Seed Coating: A Tool for Stand Establishment; a Stimulus to Seed Quality

Glen Kaufman[1]

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Summary. Seeds are coated for ease of handling, singulation, precise placement, and the incorporation of beneficial chemicals or microbials. Coated seeds are accepted widely as a standard product for many crops. Quality demands for seed suitable for coating have improved knowledge of physiological seed quality. Higher, better-defined quality standards in the seed and coating industry, combined with additional quality demand for enhanced seed, will continue to improve stand establishment potential for growers.

Coatings first were developed for cereal seeds in the 1930s by Germain's, a British seed company. Large-scale commercial use of coating began in the 1960s, with. precision sowing for the European greenhouse transplant industry. When California outlawed the short-handled hoe in the mid-1970s, the use of coated lettuce seed for precision field seeders increased.

Precision sowing greatly reduced the number of skips and doubles in soil blocks or cell-trays for transplants. Field precision sowing spaced seeds and, thus, individual seedlings sufficiently to permit accurate thinning with a long-handled hoe, while reducing damage to the root systems of the remaining plants.

The combination of U.S. field precision seeding and European greenhouse transplant production created a demand for high-quality coatings to achieve accurate sowing, satisfactory seedling emergence, and stand establishment. University and commercial research programs responded to this demand, producing coatings now used widely for seeds of vegetables, flowers, and some field crops (Kurosawa, 1976; Mayberry and Robinson, 1982; Markey, 1990; Robinson et al., 1983; Valdes and Bradford, 1987; Valdes et al., 1985).

In the United States, the major high-volume vegetable crop using seed coatings is lettuce. Roughly 95,000 ha are sown with coated seed. Brassicas, carrot, celery, endive, escarole, onion, pepper, and tomato also are coated to a significant extent, varying with growing area and season, individual grower preference, the use of direct sowing or transplants, the economics of seed and coating costs, etc.

Begonia is the flower crop most frequently sown in coated form. Impatiens, marigolds, and petunias also are coated commercially, and the market for coating these and other flower species is growing strongly. Alfalfa and tobacco are two agronomic crops that are coated.

Why is seedcoated?

Seed is coated when growers need a precision-sown crop and the noncoated ("raw") seed is too small, light, or variable in size or shape to be sown accurately with existing equipment.

Precision sowing is desirable when growers need singulation, e.g., for cell-tray plant production in a greenhouse' or strict control of spacing or depth of placement (e.g., onion spacing is critical to achieve desired bulb size at harvest). Singulation and controlled spacing also are vital for crops that are direct-sown and then thinned back to the desired plant population. The field-thinning operation is faster, cheaper, and more accurate when coated seeds are used.

One Florida lettuce grower who used raw seed before 1984 informed me in 1985 that reduced thinning costs paid nearly all the additional cost of coating seed. He stated that the stands were superior, and that this improvement was essentially free. Superior stands meant that the incidence of skips or doubles was reduced and the plants were spaced closer to the ideal of 11.5 to 12 inches on center in the row.

The objective of coating is to deliver the seed in a form that is larger, rounder, smoother, heavier, and more uniform than the original seed. The coated seed can then be sown with a belt, plate, cup, vacuum, or other type of seeder. The coated seed, or "pills," can be placed individually, with improved spacing and depth control. The pills also flow better through the seeding mechanism, because their surface is smoother than that of non-coated seeds.

Coating can be a carrier. Fungicides and beneficial microbials that protect the seed and the emerging seedling are carried in the coating (Vavrina and McGovern, 1990). For example, alfalfa seed coating with incorporated rhizobacteria is used to inoculate the field with this beneficial microbial.

How is seed coated?

Seed coating relies on technology developed by the pharmaceutical industry to make medicinal pills. Commercial coating operations put seed in a rotating pan, mist with water or other liquid, and gradually add a fine, inert powder, e.g., diatomaceous earth, to the coating pan. Each misted seed becomes the center of an agglomeration of powder that gradually increases in size. The pills are rounded and smoothed by the tumbling action in the pan, similar to pebbles on a beach. The coating powder is compacted by compression from the weight of material in the pan.

Binders often are incorporated near the end of the coating process to harden the outer layer of the pill. Binders can also reduce the amount of dust produced by the finished product in handling, shipping, and sowing. Care must be taken with binders to avoid delaying or reducing the germination percentage.

