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Seed Coating and Sustainable Agriculture

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Abstract

Increased productivity in agriculture is possible with technological developments. One of these technologies is the protection of seed quality. Synthetic seeds are artificially encapsulated plant propagation material. It is coated with special substances containing nutrients and protective compounds. The main goal of seed coating technologies is to enable small seeds to grow to larger and uniform sizes. Synthetic seed production offers the opportunity for a cheap and practical tissue culture production technique. Plant nutrients, fungicides, insecticides, herbicides and beneficial organisms can be added to the seed coating material. Seed coating technologies are mostly carried out as pelletizing, film coating or pellet+film coating methods. Owing to the seed coating method, the performance of the seeds for germination will increase and thus the ability of the plants to combat against possible diseases and pests during the germination and seedling periods will increase. One of the difficulties in agricultural practice and research today is how to cope with biotic and abiotic stress conditions, especially climatic changes, in an economically and environmentally sustainable approach. In this prepared study, information is given about seed coating and its applications in field crops.

Key Words: *Alternative control, Biofortification, Priming, Synthetic seed, Sustainable agriculture*

1. Introduction

The effective integration of technological advances into production processes is an important and also remarkable factors that increase productivity of agriculture. Among these innovations, especially the protection and improvement of seed quality has a critical role in terms of sustainable agricultural practices (Bennett et al., 2013). Seed coating technologies have been developed to increase productivity in agricultural production; however, they have made it possible for plants to become more resistant to environmental stress factors (Pedrini et al., 2017). That kind of technologies are not only increasing the germination ratio, but also they support to management of fields owing to promoting the homogeneous seed emergence (Halmer, 2006). Various nutrients, insecticides and also fungicides incorporated to coating based materials protect the plants counter to pests and diseases during the early development periods (Colla et al., 2015).

According to another related research, it was reported that combination of seed coating technologies by biologic based coating materials contributed to improvement of soil health besides increase in activity of soil microbials (Bashan et al., 2014). Particularly, hydrogel-based type coating materials are known as increasing the capacity of moisture retention in seeds under drought conditions, therefore increasing of the plant tolerance against water stress (Gao et al., 2019).

Seed coating technology cause to significant increases in seed germination percentage, and so improves the plant ability to combat wtih pests and diseases on germination period besides seedling period (Taylor et al., 1998). The main focus for seed coating technology is providing of reach to homogeneous and larger size to small seeds, therefore increase in efficiency and also success to sowing ratio (Haciyusufoğlu et al., 2015). Plant based nutrients, insecticides, fungicides, herbicides and also the beneficial microorganisms may also be integrated to seed coating materials as well (Rufino et al., 2013; Corlett et al., 2014).

According to many literature related with seed coating, the positive effects reported for germination ratio, development of root and shoot, growing of seedling, accumulation of dry matter, area of leaf and yield as well have been reported (Tavares et al., 2013; Dumanoğlu and Öztürk, 2022). Moreover, using of coated seeds has great importance in the sedd breeding based researches. Healthy plants that are obtained from the quality seeds can remarkable contribute for more controlled and also efficient results in the breeding programs (Sarıçam et al., 2018). In this study, prepared in the light of the scientific literature in question, scientific findings about seed coating and its applications in sustainable agricultural systems were presented.

2. Seed Coating Technologies

2.1. Definition and Importance of Seed Coating

Seed coating technology developed for the aim of providing more healthy and also efficient growing by additşon of variegated nutrients, protection based components and growing regulators to the exterior layer of seeds (Taylor & Min, 1991). This technique is especially important for small seeds in order to ensure their uniform distribution in the field and to support their early development. Problems arise in machine sowing of seeds with small diameter, non-spherical shape and hairy tops compared to large diameter, smooth shaped seeds. In order to make the shape of such seeds more spherical, to increase their diameter, and to eliminate the hair and thorn-like appearance on them, it is possible to eliminate the negativities by covering the seeds with certain substances. The process of coating the seeds with certain substances in this way can be called seed coating, and the maintenance and improvement of the existing quality of the seed after harvest and the preservation of the value of the seed can be called post-harvest practices, which can be grouped as good seed storage, pre-sowing practices (priming), seed conditioning and coating technologies (pellet and film coating).

