Modern Seed Technology

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There are three major types of seed treating/coating equipment: dry powder applicator, rotary pan, and pelleting pan with the provisions to apply dry powders, liquids, or a combination of both. Additional terms for coatings produced from these types of equipment include dry coating, seed dressing, film coating, encrustments, and seed pelleting. The seed weight increases for these different coating methods ranges from <0.05% to >5000% (>100,000-fold range).

Keywords: seed enhancement ; seed treatment ; seed dressing ; seed coating ; film coat ; pellet ; organic agriculture

1. Introduction

High seed quality is always demanded by farmers and may result in up to a 30% increase in crop yields [1][2]. Sowing high-quality seeds is essential, but their use does not guarantee successful stand establishment. The difference in time between sowing and stand establishment is a crucial period. Seeds may be exposed to a wide range of biotic and abiotic stresses resulting in decreased stand performance [3]. However, judicious use of chemical, biochemical, and biological seed treatments can protect and enhance establishment, growth and potential productivity [4]. In this review, seed treatments refer to materials that are active components, while seed dressings are the minimal coating that results after the application of seed treatments onto seeds. Seed treatments are most effective when they are objective oriented and crop specific to ensure optimal stand establishment and enhance yields under changing climatic conditions [5].

Seed treatments may be applied commercially by the seed industry or in some cases “on farm” for crop protection and enhanced seedling growth [2][6]. There is also a growing trend for the development and use of organically approved treatments for sustainable agriculture. Collectively, innovative seed coating technologies are needed as delivery systems for the application of active ingredients at effective dosages to crop seeds [7][8].

A brief history of seed treatments for plant protection illustrates the practical need for better delivery systems and improved ability to sow seeds [9]. Copper sulphate was found to be an effective seed treatment for bunt on cereals in the 1800s when applied as a soak. However, treating large quantities of seed required subsequent drying that made the process cumbersome and time consuming. The soaking process was replaced by the “heap” or “barn floor” method where a small amount of liquid was sprinkled over the seed and then mixed [9]. The soaking (also known as steeping) method is still in use for sugar beet seed using the method described by Halmer (2000) [10].

In 1866, a technique was developed to improve sowing of cotton seed using a paste of wheat flour to form a pellet [11]. During the mid-20th century, many coating technologies for improved agricultural productivity were developed and reviewed by Jeffs (1986) [9]. Seed coating technology continued to advance through the 1970s to 1990s and reviewed by Taylor and Harman (1990), Scott (1989) and Hill (1999) [7][12][13]. More recent reviews focus on seed enhancements and seed coating equipment in the 21st century by Taylor (2003), Pedrini et al. (2017), Halmer (2000), and Pedrini et al., (2020) [6][8][10][14].

Seed enhancements may be defined as post-harvest treatments that improve germination or seedling growth or facilitate the delivery of seeds and other materials required at time of sowing [15]. Seed coating is used for the application of biostimulants, plant nutrients, (including inoculants) and other products that will ameliorate biotic and abiotic stresses encountered after sowing [11][16].

The global market for seed coating materials (colorants, polymers, fillers and other additives) in 2019 was US $1.8 billion and is forecasted to reach $3.0 billion by 2025 [17]. The major group of active ingredients are chemical seed treatments estimated between $3 to $5 billion in 2020, and accounts for at least 2/3 of the total seed treatment market [18]. The biological seed treatment market includes a wide range of biologicals including biofertlizers, biopesticides and biostimulants [19]. The biological seed treatment market is estimated between $1 to $1.5 billion in 2020, and bioinoculants are the dominant group with about 70% of total [18].

The focus of this review is the use of selected seed coating components, including liquids and solid particulates, with designated seed coating equipment and technology for uniform delivery of treatments over seeds uniformly. Applications of selected seed treatment and coatings are presented as biostimulants, nutrients, and in management of abiotic and biotic stress. Seed coating technologies described may be applied to a wide range of crop seeds: grains, oilseed, vegetable, ornamentals, and other seed species [20].

2. Seed Treatment Active Components and other Coating Materials

A wide range of materials is used in seed treatments and coatings. These materials were categorized by their composition and origin as synthetic chemicals (SYN), natural products or derivatives from natural products (NP), biological agents (BIO) and minerals mined from the earth (MIN) (Table 1). Among these categories, particular materials may be used for organic use and labelling, and the US Organic Materials Review Institute (OMRI) [21] approved materials were noted as organic (*OR*). Seed treatment and coatings are further characterized by function, as active components, liquids or solid particulates.