Specific details of the materials used as binders are closely held as proprietary information by the coating companies. I am unaware of any public information on the classes of materials used as binders.

Blanks and doubles are eliminated by intensive screening and other techniques. Uniform size and uniform rate of increase in size are evaluated throughout the process with frequent hand-screening. At intervals during coating, and at the end, all of the pills

[1]Marketing Research Manager, Royal Sluis, Inc., Salinac, Calif., at the time of writing At present, Sales Representative, Precision, Agricultural Products, Inc., Immokalee, Fla.,

This article is a record of my experience with commercial seed coating. It is neither a survey of the literature nor a statistical comparison of experimental and commercial coatings. Instead, the intent is to provide a background about coatings, as actually used.

are removed from the pan and mechanically sized on a set of vibrating screens. Smaller pills are returned to the pan and built up to the size of the remainder of the lot. After drying, usually with a forced-air system at controlled, moderate temperatures, the pills are screened a final tune before packaging. Undersized pills may be built up or discarded. Oversized pills are discarded. The recoveryrate (number of pills divided by the original number of seeds) has been 97% ± 2% for commercial seed lots at one commercial coating company for the past 10 years.

Size uniformity after coating is a major criterion of coating quality. The usual tolerance for coated seed size is ± l/64 inch (≈ 0.4 mm). This is the U.S. seed trade standard for sizing, established long before coatings were introduced. For example, coated lettuce seed is sown most frequently with a belt planter through 13/64-inch-diameter round holes in the belt. This hole size requires that the lettuce pills be sized over a 7.5/64-inch screen and through an 8.5/64-inch screen. These tolerances result in levels of singulation well above 95% in the the field, with placement in the row controlled to within <l/2 inch.

Accuracy of seed placement can vary with weight of the pill, as well as the size tolerances. Sowing accuracy also depends on the skill of the equipment operators, the adjustment and wear of the seeder, and the speed of the tractor through the field. The same constraints are true for greenhouse seeding: experience, attention to details, and appropriate equipment are necessary to obtain the full benefit of coated seed.

Types of coatings

Two basic types of pill produced with inert coating powders are dissolving or "melt" coats and "split" coats. The melt coats dissolve when wet and gradually wash away from around the seed. Split coats initially retain their shape when wet and, by capillary action, pass moisture through the pill to be imbibed by the seed. The seed swells and cracks the pill by internal turgor pressure.

The split coats often permit germination with less water and, as they split, allow uniform, rapid oxygen access to the surface of the seed. The melt coats often require more water to wash the coating material away from the seed, and more time for oxygen to reach the seed through the saturated coating material. Melt coats may offer advantages when soils are saturated, but oxygen availability always influences the speed, uniformity, and total percentage of germination.

Powder coatings, both split and melt, multiply raw seed weight and, depending on the coating, the number of seeds per pound may decrease dramatically (Table 1). Generally, the heavier pills are easier to control because they bounce and roll less than lighter pills. However, the sowing equipment must be able to handle the pill weight. This can be critical, especially for vacuum-type seeders.

In addition to the types ofcoating products described above, there is recent and increasing use of "film-coating." A thin polymer film smoothes the seed surface for better flowability. The polymer also influences water uptake and the adherence of chemical fungicide treatments. Film-coating only increases the raw weight of seed by 1% to 5%, far less than powder coatings.

Seed coating aims to influence the external physical properties of seed, affecting the sowing characteristics only. By itself, the ideal coating would be neutral in its influence on the speed, uniformity, and percentage of germination when compared to the original raw seed lot. The ideal coating would perform in the same manner as the raw seed under a wide range of environmental conditions: light, moisture, temperature, salts, pH, soil type, etc. Also, the stress of the coating process should not influence the germination pattern or longevity (shelf-life) of the seed lot adversely, nor induce secondary dormancy-i.e., affect seed quality.

Seed quality

No single test is sufficient to distinguish all the attributes that contribute to the physiological quality of a given seed lot. From a grower's viewpoint, a high-quality lot is defined by results. A high-quality lot is one that gives fast, uniform, high-percentage emergence, resulting in a healthy, near-100% stand under the conditions in the grower's field or greenhouse.

