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Seed Technology and Seed Enhancement

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Abstract

This paper reviews the uses, properties and manufacture of the main array of 'seed enhancement technologies' that are implemented in current commercial practice, with a particular emphasis on cultivated horticultural and ornamental species. Recent developments, as well as some of the newer technical approaches that are still in the research or at an early commercial stage, are covered. Coating technologies - pelleting, encrusting and filmcoating - are now used increasingly widely to facilitate seed planting, by altering seed shape, weight and surface texture, improving seed-soil contact, or manipulating imbibition. They are also used to deliver materials such as micronutrients and crop protection agents, including the high-dose systemic insecticides. New pellet manufacturing techniques, using rotary coaters, have provided an alternative to traditional 'pan coating'. Hydration treatments manipulate vigour or physiological status, such as by priming, steeping, and pregermination. These treatments are used to make germination and seedling growth more rapid and synchronous in the seedbed in the open field or in protected conditions, and better tolerate environmental stresses. Both priming and coating technologies can also deliver beneficial microorganisms from seeds to crops. Organic farming market standards are stimulating the evaluation and optimization of methods to produce healthy planting material and new seed sanitation treatments as alternatives to fungicides or conventional hot water or bleach treatment while retaining seed viability in storage. Sorting on the basis of colour, X-ray analysis of internal structures or buoyant density in solvents offer the ability to remove weak or dead seeds, and hence 'upgrade' seedlot quality.

INTRODUCTION

'Treatment' is a broad generic term to describe the range of materials, formulations, techniques, equipment and processes that may be intentionally applied to seed after the application of conventional seed conditioning technologies to improve seed physiological performance, 'planting value' and physical handling characteristics, and provide protection or improved growth to seeds, emerging seedlings and established plants after sowing.

Seed enhancements comprise the so-called 'functional seed treatments' that may be performed after seed harvesting and conditioning (cleaning and size grading) to improve physical, physiological or pathological properties that affect performance during storage, planting and afterwards. The term also describes the physical and biological processes and mechanisms that occur during treatment and in response to it. This review also covers the application of crop protection products (fungicides and insecticides), though strictly these are not usually described as 'enhancements'. The inter-relationships of seed enhancements with other processing and quality testing technologies are shown in Fig. 1.

Broadly speaking, seed enhancements are aimed at: (1) improving germination or seedling growth, such as improving the vigour or otherwise manipulating the physiological status of seeds, commonly by hydration treatments such as priming, steeping, hardening and pregermination ('physiological enhancement'); (2) improving seed appearance and handling characteristics, such as pelleting and encrusting to facilitate planting; (3) delivering materials required at the time of planting, such as micronutrients, plant growth regulators, protection products, growth stimulants and inoculants, using pelleting, encrusting or filmcoating; and (4) removing weak or dead seeds by non-traditional conditioning 'upgrading' techniques.

Recent in-depth reviews of the principles of seed technology include books and reviews on seed production (George, 1999; McDonald and Copeland, 1997; Basra, 2006), vegetable and flower seeds (McDonald and Kwong, 2004), seed quality (Basra, 1995), seed enhancement (Taylor and Harman, 1990; Taylor et al., 1998a; Halmer, 2000, 2004), seed pathology and seed-applied crop protection treatment (Maude, 1996; Hutchins and Reeves, 1997; Brandl, 2001), and a general encyclopedia (Black et al., 2006). In commercial practice, seed (breeding) companies, merchants or specialist seed technology companies usually perform the treatments, frequently on a just-in-time basis. Quite often their methodologies are proprietary: some processes or uses are patented, whereas others are not; but in either case detailed operational procedures and equipment are sometimes kept confidential.

RATIONALES FOR SEED ENHANCEMENT

Many horticultural production systems – notably of field root, bulb and salad crops, and many ornamentals – are based on a high degree of crop uniformity. Because crop reliability, and harvest yield and/or saleable quality often respond to population density and evenness of spacing, these plants should as far as possible be placed in defined patterns, as well as at the desired sowing depth. These requirements apply whether the crop is to be grown by sowing directly in the field, or partly or wholly in protected conditions, including the raising of transplants, in single cells, blocks or plugs of soil or other growing media that are now widespread in many vegetable and flower seed crops. Other horticultural crops require reasonably accurate, though not necessarily equidistant, placement in the field; examples include some bulb onion markets, and high-density sowings of 'baby-leaf' salad crops for the bag-mix market (including lettuce, endive, radicchio and spinach) in alternating rows, or even intermixed.

