# From Seed Technology to Seed Products

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**Research developments over the past 20 years in the areas of precision sowing, crop protection, and germination performance as they relate to the vegetable and flower seed industry are discussed. It will be shown that technology oriented research in these fields has led to innovative, value-added seed products. The marketing of these seed products is targeted at the needs of growers. Products that are discussed include "100% usable plant seed" based on pregermination technology, "high vigor seed" based on priming technology, and "seed plus shield" based on coating technology.**

## INTRODUCTION

The goal of seed technology is to improve the quality of seed. Thirty years ago seed batches were processed to remove impurities, but no efforts were made to further improve quality. Research in this field with vegetable and flower seeds started in the 1970s. In this paper three areas are highlighted: precision sowing, crop protection and germination performance. All activities related to seed-borne diseases, and to the production of a standard seed quality, are excluded because the starting point of this paper is seed with a standard germination performance and freedom from pathogens.

## PRECISION SOWING

The first concern of the grower is how to get the seed planted into the soil or plugs. With improvements in the quality of seeds and the quality of precision planters, the concept of precision sowing was introduced some 15 years ago in the horticultural industry.

Two types of planting machines have been developed for sowing: mechanical and pneumatic. Pneumatic sowing machines use vacuum to suck the seeds onto perforated drums or disks, while mechanical sowing machines use plates or bands with holes that exactly fit the seeds.

For sowing machines to work there best, the seeds have to be sized into diameter classes, the seeds must be as smooth as possible, and the seed must be perfectly clean. To provide dust-free and smooth seeds the seed industry applies film coatings. This means that the seed is provided with a coating made of a polymer with a thickness of between 1-5 μm.

Seed coatings started to become popular in the 1980s. The technology is now generally available, not only by the seed suppliers but also by custom coating companies like SeedCote Systems (UK), Ceres (France), SUET (Germany), and Incotec (U.S.A., Netherlands).

The use of colors to visualize sowing performance has been integrated into the concept. Thus, a seed coating improves sowing precision and it helps performance checking of the equipment.

Sizing of seeds has become a standard procedure for most seed types to improve the sowing performance. This processing step has great consequences for the stock management in seed-processing operations. One seed lot may be split up into four or five sizes. Each of these sizes must be treated as separate lots in further processing and quality control. Although people assume that large seeds perform better than small seeds, the literature is not conclusive (Villeneuve et al., 1993). However, a clear advantage of the calibration is uniformity in plant size.

A very important breakthrough in applied seed technology was the invention of the seed pellet in the 1960s by Royal Sluis. The pellet made automated sowing in plugs possible and thereby changed the plant-raising industry. Over the years the number of crops that could be bought with a pellet increased. Noteworthy was the Celery QuickPil by Royal Sluis in the early 1980s and some years later the Celery Prestinun pellet by Nunhems that caused a significant change in celery growing. For several open-field vegetables like carrot (*Daucus carota*) and onion (*Allium repa*) pellets are also available. For these crops the higher speed of sowing is an important reason to buy pelleted seed.

A typical lettuce pellet is made of natural materials. In recent years new types of pellets are being developed on the basis of synthetic polymers. On top of improved germination performance the new generation of pellets is more suitable for combinations with agrochemicals used for crop protection.

## COATING TECHNOLOGY

Treatments to protect the seed against diseases are the oldest type of seed treatments. Over the years a number of effective chemicals have come on the market that may be used as seed treatments. The first generation treatments, now called "traditional treatments" consisted of the addition of a small amount of chemical to a batch of seed. These treatments made a lot of dust during seed handling and sowing, and were therefore replaced by slurry treatments with a mixture of the chemical and a sticker. This second generation of treatments is called "dustfree", and that is exactly what they are meant for. However, this type of treatment is becoming obsolete because the distribution of the chemical over one seed and between seeds cannot be controlled. A dustfree treatment also does not give the flexibility that is required for different combinations of seed treatments.

The third generation of seed treatments are called "film coatings" or "polymer coatings". The bases of these coatings are polymers — the type being dependent on the producer and the application purpose — that hold the chemical or a combination of chemicals and a dye. The color that is added to the coating makes the seed very recognizable, can be used to identify seed from a typical originator, and is useful to check sowing performance.

Typical equipment used to apply these coatings comes from the pharmaceutical industry, but adapted versions have been designed over the years to fit the particular needs of the seed industry.

## CROP PROTECTION

In recent years the agrochemical industry has shown a renewed interest in the application of agrochemicals in seed coatings. This new interest is based on the decreasing public acceptance of agrochemicals and the bigger influence of retailers on the way vegetables are produced.