Unfortunately, defining quality by historical results is not enough. A predictive test of field performance is needed to provide growers a reasonable assurance of obtaining an acceptable stand, given good cultural practices and typical (or at least not greatly abnormal) weather, insect, or disease conditions. The stand potential needs to be assessed both before and after coating. The goal for a commercial seed or coating company is to develop a fast, reliable series of tests that will predict accurately the stand establishment potential of a seed lot under a range of possible field conditions, including stress.

The Federal Seed Act and various state seed laws stipulate that seed germination be labeled according to standardized tests established by the Assn. of Official Seed Analysts (Copeland, 1981). For example, lettuce seed must be labeled with the percentage of germinated seeds counted after 7 days at a constant 20C in the light. Celery is tested under the same conditions, but the percentage is counted after 21 days.

This official germination figure is extremely useful, but additional tests are needed to determine if a seed lot is suitable for coating. This single laboratory test does not provide sufficient information to determine if the seed lot will retain its germination pattern (percentage, speed, uniformity, reaction to high or low temperatures, and shelf-life) after coating or how it may perform under actual conditions in growers' fields or greenhouses. Additional tests can include variations on the standard lab test, thermogradient table tests, and greenhouse tests.

Additional tests

Lab tests. Variations on the standard lab germination test increase the stress level, usually using temperature and/or darkness. Lettuce might be tested

Table 1. ***Approximate number of seeds per pound.***

Species	Seeds/lb (raw)	Pills/lb (coated)	Weight increase (%)
Begonia	70,000,000	250,000	28,000
Lettuce	430,000	12,500–40,000	3,400–1,100
Onion	120,000	15,000–30,000	800–400
Tobacco	5,000,000	165,000	3,000

at 15 or 25C or at alternating 20/30C, perhaps in the absence of light.

The lettuce variety Etna was rejected for coating, based on such a test, while 'Domingos 43' was accepted (Table 2). 'Etna' failed to meet the coating company's standard of ≥ 93% germination with ≤ 3% abnormal seedlings at 20C. This standard is empirical, not theoretical, and was chosen based on years of experience with lots that gave satisfactory or unsatisfactory field results. The standard is conservative and, if no other lot is available, the seed still might be coated, provided that the grower knows and explicitly accepts the limitations of the seed and the risk of a weak stand.

In another test, the onion variety Sweet Perfection tested as an excellent raw seed lot (Table 3). Germination patterns for onions differ from lettuce; onion seed lots with total potential germination of 80% to 85% frequently are encountered and accepted by growers. Lettuce seed lot germinations <90% are strongly resisted by commercial growers, who prefer seed with germination ≥ 95%.

Thermogradient table tests. A thermogradient table is a uniform sheet of metal with a cold water bath along one side and a hot water bath along the other. This creates a continuous temperature gradient, typically with a range of 20C; e.g., 12 to 32C or 16 to 36C. Ten individual tests can be run on blotters across the width of the table, at 2° increments. This type of test determines the maximum and minimum temperatures at which an individual lot will germinate, as well as its ideal or preferred temperature range for fastest germination and growth (Figs. 1 and 2).

The different tests are used in combination. For example, the lettuce variety Domingos 43 showed heat dormancy at 20/30C, with reduced germination after 24 h (Table 2). The severity of dormancy then was tested on a thermogradient table. This test indicated potential germination of >87% in 24 h and ≥ 96% in 48 h at temperatures up to 23C. This is acceptable for this variety at the usual soil temperatures when it is autumn-sown in southern California and Arizona.

Table 3. ***Germination percentage of raw and coated 'Sweet Perfection' onion seed, lot 57412, after two time periods in the laboratory at 20C and after four time periods in the greenhouse with no temperature control.***

Time (days)	Percentage: Raw seed	Percentage: Coated seed
Laboratory at 20C		
3	74	83
7	94 + 2[z]	95 + 2
Greenhouse, no temperature control		
6	---[y]	18
8	---	82
10	---	95
14	---	95 + 2

[z]*Numbers appearing after the plus sign are the percentage of abnormal seedlings (necrotic, short-rooted, deformed, etc.) in addition to the percentage of normal seedlings.*
[y]*Raw onion seed was not tested in the greenhouse.*

Greenhouse tests. Greenhouse tests give a stand establishment estimate under real conditions. These tests also can be prolonged to give a subjective estimate of seedling quality. The greenhouse test can, for example, identify seedlings with necrotic tissue on the cotyledons that might not be apparent in other tests. The percentage of seedlings with significant necrosis is deducted from the stand establishment potential of the lot.

