometry. Pelleting, on the other hand, entails placing the seed in an inert or semi-inert material such that the seed obtains the same shape and weight, resulting in accurate mechanical sowing (Taylor *et al.*, 1998). The technologies have become increasingly relevant for high-value crops, small-seeded vegetables, cereals, and agroecosystems affected by weather-related stress.

Concept and Classification of Seed Coating Technologies

The technologies used in seed coating can differ in terms of the thickness of the applied material and the purpose of its application. In film coating, polymers serve as binding agents for the active ingredients, and very little change in seed morphology occurs. The process of encrusting is characterized by moderate growth in the size of the seeds even as the structure of the seeds remains visible. The most widespread modification in pelleting produces nearly spherical units, which are used in fine-precision planters (Halmer, 2008). Coatings can be protective, nutritional, physiological, or biological, depending on the purpose they serve. In current seed treatments, a combination of functions in a single coating system is commonly employed to promote early development and stress resistance.

Materials Used in Seed Coating and Pelleting

1. Binding Agents and Fillers

Polymers form the backbone of coating formulations, providing adhesion and structural integrity. Synthetic polymers such as polyvinyl alcohol and polyethylene glycol, as well as biodegradable alternatives such as cellulose derivatives and starch-based compounds, are commonly employed. Pelleting fillers may consist of clay minerals, limestone, talc, or organic powders that ensure uniform pellet formation.

2. Active Ingredients

Seed coatings serve as carriers for agrochemicals, such as fungicides and insecticides, providing localized protection during germination. Nutrient amendments, including micronutrients like zinc, iron, and boron, are incorporated to support early metabolic processes. Additionally, plant growth regulators and osmoprotective compounds are increasingly used to enhance stress resilience (Farooq *et al.*, 2019).

3. Biological and Microbial Components

The inclusion of beneficial microorganisms, such as rhizobia, phosphate-solubilizing bacteria, and mycorrhizal fungi, has expanded the functional scope of seed coatings. These biological additives improve nutrient acquisition, root development, and soil–plant interactions while reducing dependency on chemical fertilizers (Bennett *et al.*, 2013).

Mechanisms Supporting Precision Agriculture

Seed coating and pelleting directly address key objectives of precision agriculture by enabling accurate seed placement, consistent emergence, and targeted input delivery. Pelleted seeds exhibit uniform flow characteristics, improving planter performance and spacing accuracy. Coated seeds release active ingredients in proximity to the germinating embryo, enhancing efficiency and reducing off-target losses (Taylor & Harman, 1990). The controlled microenvironment created by coatings moderates water uptake, reduces imbibitional damage, and protects seeds from soil-borne pathogens. This results in improved stand establishment and synchronized crop development, both of which are critical for site-specific management practices. Moreover, the importance of seed quality as the foundation of crop resilience has been emphasized, with improved seed technologies like coating and pelleting playing a vital role in enhancing crop performance under variable and stress-prone environments (Patel & Pradhan, 2025).

Agronomic Benefits

1. Improved Germination and Seedling Vigour

Coated and pelleted seeds often exhibit improved emergence due to enhanced hydration dynamics and earlier nutrient availability. This is particularly beneficial under suboptimal moisture, salinity, or temperature conditions.

2. Reduced Input Usage

By delivering agrochemicals directly to the seed zone, coating technologies minimize the quantity of pesticides and fertilizers required. This targeted approach lowers production costs and environmental contamination.

3. Enhanced Crop Uniformity

Uniform plant establishment facilitates mechanized operations, optimized irrigation scheduling, and precise nutrient management, ultimately contributing to higher productivity and harvest efficiency.

Role in Sustainable and Climate-Smart Agriculture

Sustainability considerations have driven the development of eco-friendly coating materials and biologically active formulations. Biodegradable polymers and microbial inoculants align seed enhancement practices with environmental safety goals. Moreover, coatings designed to improve tolerance to drought, salinity, and temperature extremes support climate-resilient cropping systems (Paparella *et al.*, 2015).

Limitations and Challenges

Despite their advantages, seed coating and pelleting technologies face constraints related to cost, formulation complexity, and shelf-life of treated seeds. Excessive coating thickness may impede oxygen diffusion or delay germination. Compatibility issues between chemical and biological components also require careful formulation and quality control (Halmer, 2008). Regulatory frameworks governing treated seeds and farmer awareness further influence adoption, particularly in resource-limited regions.

Future Perspectives

Advancements in material science, nanotechnology, and microbiome research are expected to redefine seed coating and pelleting systems. Innovative coatings capable of responding to soil moisture or temperature signals and nano-enabled delivery of nutrients and protectants represent promising directions. Integration of digital agriculture with seed enhancement technologies will further strengthen precision farming outcomes.

Conclusion

Seed coating and pelleting technologies are vital tools in modern precision agriculture, improving planting accuracy, input efficiency, and early crop performance. By delivering functional materials through targeted applications, these techniques enhance seed value while supporting sustainability and climate resilience. Continued innovation and adaptive management will be essential for maximizing their benefits across diverse cropping systems.

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