The seed industry has become aware of the unique opportunities. While in the past seed treatments were provided to protect the seed during emergence, the seed houses are now in a position to use the seed as a vehicle to bring agrochemicals into the soil, as close as possible to the plant. Because the chemical is placed exactly were it should be and nowhere else, the reduction in the amount required for good protection is enormous.

To have an effective and long-lasting coating, the chemical must either remain active in the soil for a number of weeks when targeted for soil-borne diseases, or must be taken up by the plant and have systemic action against air-borne diseases. An example of the latter is the use of Metalaxyl as a seed coating against downy mildew in brassicas (Fig. 1).

Seed coatings that protect the young plant against insects have also been developed. S&G Seeds was the first seed company to introduce such a coating for brassicas: the Gigant coating, protecting the plants against cabbage root fly (Fig. 2).

This development is leading towards a coating that protects the young plant against all the main diseases and pests that may occur during the first weeks after sowing, and in some crops even close till harvest. The convenience and cost reduction of such crop protection is of interest to the grower, and at the same time the amount of chemicals needed for crop protection is reduced.

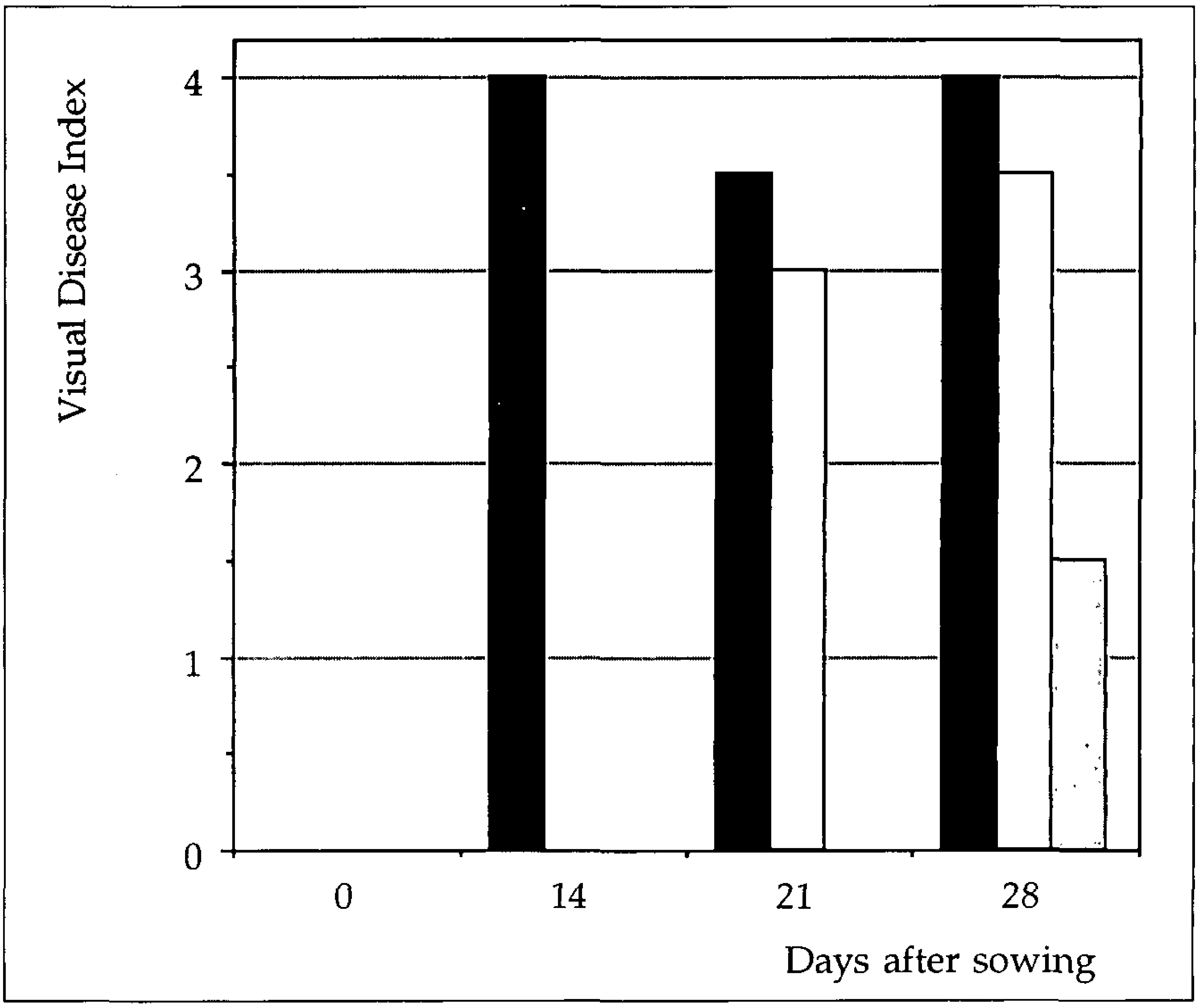


**Figure 1.** Effect of a seed coating with metalaxyl [0.70 g a.i $kg^{-1}$ (□) and 1.05 g a.i. $kg^{-1}$ (□) ] on the infection of cabbage seedlings with downy mildew. The control (■) seed coating did not contain metalaxyl, and no other protection agents were used. (Hofstede, S&G Seeds, unpublished results).