It is generally understood that speedy and uniform germination are desirable properties to ensure reliable and timely crop establishment. Seed enhancements are used to help ensure this outcome. It is further substantiated that the original degree of variation in plant size in the population increases as the crop matures: larger plants continuing to secure proportionally more of the available resources up to canopy fill (Benjamin, 1990). The commercial uptake of seed enhancements has been further augmented with the increasing advent of seedling transplant systems, in which markets place a high premium on all seeds germinating to avoid inefficient use of greenhouse resources, and also on seeds germinating rapidly and uniformly, for faster turnaround time, more predictable timing of shipments, more desirable 'tray appearance' and more efficient and reliable seedling handling in the transplanting operation (McDonald, 2000).

Treatment with seed-applied fungicide and insecticide formulations, or other crop protection materials or processes, to protect the seed and seedling by controlling or repelling the action of pests and fungal, viral, and bacterial pathogens (that are not otherwise controlled by resistant varieties or by biological, cultural, physical or sanitary means) constitutes a very large economic market sector worldwide. Using the seed as a carrier is a well targeted way to deliver protective agents to crops, is convenient to the farmer, and has the environmental advantages of using greatly reduced chemical usage rates on the whole field compared to foliar spray or soil-applied alternatives. Protection is increasingly being extended further into the life of the established plant by the development of systemic agrochemicals. As these treatments come to market they are first registered for use on large-volume broadacre crops, but some are now beginning to become registered for use on horticultural crops.

COATING TECHNOLOGY

Coatings have become valuable enhancements to improve the accuracy of mechanical singulation through planting equipment in developed horticultural systems.

Even after conditioning, the natural shape of many seed species is not ideal for mechanical precision planters. The precision metering systems in common use comprise plate-type, belt and vacuum disc-type meters; over the past 20 years the last type has become the standard for use in horticultural field production. The vacuum seeding principle is also frequently used to sow tray formats, e.g., using nozzle arrays or flat template plates drilled with holes to suit the layout, or perforated-drum seeders. Nursery beds are sown using field drills or drum seeders.

Coatings are also used to apply treatment materials. Materials can be incorporated throughout the encrusting or pelleting material or at a discrete stage during the build-up of the coating layers. Alternatively, filmcoating techniques are now widely used to apply crop protection products (such as fungicide and insecticide treatments) onto either 'raw' or pre-pelleted seeds.

Pelleting and Encrusting

The primary historical and continuing purpose of pelleting and encrusting is to build up seed to change its shape, weight or size, or its surface structure, by applying variable amounts of filler materials and binders: to make seeds fit planting equipment better. Pelleting is usually carried out to make irregularly shaped seed ovoid and smooth, or to make small seeds much larger. Depending on geometry and materials used, seed weight may be increased by between about 1-fold up to about 50-fold. In comparison, encrusting (also termed 'minipelleting' or, sometimes, 'coating') applies less material, so that the original seed shape is still more or less visible. Apart from improving planter performance, coating is also used to upgrade size ranges and to increase weight to prevent drift, e.g., for aerial-seeding of amenity grasses. Pelleted and coated seed is commonly coloured to make it easier to check seed depth and spacing after planting, as well as to identify seed company products, or distinguish varieties or treatments.

Horticultural species pelleted in substantial commercial amounts include carrot, celery, chicory and endive, leek, lettuce, onion, pepper, tomato, and to a lesser extent, some Brassica species and 'super-sweet' corn varieties, and certain flower species, particularly those with tiny seeds. Baby-leaf salad-leaf crop seed is often minipelleted.