Seed quality testing is an integral part of seed coating. Without it, the performance of coated seed would be erratic and unreliable for commercial growers. Precision sowing without dependable, precise emergence wastes the advantages of coated seed. For example, 'Etna' probably would have a field or greenhouse stand well below 90% (Table 2). Depending on circumstances, this might be acceptable, but it would fail to meet, the expectations of many growers.

No single test is adequate to accept a raw seed lot for coating, but several in combination can identify acceptable and unacceptable lots with a high level of accuracy. Prudent coating companies repeat all or part of their battery of tests on the final coated product to ensure that the commercial product meets the expectations of the pre-coating tests.

Testing methods, which differ among companies, have been developed to evaluate the coatability of a raw seed lot and to check the coated lot's quality. This intensified testing for subtle quality distinctions has improved understanding of quality and how to measure it. This helps both seed and coating companies to improve quality with techniques employed in seed growing, harvesting, conditioning, storing, and coating. When it is possible to measure the quality differences it is also possible to develop and choose superior techniques.

The result has been a gradual increase in quality standards throughout the seed industry. Thus, the "Stimulus to Seed Quality" in the title of this paper. For example, 15 years ago, lettuce seed could be sold at 85% germination, and 90% was considered good. Today, 90% is considered a weak minimum and growers seek 95% or better. Commercial growers have higher expectations of physiological performance, mirroring their higher expectations of genetic performance by new varieties of each crop species.

This developing ability to measure and deliver higher seed quality, reinforced by the market's higher expectations, is the major long-term benefit of seed coating. The particular economic benefits of precise placement, reduced thinning costs, ease of handling, etc., motivate growers to change from raw to coated seed and pay the associated research and production costs. Meanwhile, the ongoing pressure to maintain and exceed existing quality standards benefits all participants.

Table 2. ***Germination percentage of two lettuce varieties after two time periods in three environments.***

Variety	Percentage: Raw seed at 20C	Percentage: Raw seed at 20/30C	Percentage: Coated seed at 20C
Etna (lot 1292)			
1 day	89	90	---[z]
7 days	92 + 7[y]	92 + 2	---
Domingos 43 (lot 5980)			
1 day	100	68	99
7 days	99 + 1	99	98 + 1

[z]*Numbers appearing after the plus sign are the percentage of abnormal seedlings (necrotic, short-rooted, deformed, etc.) in addition to the percentage of normal seedlings.*
[y]*'Etna' lot 1292 was not coated, so no data are available.*

Seed enhancement

There is obvious value to improving performance beyond that of the raw seed. Techniques to evaluate seed quality have been refined further to evaluate methods of enhancing performance.

Enhancement techniques can include seed production and conditioning methods, addition of chemical and biological agents, and seed priming. The purpose of these techniques include increased total germination, faster germination, better uniformity and temperature range of germination, to break postharvest dormancy, to reduce light sensitivity, and to prevent disease.

Many of these techniques can be combined with coatings. The 'Royal Green' lettuce, like nearly all green leaf lettuces, can be a slow, irregular germinator in heat and/or the absence of light (Table 4). Low light conditions make such varieties especially prone to heat dormancy at relatively cool temperatures. Priming the seed can reduce the need for light and simultaneously improve the range of temperatures where germination is rapid and uniform. The thermogradient table test, in the dark, is indispensable for quality evaluation of the primed and coated product illustrated (Figs. 1 and 2).

Fungicides are another example of an enhancement applied to seed to protect vulnerable seedlings from various fungal diseases. Dust or slurry dithiocarbamate treatments are used widely and generally are successful. However, dosage is variable from seed to seed, and there is a degree of "dust-off" when the seed is handled.

Fungicide treatments can be combined with film coatings and thereby applied at more even dosage rates, simultaneously eliminating dust-off for a cleaner, safer product. Powder coatings achieve similar results by blending precise amounts of fungicides in the coating powder for nearly identical dosage on each seed. Then a final layer of coating powder without fungicide can be applied at the end of the coating process, eliminating the chemical from the pill surface (Canerday, 1990; Dzlezak, 1988; Jackson et al., 1989).