2.2. Seed Coating Techniques

Seed coating methods are techniques developed to support the early development of the plant and provide protection against environmental stress conditions. These methods are carried out by applying various substances to the outer surface of the seed and can be broadly categorized into four main groups: pelleting, film coating, pellet+film and bio-coating. Pelleting provides ease of mechanical sowing, especially for small and irregularly shaped seeds, by shaping them into a more uniform form so that sowing depth and uniform emergence can be controlled (Rehman and Farooq, 2016). Film coating, on the other hand, allows nutrients, pesticides or microbial preparations to be applied to the seed with a very thin layer without disturbing the natural shape of the seed and offers the advantage of controlled release (Scott, 1989). Pellet+film coating is one of the most advanced methods, combining these two methods to provide both physical protection and biochemical support (Pill & Finch-Savage, 1988). Bio-coating activates the plant's immune system against biotic and abiotic stresses at an early stage by applying beneficial microorganisms (e.g. Rhizobium, Trichoderma, Bacillus spp.) to the seed surface (Bashan et al., 2014). These methods can be flexibly adjusted according to environmental conditions, crop type and the objectives of the producer, contributing to the sustainability goals of modern agriculture.

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2.2.1. Film coating

Film coating is a modern coating method that provides seed protection and improvement through a thin, adhesive and often clear layer applied to the seed surface (Scott, 1989). Initially developed in the pharmaceutical and food industry, this technology was later successfully applied to seed coating applications in agriculture. During the film coating process, the size and shape of the seeds remain largely unchanged, while active substances such as nutrients, fungicides, insecticides, biostimulants and color pigments can be brought into contact with the seed. One of the most commonly used equipment is the rotary coater, in which film-forming polymers are formulated to dissolve or disperse the active ingredient and applied to the seeds in a controlled manner. One of the main advantages of film coating is the high application recovery (about 90%) and uniform distribution on the seed surface. It also improves the flow ability of the seeds, offering advantages in terms of mechanical performance during both processing and planting. The weight gain achieved by film coating is typically 2% to 5% of the seed weight, which allows for active ingredient transportation without significantly affecting physical performance. Research has shown that maize seeds coated using proprietary film coating polymers (e.g. PolySeedCF) reduce dust formation and minimize environmental impacts by preventing leaching of applied insecticides. With these characteristics, film coating is an advanced seed treatment technology with both ecological and economic benefits.

2.2.2. Pelletization

Pelletization is a method of seed coating that is applied especially to small and irregularly shaped seeds in order to give them a smooth, round and evenly sized form. Thanks to this technique, the seeds become larger and more uniform, so that they can be contacted with the soil with high precision and homogeneity in precision planters (Halmer, 2006). During the pelleting process, the seed usually remains in the center as a kernel and inert materials such as lime, clay, cellulose, chalk, starch and polymers are added as a covering blanket. Nutrients, plant growth regulators and preservatives can also be added. Pelleting significantly improves seed dispersal, sowing depth and emergence rate, which is of great benefit to growers with germination problems, especially for small-seeded species such as carrots, lettuce and alfalfa (Gray & Steckel, 1999). This method also improves germination success by increasing seed access to water and nutrients in harsh environmental conditions such as drought or nutrient deficiency. However, the quality of the coating material and the solubility time should be carefully adjusted. Otherwise, undesirable effects such as delayed germination may occur. Advanced pelleting techniques make it possible to coat seeds with biological and chemical protection agents, creating a multi-purpose application area.

2.2.3. Pellet + Film Coating

It is one of the most developed combinational approaches among seed coating technologies. In this method, the pelletizing process gives the seeds physical integrity and a standardized form, while the film coating applied on top of it enables the precise addition of pesticides, nutrients or biological agents to the outer surface of the seed (Pill & Finch-Savage, 1988). Particularly for small seeds with low germination potential, this method optimizes both emergence rate and seedling development. Thanks to the controlled release of the film coating, the substances needed by the seed can be delivered directly with minimal impact on the environment.

2.2.4. Bio - Coating

It is an innovative technique in which seeds are coated with useful microorganisms to increase both the nutritional capacity of the plant and its resistance to environmental stresses. Among the microorganisms used in this method, species such as *Rhizobium*, *Azospirillum*, *Trichoderma* and *Bacillus subtilis* stand out. These biological agents compete with harmful pathogens in the soil and inhibit their growth, while at the same time producing phytohormones that promote plant growth (Bashan et al., 2014). Bio-coating not only increases yields but also supports sustainable agriculture by maintaining soil microbial diversity and health. The fact that it helps to reduce chemical inputs makes it often preferred in ecological agriculture practices. *Rhizobium* species, on the other hand, establish symbiotic relationships, particularly with legumes, and bind atmospheric nitrogen, making it available to the plant and reduce the need for chemical fertilizers (Zahran, 1999). For example, *Trichoderma* spp. both promote root growth and provide prevention against diseases such as root rot (Harman, 2000).