In pelleting, powdered material blends are progressively added, along with water, until the desired weight or size increase is reached; the product is then dried with heated air, usually in a separate equipment. The process is usually conducted on a batch basis or batch-continuous basis – typically from about 250 g to 100 kg seed per batch. In the traditional 'dragée' method, the seed is continuously tumbled in a coating pan or drum, to distribute and mould the blend. This ensures correct shape and acceptably narrow size distribution of the finished pellet, prevents the formation of 'empty' seedless pellets or seeds sticking together. Special techniques can produce multi-seeded pellets, if required. Seed can be encrusted in the same way or in simpler machines, where components are stirred together in a trough or a vortex mixer in a single-stage addition. A more recent innovation is the use of rotary coaters for pelleting, in which materials are added directly into the spinning toroidal (doughnut-shaped) seed mass, resulting in a much more rapid build-up of the coated seed. Though automated for some species, pelleting other species is a skilled manual process.

There are few detailed research investigations of this subject in the scientific literature, although patents give useful descriptions and insights into the technologies involved. Halmer (2000) has reviewed equipment and techniques and the general types of filler materials and binders in pelleting and encrusting, and the processes for applying pesticide formulations onto seeds using these (and other) techniques.

Filmcoating

Thin-filmcoating (commonly called 'filmcoating' or sometimes 'coating') is employed mainly to apply colorants and crop protection products such as fungicide and insecticide treatments onto seeds. These materials are applied in a firmer and more uniform way than can be achieved using conventional slurry application techniques. As well as improving treatment accuracy, filmcoating is used to minimize chemical dust-off losses during seed handling and drilling, and exposure of the operators who handle treated seed. It also presents seed for sale in a cosmetically attractive form. Characteristically, each seed is covered with a water-permeable polymer layer, which only adds about 1-10% to the weight so that shape and size is little changed.

Filmcoating is now well established for many high-value horticultural seed species (as well as being recently adopted for treating some higher-volume crops, such as maize, soybean, sunflower, canola/oilseed rape and some turf grasses). Filmcoating is also widely used to apply insecticides and fungicides to the outside of pelleted seed. In some cases the preferred method of application to minimize germination-slowing effects, especially where active ingredients must be applied at very high loading-rates.

Where the amount of materials to be applied is relatively large, or where a higher analytical standard of seed-to-seed distribution or cosmetic finish is required – which are often the case with horticultural seed – large amounts of liquid are usually needed, which involves concurrent spraying and drying. Batches of seed are presented to a spray system many times in enclosed chambers to build up an even film layer. A multi-layer coat may be applied to separate one component from another, to protect the seeds or those who handle seed, or to control the release of an active ingredient after planting. In spouted or fluidized bed systems, seed is held in vertical, cylindrical or inverted-conical vessels; solutions are sprayed from below or above into a vigorous upward-moving stream of air, which stirs and dries the mass more or less immediately after the liquid is applied. In 'side-vented pan coaters', seed is held within a horizontally-inclined, perforated rotating drum, equipped with baffles or riser-blades; solutions are sprayed on to the surface of the seed mass, which is stirred and mixed, as drying air is drawn across the drum and through the seed.

Types of binders used include derivatized soluble starches and celluloses (e.g., with hydroxypropyl or methyl-substitution), polyvinyl acetate, polyvinyl alcohol or polyvinylpyrrolidone. Filler materials, such as talc or mica, may be included in the sprayed formulation or added separately as powders during the process, to aid seed flow or produce cosmetic effects. Proprietary ready-to-use versions of these formulations are widely available. In some cases, filmcoating materials are incorporated into the formulated seed treatment pesticide, particularly where the application rate is relatively low. Additional description is in Halmer (2000).

Coatings to Modify Germination Properties

Commercial pelleting, encrusting and filmcoating types are usually designed to present minimal mechanical or physiological barriers to germination, while being strong enough to plant the seed and to keep other treatments stuck onto it. But the coating materials used can also be tailored to manipulate seed imbibition or otherwise modify seed water availability and gaseous exchange, and so control the timing of germination and emergence. Water-attracting materials can aid imbibition and give more intimate seed-soil contact, or may retain moisture in the vicinity of the seed as soils dry: such coatings are used for turf grasses in some markets. By contrast, hydrophobic materials may be included to allow germination under wet conditions in species where that can be erratic, such as onion, or materials to give the coating matrix a more porous structure. Some pellet types disintegrate rapidly or split after imbibition: behaviour suited, for example, to raising tobacco transplants in 'floating tray' systems, and for lettuce.