The preceding paragraphs are meant only to hint at the exciting potential of existing and rapidly devel-

Table 4. ***Germination percentage of 'Royal Green' lettuce seed lot 8070 for two time periods under four environments in the laboratory and greenhouse.***

Time (days)	Percentage: Raw seed at 20C, dark	Raw seed at 20/30C, light	Primed and coated seed at 20/30C, light
		Laboratory	
1	98	90	99
7	98	93 + 1	98 + 2
		Greenhouse[z]	
		Primed and coated seed, no temperature control, light	
4		85	
6		99	

[z]Raw seed is not greenhouse-tested for this product because only the primed, coated seed will be sown commercially. The tests on raw seed evaluate coating suitability; the primed, coated product receives this final test to ensure that the desired quality has been achieved.

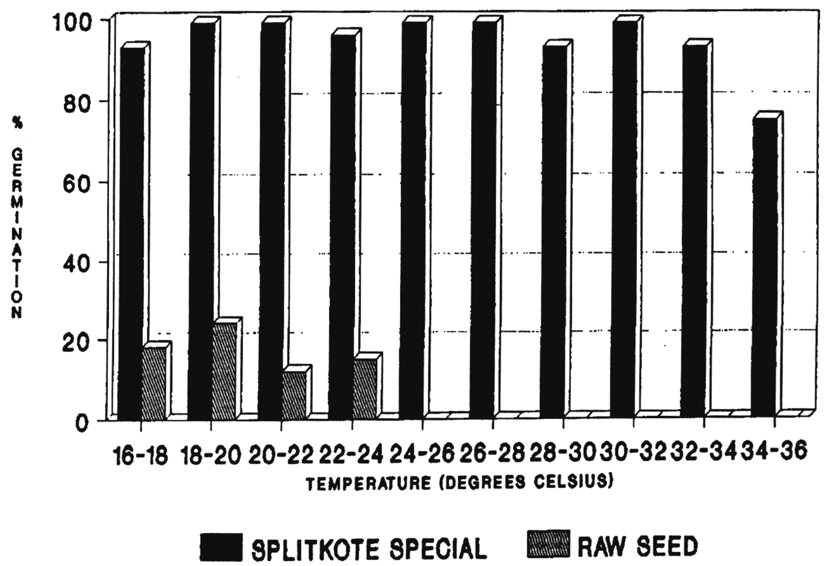

Fig. 1. ***Thermogradient table result of 'Royal Green' lettuce, lot 8070, day 1. Splitkote Special P4420 vs. raw seed.***

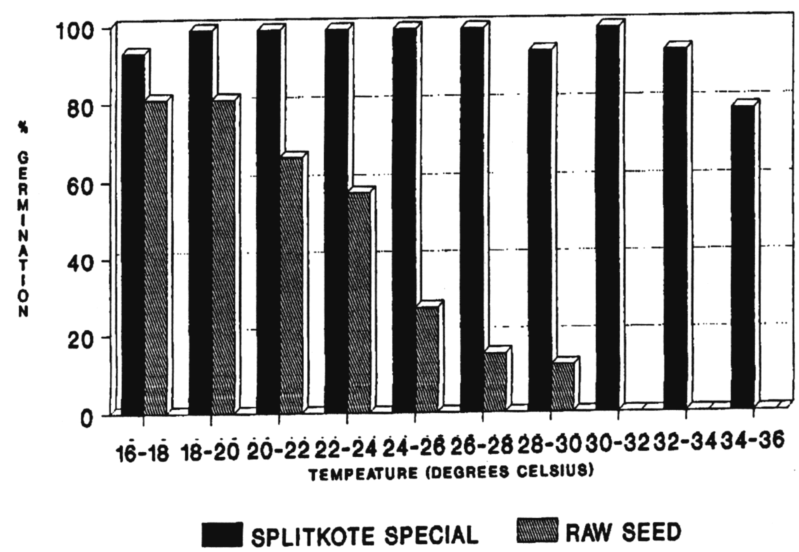

Fig. 2. ***Thermogradient table result of 'Royal Green' lettuce, lot 8070, day 2. Splitkote Special P4420 vs. raw seed.***

oping new products for enhancing seed performance. Secure production of excellent stands, even under stress conditions, is a worthwhile goal for researchers, the commercial seed industry, and growers.

Real achievements have been made and more will follow, both in seed coating and seed enhancement technology. These achievements are reinforced by the use of coatings and enhancements on high-value hybrid or advanced open-pollinated seed. Coatings, enhancements, and new varieties combine advances in physiological and genetic quality, making each more successful and cost-effective for the grower.

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