3. Seed Coating Applications in Field Crops

3.1. Improving Germination and Seedling Development

Seed coating technologies play a direct impact role on germination and young seedling development. The germination process, especially in small and sensitive seeds, can be negatively affected by environmental stress factors or soil conditions. Coated seeds minimize these adverse effects by containing moisture retaining polymers, growth promoting substances (e.g. gibberellin, cytokinin), nutrients and protective agents (Halmer, 2006). Techniques such as pelleting and film coating regulate the physical interaction of the seed with its environment, promoting uniform water uptake and regular oxygen exchange. They promote rapid and simultaneous germination (Pedrini et al., 2017). Micronutrients such as phosphorus and zinc, which are provided locally around the seed, accelerate root development and enable the formation of more robust and durable individuals during the seedling period (Cakmak and Cakmak, 2008). Seeds developed with these technologies show high performance even under conditions that delay germination such as drought and low temperatures. Therefore, post-sowing emergence rate increases and yield and quality become more predictable and sustainable.

3.2. Protection Against Diseases and Pests

Seed coating treatments provide the first line of defense against pathogens and harmful organisms that plants may encounter during early developmental stages. Thanks to the fungicides and insecticides applied to the surface of the coated seeds, protection is provided from the first moment the seed comes into contact with the soil. This is an effective measure against soil-borne diseases (e.g. *Rhizoctonia solani*, *Fusarium* spp., *Pythium* spp.) and pests (e.g. earthworms and insect larvae targeting seedlings). Furthermore, the chemical agents, biological control based mechanisms are also activated by addition of the beneficial microorganisms likewise *Pseudomonas fluorescens*, *Trichoderma* sp. and *Bacillus subtilis* to seed coating based materials (Harman, 2000; Colla et al., 2015). This type of biological based agents provide to protection of both directly competing with pathogens and stimulation of the plant immune systems. Thus, it is possible to reduce pesticide use and increase environmental sustainability. This protective effect allows plants to develop better under stress and can positively affect crop yields.

3.3. Increasing Nutrient Uptake and Plant Nutrition

The enrichment of materials used in seed coating technologies with plant nutrients is of great importance to provide optimal nutrition of plants during early development. The nutrient needs of the seed during germination and seedling development can be met to a limited extent due to the incomplete development of the root system. At this stage, micronutrients and macronutrients (especially phosphorus, zinc, potassium and iron) applied directly to the seed both support plant growth and increase the bioaccessibility of nutrients present in the soil but difficult to be taken up by the plant (Welch & Graham, 2004). For example, it has been observed that both germination rates and early root elongation of wheat seeds coated with zinc significantly increased (Cakmak, 2008). Furthermore, when plant growth-promoting amino acids, humic substances or biostimulants are incorporated into coating materials, root growth, nutrient absorption and overall plant resilience are positively affected (Colla et al., 2015). This practice supports environmental sustainability while reducing the need for fertilizer use, especially in poor or nutrient-limited soil conditions.

3.4. Resistance to Abiotic Stress Conditions

Abiotic based factors likewise drought, salinity and also temperature welded stresses, which are increasing with climate change in agriculture, pose serious threats to plant growth and productivity. The seed coating technology was used as an effective tool to increase plant tolerance to these stress conditions. By adding osmotic regulators (e.g. glycine betaine), antioxidants and biological agents to coated seeds, better germination and development of seeds under stress conditions can be achieved (Ashraf & Foolad, 2007). Additionally, some of the biological coatings facilitate the plant to combat oxidative stress by activating its defense mechanisms (Tuğrul and Kaya 2020). The mentioned practices are highly valuable to ensure the sustainability of production, especially for the marginal soils besides variable environmental conditions. Particularly, the hydrogel-containing coatings reduce water stress by retaining moisture in the micro-environment around the seeds and facilitate the plant access for water (Gao et al., 2023).

4. Conclusions

Various types of the seed coating technology are known as a versatile contribution to the productivity, environmental sustainability and stress management aims of modern agriculture. Applied through various methods such as film coating, pelleting, bio-coating and their combinations, this technology not only increases germination rates, but also promotes healthy development of young seedlings, optimizes nutrient uptake and makes plants more resilient to biotic and abiotic stress factors.

In the field crop practices, the adaptability of seed coating to species and environmental conditions increases the widespread applicability of this technology. Particularly, the bio-coatings containing microorganisms offer a solution that is compatible with sustainable agricultural policies by making it possible to reduce chemical inputs. Therewithal, the nutrients, growth regulators and protective agents incorporated into coating based materials directly provide to support of plant requirements during the development period, create potentials for high yields. In the future, the development of environmentally friendly and biodegradable coating materials, supported by digital solutions integrated with precision agriculture practices, and the dissemination of awareness-raising trainings at farmer level will further increase the effectiveness of this technology. Seed coating technologies are not only a production tool, but also a candidate solution to global challenges such as climate change, soil degradation and reducing the use of agricultural chemicals. In this context, it is of great importance to continue research and adapt the technology to local conditions.

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