Filmcoating polymers can be used as barrier layers to alleviate imbibitional-chilling injury that can lead to poor seedling establishment, such as certain cultivars of large-seeded legumes and 'super-sweet' corn, especially where the seedcoat layers are abnormally thin or damaged. An extension of this concept is to delay imbibition with water-resistant polymers until climatic conditions become suitable for continued crop growth. Polymers with in vitro temperature-dependent water-permeability properties are being marketed to coat seeds for early planting so that they can only imbibe when favourable moisture and temperature conditions have developed (Stewart, 1992). This technology is currently being targeted at field planting situations, such as to coordinate

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the flowering ('nicking') of the parental lines planted at the same time for hybrid maize seed production. But at present, this technology does not appear to have been adopted in horticultural situations.

HYDRATION TREATMENTS

Germination enhancement techniques, notably priming, are used to modify physiological performance during germination or early seedling growth. Originally, the term 'priming' had the specific connotation of 'increased synchrony' of germination, as well as its speed: the concept of bringing as many individual seeds as possible to the brink of radicle emergence. By contrast, faster germination, without improved synchrony, is termed 'advancement'. However, in both academia and industry now, 'priming' is used as an umbrella term to describe seed pre-sowing hydration methodologies in general, irrespective of the germination kinetics that result: i.e., the treatment operation rather than the specific outcome.

A variant technique, pregermination - is based on allowing seeds to just germinate (chit) in order to produce 'high viability' seedlots with a very high germination percenttage and speed and uniformity of seedling emergence. Preferentially, only those individuals that are at a specific stage of radicle emergence are selected for sowing. Pregermination is currently commercially available for high-value flower seeds, fully imbibed seeds are germinated to the point where radicles are just visible, sorted by machine vision, flotation, or other means to remove ungerminated seeds, and gradually dried to induce desiccation tolerance. This can produce either damp pre-germinated seed (30-55% moisture content) with a storage life of a few weeks at ambient temperature, or dry seed that is viable for a few months (Bruggink and van der Toorn, 1995).

Physiological Responses

Priming treatments have been developed for a range of horticultural crops (Welbaum et al., 1998). Usually, the aim is to enhance germination percentage or speed, which translates into faster, more uniform field emergence and final level of establishment. Typically, times to reach 50% of maximum germination percentage (t_{50}) can be decreased by up to a third, and sometimes more, depending on the degree of priming applied and the germination conditions. This is particularly valuable under environmental stress, such as cold, wet, or a combination of the two, or unstable soil structure prone to crusting soon after sowing. Priming also aids the reliability and uniformity of seedling establishment in protected conditions, such as the production of more saleable transplants.

Priming is thus of great importance in industry as a tool to 'invigorate' seed lots to help crop establishment, and thus improve their commercial value. It is most extensively commercialized in the field seeding or plug production of leek, tomato, pepper, onion and carrot, and the production of several potted or bedding ornamental herbaceous plants, like cyclamen, begonia, pansy (*Viola* spp.), Polyanthus and primrose (*Primula* spp.), and several culinary herbs. It is also used to enhance the germination of certain slow germinating species that will be blended in amenity grass mixtures. Primed seed is often marketed as such, but not always. This technique is also beginning to be more widely used in broadacre field crops as seed value increases, such as sugar beet.

Priming also tends to widen the range of temperatures over which seeds germinate, particularly to raise the optimal and maximum temperatures. Indeed, in some species and varieties the special agronomic objective of priming is to allow germination at supraoptimal temperatures, and thereby help avoid thermodormancy (i.e., the secondary dormancy that is induced by elevated temperature stress on imbibed seeds), requiring a dormancy-breaking treatment before all the seed population can complete germination, and thus results in a highly non-uniform emergence pattern. High temperature stress is often encountered for cool-season crops grown in hotter climates, such as lettuce varieties sown in the desert regions of southern California and Arizona. In flower crops, priming improves the performance of pansy (*Viola*) and *Vinca* seeds planted in hot conditions, and in wet stress conditions (*Verbena*).

