

Editorial

Modern Seed Technology

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Modern Seed Technology (MST) includes a wide range of technologies and practices to upgrade seed quality, enhance seedling and plant growth, and assessing seed quality using imaging technology. Another key topic of MST is Seed Enhancements. First defined as post-harvest methods that improve germination and seedling growth or facilitate the delivery of seeds at the time of sowing [1]. The broader topic of MST includes pre-harvest treatments to hasten seed maturation and post-sowing methods to enhance seed viability and vigor for greenhouse and field production. This special issue of MST has a total of 12 papers with 10 research papers and 2 review articles. Papers were submitted from five countries: Brazil, China, Denmark, Pakistan, and four papers were invited from colleagues in the United States, Multi-State project W-4168. The papers in the special issue of MST were grouped into four categories: Pre- and Post-sowing Seed Enhancements, New Crop Seed Technology, Seed Treatments, and Systemic Uptake, Seed Priming and Seed Imaging. This editorial encompasses perspectives from academia (Taylor and Amirkhani) and industry (Hill) for the future vision of Modern Seed Technology.

The first category has a paper in each sub-heading: Pre- and Post-sowing Seed Enhancements and New Crop Seed Technology.

The first opportunity to manipulate seed quality is while the seeds are still on the mother plant. The use of chemical defoliant can accelerate corn (*Zea mays* L.) seed maturation and drying and thus avoid loss of quality by an early frost. Dean et al. at Iowa State University describe the effect of a selective chemical defoliant on the migration of oil bodies, a sub-cellular event that is a prerequisite for viability and vigor [2]. The major finding was the lack of differences in migration of these oil bodies between treated and nontreated controls. Thus, chemical defoliant did not harm corn seed quality, while still protecting the seed from the damage of an early frost.

The importance of the above article is that most published research concerning Modern Seed Technologies is on post-harvest seed technology because of the emphasis on seed enhancement. Therefore, the opportunity is missed to enhance quality prior to harvesting. The authors feel that future MST research should have a better balance between pre-and post-harvest technology. Moreover, a combination of pre-and post-harvest strategies in the same investigation has the greatest potential to enhance seed performance. Thus, we expand the definition of pre-harvest strategies to include plant-breeding efforts to improve seed quality and vigor as will be cited later.

The second paper by Qin and Leskovar at Texas A&M University focused on improved transplant quality of containerized vegetable crop plants by the addition of humic substances (HS), as a biostimulant, to the plug media [3]. Humic acid has been known for some time to enhance germination and seedling growth. The incorporation of 1% HS (*v/v*) into the growing media was demonstrated to have a biostimulant effect and enhanced several plant parameters, and modulated both root and shoot growth. The HS biostimulant effect was particularly effective in mitigating the negative effects of drought and heat stress on growth.



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The above article focuses on enhancing germination and plant growth under the environmental stress of drought and heat stress because of their negative impact on stand establishment and ultimately yield. A paper from the first two authors of this article also demonstrated the positive effects of a bio-stimulant. They used a seed coating formulation composed of soy flour and vermicompost that served as a biostimulant under optimal growth conditions [4]. These biostimulant- seed treatments and coatings need to be tested under environmental stress to explore their full potential as the above authors demonstrated.

The third paper was from Mi et al., at Cornell and was on hemp (*Cannabis sativa* L.) as a new crop, or at least the reintroduction of a crop first grown in China 6000 years ago. The research was focused on the cultural practices for growing baby leaf hemp including the effect of seed size on germination and fresh and dry seedling weight [5]. Three hemp varieties were studied. The seed size distribution was determined by hand sorting with round hole sieves based on width. The distribution pattern was similar for all three varieties with a normal distribution skewed with a small percentage of small seeds. The small seed sizes had a lower percent germination and slower seedling growth than the larger-sized seeds. Thus, discarding the small percentage of small-sized seeds would upgrade the quality of the lot.

In conclusion, though the importance of seed size has been known for centuries, there is little scientific research published on hemp, and information available online may have questionable validity. Moreover, the hemp seed industry is relatively young compared to the vegetable and field crop industries, so researching the effects of seed size is important to both the seed industry and hemp growers. Continued seed technology research is needed on hemp including the development of treatments to control soil-borne pathogens responsible for damping-off. The goal is to have labeled seed treatments in the conventional and organic production of hemp.

The second category is on Seed Treatments, and Systemic Uptake (of seed treatments).