Table 1. Seed treatment and coating materials grouped as active components, liquids and solid particulates. Each group of material is further classified by function and composition. Abbreviations for material source/origin: Synthetic Chemicals—SYN, Natural products or derivatives—NP, Biologicals—BIO, Mineral—MIN, substances may be Organically approved—***OR.***

Active Components	Liquids	Solid Particulates
Biostimulants	**Water Colorants**	**Binders**
• SYN, NP, BIO ***(OR)***	• SYN, NP ***(OR)***	• Also, under Liquids • Soy flour: NP ***(OR)***
Plant nutrients	**Adjuvants**	**Fillers**
• SYN, MIN ***(OR)*** **Abiotic stress:** Drought and Salinity • SYN, BIO ***(OR)*** **Plant Protectants** • SYN, NP, BIO, MIN ***(OR)*** **Inoculants** • BIO ***(OR)***	• SYN ***(OR)*** **Binders** • Polyvinyl alcohol (PVOH) and Polyvinyl acetate (PVAc): SYN • Methyl cellulose: SYN • Carboxymethyl cellulose (CMC): SYN • Plant starches: NP ***(OR)*** • Gum Arabic: NP ***(OR)***	• Diatomaceous earth (DE): MIN ***(OR)*** • Limestone: MIN ***(OR)*** • Gypsum: MIN ***(OR)*** • Bentonite: MIN ***(OR)*** • Vermiculite: MIN ***(OR)*** • Talc: MIN ***(OR)*** • Zeolite: MIN ***(OR)*** • Silica: MIN ***(OR)*** • $BaSO_4$: MIN

2.1. Active Components

The purpose of active ingredients is aimed at protecting and enhancing seed and seedling performance in terms of germination, growth and development. The mode of action of the active ingredient dictates its role for protection and/or enhancement [16]. Active ingredients discussed in this paper include biostimulants, plant nutrients, protectants from abiotic and biotic stress, and inoculants (Table 1). Seed protectants are the most widely used group of ingredients for controlling pathogens and pests at the time of sowing. Fungicides, insecticides, nematicides, and bactericides are grouped as protectants [22]. Selected fungal and/or bacterial microorganisms are used commercially for plant protection, and as inoculants for nitrogen fixation [22][23]. Abiotic stresses due to saline soil conditions or drought stress may occur after sowing and selected biological and synthetic seed treatments may be applied in the seed coating to alleviate these stresses. Elicitors are being investigated as active components for pest management [24][25][26], and drought stress [27]. There is increased interest and demand for biostimulant- and nutrient-based seed treatments [8].

2.2. Liquids

Active components must be applied to seeds so that they adhere onto seeds throughout storage until planted. In addition, seeds treated with pesticides must easily be recognized as treated. Colorants are commonly used to indicate that seeds are treated and constitute about 60% of coating ingredient components, and in the case of seed pelleting are applied at the end of coating process [8]. Colorants also provide a visual of assessment of application uniformity, and cosmetic appearance. Water is the universal carrier of liquids that are atomized onto seeds during the coating process, and atomization is best achieved with low viscosity liquids. The proportion of water in the applied liquid is adjusted to maintain low solution viscosity. Adjuvants are used [20] as most chemical seed treatment active ingredients have limited water solubility, so surfactants are needed to produce aqueous seed treatment formulations. Surfactants may serve as an active component, and a seed coating technology with surfactants was documented to enhance germination and stand establishment when sown in water repellent soils [28].

Seed coating binders act as adhesives to adhere treatments to seeds. The binder provides the coating integrity during and after drying. They prevent cracking and dusting off during handling and sowing [2]. Commonly used binders (Table 1) for maintaining physical integrity of seeds are: polyvinyl alcohol [29], polyvinyl acetate [30], methyl cellulose [31], and carboxymethyl cellulose [32]. For organic seed coatings plant starches (maltodextrins) [33] and gum Arabic [34] are commonly used. Most binders are commonly referred to as polymers [35]. In preparing binders in water, solution viscosity must be low for complete atomization of the liquid onto seeds, based on the fourth author's experience preferably <100 centipoise (cP), or <0.1 pascal-second (Pa-s).

2.3. Solid Particulates

Solid particulates are the bulking materials used in seed coating technologies and form the physical coating after drying [7] [30]. Solid particulates may also be binders. Solid particulate binders are applied as fine powders and become hydrolyzed as water is applied during the coating process. Fillers are also fine powders and can be mixed with the solid particulate binders to produce a seed-coating blend. Successful seed pelleting depends upon the optimization and selection of the most appropriate filler materials that do not interfere with germination [32].

Filler materials are generally inexpensive, non-toxic, easily available, and produce a uniform coating surface texture that should not impede radicle emergence [6]. Several filler materials are used for seed pelleting including diatomaceous earth [36], limestone, gypsum [32], bentonite [34], vermiculite [37], talc [38], zeolite [32], silica sand [39] and barium sulphate [40] (Table 1). These fillers are generally mineral materials that are mined from the earth with minimal modification except for grinding to obtain a fine powder size used in seed coating. Particle size should pass through a 200-mesh sieve (<75 µm) for uniform distribution over the seed surface based on the fourth author's experience.

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