Priming Methods

Priming techniques manipulate seed water-relations, temperature and duration so as to allow some of the metabolic and cellular changes associated with germination to occur. Seeds are imbibed or partially imbibed to a water content and/or for a period of time less than that required for them to complete germination (radicle/embryo emergence from the seed), and then usually dried. Industrial seed priming is carried out in such a way that after becoming fully imbibed most individual seeds in the seedlot remain tolerant to re-imposed desiccation, without suffering immediate damage. The primed seedlot is then further treated, as required, e.g. with coating or pesticides, before or after drying.

Water is either made freely available to the seed (i.e., at water potentials close to 0 MPa) – as in steeping or soaking, which some now call 'hydropriming' – or is restricted to a predetermined moisture content, or sequence of moisture contents, usually employing external water potentials equivalent to between -0.5 MPa and -2.0 MPa. Some seeds, e.g., umbelliferous species, benefit from prewashing (steeping) and drying to remove soluble endogenous germination inhibitors; and positively photoblastic species (such as lettuce) benefit from treatment in the presence of light of appropriate wavelengths. Materials such as nutrients and growth regulators may be included with the priming water. In general, the period of treatment typically ranges from less than 1 day to about 2 weeks, using temperatures in the range 15-25°C. The technique and rate of drying after priming is important to subsequent seed performance. Slow drying at moderate temperatures is generally preferable. Controlled moisture-loss after priming can be effective in extending seed storage longevity and heat shock or mild water stress are other manipulations reported to achieve this effect.

Because of the variability in response from one batch of seeds to another, in practice the optimum priming conditions used in commercial production often need to be determined on a case-by-case basis for individual cultivars or seedlots. This can be done, for example, by conducting pilot priming runs on small samples, and testing germination responses.

Essentially three basic systems are employed to deliver and restrict the amount of water and to supply air to seed during priming.

1) 'Osmopriming' – exposure to, or submersion in, solutions of osmotica (mannitol or inorganic salts, or polyethylene glycol, PEG, the last perhaps being the preferred osmoticum in research and the seed industry;
2) 'Matrix priming' – mixing with moist solid particulate materials, such as exfoliated vermiculite, diatomaceous earth or lignaceous shale (Taylor et al., 1988b);
3) 'Hydropriming' – controlled imbibition, i.e., the continuous or staged addition of a limited amount of water, such as in 'drum priming' (Rowse, 1996), though hydropriming is also used to mean imbibition in effectively unlimited water for a short period of time).

All these three systems are batch processes, ranging on the commercial production-scale from tens of grams to several tonnes. Systems are engineered to ensure adequate aeration, and to prevent the formation of temperature or moisture gradients within the seed mass. Halmer (2004) gives further details.

An array of technical variations on these basic approaches has been developed in recent years. These include 'biopriming', in which beneficial microorganisms are included in the priming processes, either as a mechanism to deliver them to the crop or to control pathogen proliferation during priming itself. The solid matrix priming technique, for example, was initially advocated as an effective method of pre-inoculating seed with *Trichoderma* species. Priming may be combined with plant growth regulators (gibberellins, ethylene and/or cytokinins like benzyl adenine). Also, treatment with growth retardants has been advocated to dwarf the growth habit of transplants, such as bedding plants, which tend to develop an etiolated growth habit, especially if grown in low light environments. For instance, priming tomato or marigold seeds with a triazole (50 ppm paclobutrazol) produces seedlings that are shorter, greener, more uniform, with stronger thicker stems and higher root:shoot weight ratios than non-primed controls (Souza-Machado et al., 1996).

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Optimisation of Priming

One practical drawback of priming is that many, though not all, species can suffer from faster deterioration during seed storage under normal (air-dry) conditions, compared to untreated seeds. Symptoms include the onset of a reduced rate, uniformity and final percentage of germination, and an increased proportion of injured or abnormal seedlings, and an increased susceptibility to accelerated ageing – although the degree of disadvantage in vulnerable species varies between seedlots and storage conditions. These undesirable responses are exacerbated as priming is allowed to proceed progressively 'too far', and in the extreme may result in the death of some individual seeds: an unacceptable outcome generally, and especially so in the raising of high-value seedling transplants.