This category contains half of the papers in this special issue. The first paper by Afzal, Javed, Amirkhani, and Taylor is a joint paper from the University of Agriculture, in Pakistan and Cornell AgriTech and is a review paper on seed coating technologies [6]. For the first time, equipment and processes are described for five major seed coating technologies: dry coating, seed dressing, film coating, encrustments, and seed pelleting. Comparisons are made between each coating type with respect to weight increase after application, relative amounts of loading active ingredients, and time required performing each coating. The trend is to reduce chemical seed treatments and move to active ingredients that are organically approved. The major impetus is that organic seed treatments must be used for certified organic crop production. For organic certification, seed treatment binders and filler coating components must also be approved for organic use. This review paper presented a list of plant protectant groups, seed treatment binders, and fillers, and denotes those materials that may be approved. Seed coatings can be custom designed. Dry seed coating compositions may be required for the application of beneficial fungi that cannot withstand hydration and dehydration without loss of viability. In particular, the Entomopathogenic fungi (EPF), *Metarhizium* and *Beauveria* both require dry-coating technologies in the seed-coating process. Thus, the other four coating techniques: seed dressing, film coating, encrustments, and seed pelleting cannot be used for EPF seed treatment application as water is used in each.

The future of plant protection may well lie in the discussion above. The seed becomes the delivery system for crop protection. The controlled release of microencapsulated pesticides is just one example [7]. Already seed coating enables the additions of fungicides and insecticides to be applied in a far lower dosage on a per acre basis than with in-furrow or foliar applications [8]. Discussion of current progress will allow the seed industry to scale up and implement these new technologies in agriculture.

The second seed-treatment paper in this category is by Averitt et al. and is based on soybean lines with modified seed composition achieved through the use of mutant lines [9].

The larger context is that plant breeding may be used to improve seed quality and stand establishment when standard varieties have inherent low seed-quality potential and are also susceptible to both biotic and abiotic stress. For example, white-seeded snap bean (*Phaseolus vulgaris* L.) varieties are used in the processing vegetable industry but have lower seed quality potential than dark-seeded varieties. Dickson at Cornell summarized research using conventional plant breeding to improve white-seeded bean seed quality over 40 years ago [10]. Plant breeding may also be used to alter the composition of reserve materials in seeds for the purpose of improved taste in vegetable crops, and genetic improvements have greatly enhanced the flavor and shelf-life of fresh market sweetcorn [11].

In many cases where plant breeding alters seed composition for enhanced human and animal consumption, seed quality is compromised. This paper examines the use of soybean genotypes with low phytic acid (LPA) in comparison with normal phytic acid (NPA), and LPA lines have lower germination and low field emergence. The research presented in this paper focused on the use of chemical seed treatment fungicides and seed treatment combinations to compensate for the inherent low seed quality. Collectively, selected seed treatment combinations improved the field emergence of LPA genotypes. Further, seed priming (described later) by itself had a negative impact on stand establishment in LPA genotypes, while first priming followed with a formulation of three seed treatment fungicides improved field emergence.

The next two papers focus on seed coat- permeability and systemic uptake of seed treatments. The experimental approach in both papers used fluorescent tracers to mimic active ingredients to visualize movement within seed and seedlings and thus avoid the use of chemical pesticides. These two papers build on the characterization of the physical/chemical properties responsible for seed-coat permeability of crop seeds. Taylor and Salanenka developed a system to classify seed coat permeability based on the diffusion of ionic and nonionic compounds through the seed coat or seed covering layers [12]. Seed-coat permeability of seeds were grouped as permeable, selective permeability, and nonpermeable. Seeds with permeable seed coats allowed both ionic and nonionic compounds to diffuse through the seed coat, such as soybean and snap beans, while selective seed coat permeability only allowed nonionic compounds to pass including tomato (*Solanum lycopersicum* L.), onion (*Allium cepa* L.), and corn (*Zea mays* L.). Nonpermeable seeds blocked both ionic and nonionic compounds from entering the embryo from the environment and included cucurbits and lettuce (*Lactuca sativa* L.). A simple lab test was proposed to test the seed-coat permeability of any plant species [12].

The first paper on Systemic Uptake by Mayton et al., at Cornell AgriTech, was on tomato seed coat permeability and drilled down on a compound's lipophilicity measured as the log K_{ow} for optimal seed uptake [13]. This research was all possible with the synthesis of a series of 11 fluorescent; n-alkyl piperonyl amides ranging from log K_{ow} 0.02 to 5.66 by Stephen Donovan (co-author). The optimal log K_{ow} for tomato seed uptake was in the range of 2.9 to 3.8. However, less than 5% of the applied compound was measured in the embryo. Therefore, for control of internal seed-borne pathogens, both the log K_{ow} is important for targeting pathogens residing in the embryo and adequate dosage for efficacy.

The next paper by Wang et al., at Cornell AgriTech, investigated the uptake of 32 fluorescent tracers representing 10 chemical families on soybean seed and seedling uptake [14]. Most xanthene and coumarin compounds tested displayed both seed and seedling uptake. Though the log K_{ow} of a compound is well established to govern root uptake, the log K_{ow} alone could not predict seed uptake. Therefore, the physical/chemical properties for uptake of organic compounds by plant roots are not the same as uptake in seeds during the early stages of germination. Seedling uptake of xanthene compounds, Rhodamine B and Rhodamine 800, a NIR fluorescent tracer were further studied and detected in the true leaves of soybean.

The third category is on Seed Priming as seed enhancements.

There were two papers on Seed Priming. Seed priming is a general term that includes several techniques to hydrate seeds under controlled conditions so physiological processes

of germination can occur without the completion of radicle emergence (Phase III, or visible germination) [15]. Common to all seed priming techniques is that radicle emergence is arrested due to restricted water uptake.

In the two papers in this section, seeds were allowed to imbibe in a dilute solution of potassium nitrate [16] or zinc sulfate [17], but germination was arrested prior to drying. In these studies, the concentration of KNO_3 or ZnSO_4 in solution was not sufficient to lower osmotic potential to arrest Phase III germination [16]. Thus the seed priming techniques described in the two papers may be considered as seed steeping [18]. There is not a review paper on seed priming in this special issue, so the reader is referred to previous reviews published from 1977 to 2010 cited in [15].

The first seed priming paper by Ali et al. used a range of potassium nitrate concentrations and 0.75% was optimal for germination, seedling growth, and other physiological attributes [16]. The objective of enhancing tomato seed germination is not new and an early paper reported the use of potassium nitrate and other salt solutions to enhance tomato seed germination almost 60 years earlier [19]. Another objective of seed priming is to improve germination under low temperatures.

The second priming paper by Imran et al., [17] investigated spinach seeds imbibed in dilute ZnSO_4 solutions. The optimal concentration was found to be 6 mM resulting in enhanced germination at 8 °C. Collectively, both 'nutrient priming' techniques provided enhanced germination and seedling performance. Optimal efficacy required a precise concentration.

The last subject area was Seed Imaging using multispectral imaging (MSI) and near-infrared spectroscopy (NIRS).

The first paper in this section from Mortensen et al., at Aarhus University, Denmark was an invited review paper on both MSI and NIRS [20]. These technologies are nondestructive and noninvasive tools and have the potential in seed testing for rapid and reproducible results. Applications of MSI in seed testing include varietal identity and purity, detecting seed damage from mechanical abuse and insects, and seed health in detecting fungal infection. Both MSI and NIRS have the potential to detect seed viability on a single-seed basis, and germinating seeds validated predicted seed viability. Combining imaging with seed sorting technology could effectively upgrade seed-lot quality by detecting and removing nonviable seeds.

The second paper in this section by Rego et al. in Brazil focused on seed health using MSI for detecting seed-borne fungi in cowpea (*Vigna unguiculata* L.). MSI was able to detect seeds inoculated with *Fusarium*, *Rhizoctonia*, and *Aspergillus* [21]. A key finding was that if seeds were first imbibed and then frozen at -20 °C, pathogen detection was enhanced.

The last paper in this category is from Bello and Bradford at UC Davis. The paper was on investigating and detecting a physiological abnormality in *Brassica oleracea* called "blindness" [22]. MSI was used along with two other modern seed testing techniques: chlorophyll fluorescence and oxygen consumption. All data collection was done on a single-seed basis. In general, more immature seeds were detected by chlorophyll fluorescence; and at specific wavelengths from the MSI were associated with greater occurrence of blindness. The bigger story is that nondestructive and noninvasive imaging technologies have the potential to detect poor-quality seed lots and poor-quality seeds within a seed lot. Seed imaging integrated with seed sorting technology could upgrade seed-lot quality.

In summary, the first and third authors of this article experienced an evolution in seed technology research and development over the past 40 years. Papers in this special issue of Modern Seed Technology are an excellent illustration of current research findings in several categories from many seed research groups throughout the world. Drs. Taylor and Amirkhani are proud to contribute several papers to this special issue of Modern Seed Technology. Future research in this area will be driven by the integration of new technologies from other disciplines with seed technology. We look forward to future developments that move from evolutionary to revolutionary in exploiting seeds as the delivery systems in agriculture.

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