Because of seedlot variability, optimum priming conditions often must be determined for each seedlot to identify the best compromise between the most rapid germination and the longest storage life. As a result, the seed industry continues to seek simple methods to predict the optimal conditions for priming through initial screening tests. Such tests should correlate well with degree of priming, and/or the loss of desiccation tolerance. The results could be used to assess the potential effectiveness of priming a particular seedlot, to set the priming parameters, or afterwards to measure how well enhanced a seedlot is, or predict its storage life. Such tests must give precise and reliable information across varieties/seedlots, and be fast and convenient to perform.

Priming continues to be of considerable interest as a subject of basic seed physiological research, both in its own right and as a tool for understanding germination processes and the loss of desiccation tolerance. The subject has developed a very extensive literature, dealing with both methodologies and biochemical, physiological and agronomic responses (e.g., McDonald, 2000).

One approach investigated to the optimization problem has to apply the mathematical models that are based on the hydrothermal time equations; theoretically, once the seedlot variables are determined, it should be possible to optimally prime that seedlot. Another approach has been to measure the proportion of cell nuclei that have entered the G2 phase - the 4C:2C ratio. However, results with both of these approaches have been equivocal: for an extensive review, see Halmer (2004). Functional genomics, which measure complete expression patterns using transcriptomics and/or proteomics may be used, in future, to characterise seed quality and to develop and perhaps optimise priming enhancement procedures.

DISINFECTION

Though some seedborne fungal pathogens can be reduced to acceptable levels, or effectively eradicated, using fungicides, other fungal pathogens and bacterial pathogens cannot. Instead this may be achieved using moist or dry heat (thermotherapy), by steeping in chemicals (oxidising agents, such as bleach). Hot water seed treatments, for example, have been used for many years, on a very limited scale (Maude, 1996). A successful hot air treatment has been established for cereal seeds using superheated steam. Important disadvantages for some of these methods include affecting germination quality.

The requirements of producing organic seed have led to a resurgence of non-pesticidal seed treatments. Detailed standards vary between countries and certifying authorities. According to current European regulations, for instance, all seeds and planting material used for organic farming should be produced under organic methods. This is a stimulating development of physical treatments, such as with hot water or hot air, but also the application of plant extracts. For example, essential oils extracted from some herbs have been shown to have an anti-microbial activity and to be effective in controlling certain seed borne bacteria and fungi.

A third approach might be biological control, to make use of the suppressive activity of antagonistic (or 'beneficial') microorganisms. As mentioned previously, these may be combined with, or delivered by, priming techniques ('biopriming'). Alternatively they may be applied in coating, though the relatively harsh environmental conditions present on the seed during commercial seed pelleting and filmcoating and subsequent drying processes often kill vegetative cells, and this is reflected by the frequent use of bacterial and fungal spores in research publications.

UPGRADING

Conventional seed conditioning takes advantage of differences in physical properties that are great enough to separate 'good' from 'inferior' seed and its impurities – such as size, weight (specific gravity), shape, length, width and surface texture. A further range of specialist techniques has been developed for particular separation tasks, to remove weak or dead seeds, and thus give higher levels of germination or usable seedlings.

Density Sorting

Seeds are separated into fractions of different quality obtained by the differential buoyancy of imbibed seeds in water or aqueous solutions, such as to sub-fractionate primed seedlots (Hill et al., 1989). Alternatively, mixtures of non-aqueous solvents are used, such as chloroform and hexane, to upgrade high-value horticultural and ornamental seed lots (Taylor et al., 1982). Equipment has been engineered with very short exposure times that are safe for seed viability or storability, and with no escaping vapours for operator safety. Germination of test fractions using a series of solvent density mixtures, determine the most appropriate fractionating density for the production separation. Although throughput is relatively slow, the technique is now used commercially for high-value horticultural and ornamental seeds.

Colour Sorting

This technique removes 'defective' or 'inferior' individual seeds, one at a time, based on differences in reflected colour or brightness, under one or two selected visible or infrared light wavelengths. Seeds are passed through an illuminated optical inspection zone, equipped with photoelectric cells, positioned above an air ejector whose activation is computer controlled based on the reflectance analysis. In traditional colour sorting, immature seeds are rejected on the basis of their pale green colour. A new variation, known as 'chlorophyll sorting', uses laser-induced fluorescence to detect residual amounts in seedcoats that may not even be visible to the eye (Jalink et al., 1998). This technique is of value in upgrading some tomato, pepper, leek, cucumber, cabbage as well as flower seedlots.

X-Ray Sorting

In future X-radiography might become the basis of a rapid real-time automated sorting method by image analysis, analogous to colour sorting. A commercial procedure currently under development is reported to be suited, for example, to selecting high quality primed tomato seed fractions, by recognising characteristic change in internal seed morphology.

INDUCED STRESS TOLERANCE

The role of priming in assisting germination and plant establishment in otherwise stressful environments has already been mentioned. But seeds also offer the potential for delivering materials that can provide equivalent benefits, for examples preconditioning seed with salicylates (Rajasekaran et al., 2002). Seed-applied materials could also protect the seedling or young plant against stresses due to adverse environmental conditions they will later experience, such as due to cold, heat, salinity, drought or transplantation shock (e.g., Rajasekaran and Blake, 2002).

CONCLUSIONS

Seed enhancements, singly and together, are directed towards improving quality to ensure that high-quality seedlots is made available for sowing, both in terms of its physical (pelleting, encrusting, filmcoating) and physiological (priming, upgrading, nutrient) performance. They also may deliver disinfection of seedborne pathogens and/or inoculation with beneficial microorganisms, and protection for the crop against the action of pests and pathogens. All these treatments must be delivered on seed accurately, evenly, securely, efficiently and safely, with consistent and reliable quality, and in a manner that delivers value to both the seed industry and the grower.

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Figures

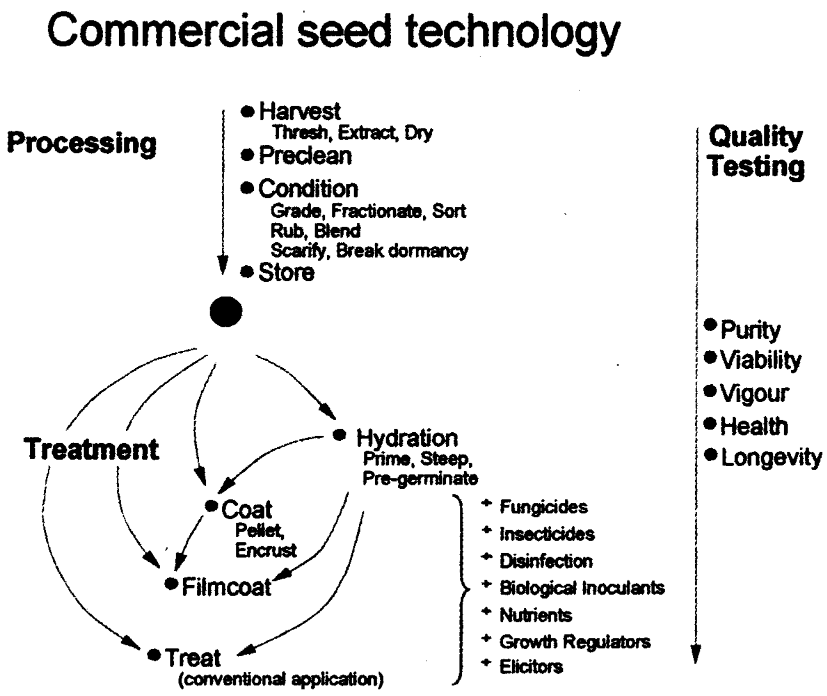

Fig. 1. The inter-relationships of seed processing technologies used in agricultural and horticultural practice to process and treat seed, after harvest, for growing the next crop. Processing involves various techniques, according to seed type. Optional treatments are used singly or in permutation, according to agronomic and market needs. Quality tests are conducted at stages throughout processing and treatment Redrawn from Halmer (2000).