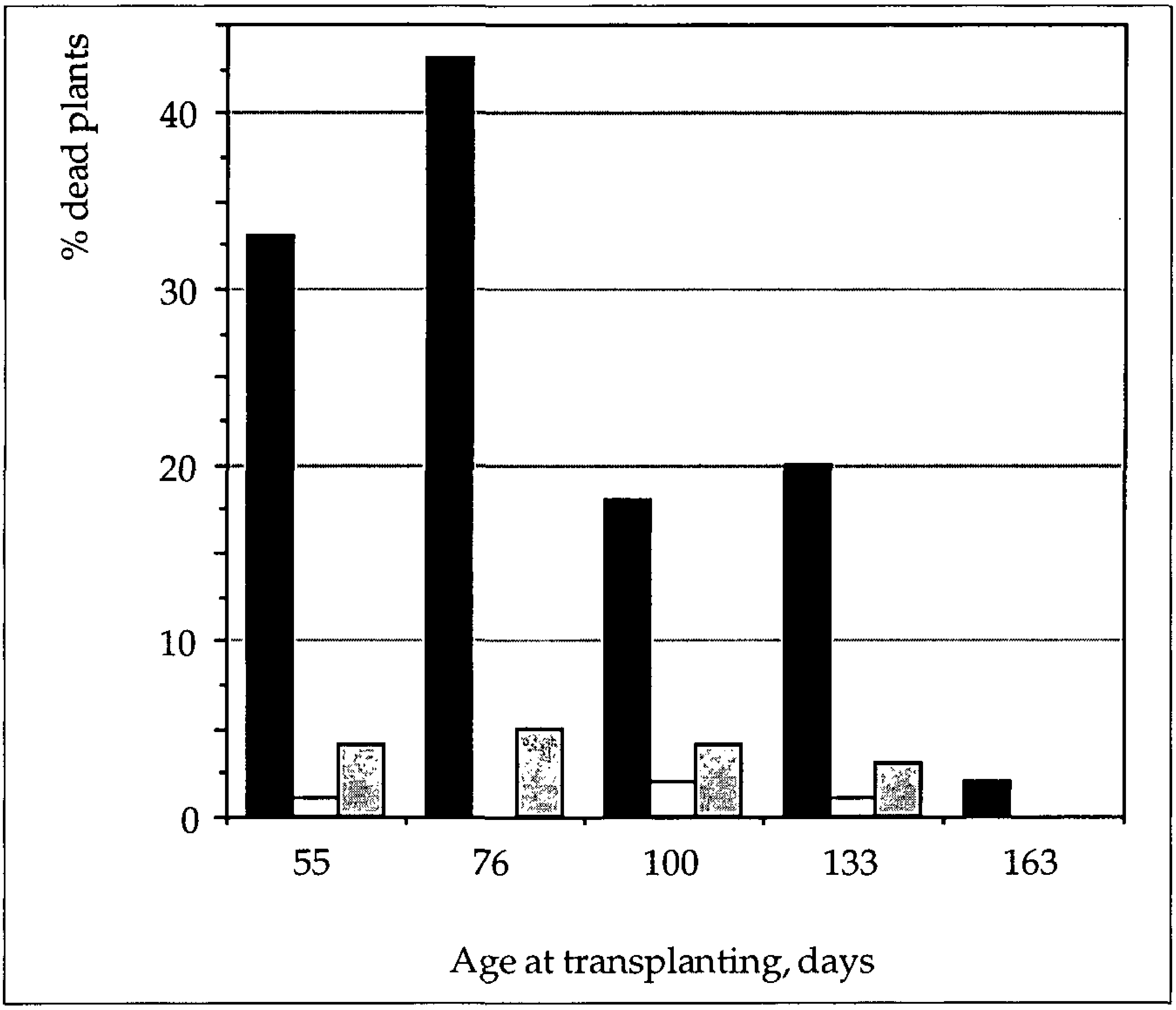


**Figure 2.** Percentage dead cauliflower plants from cabbage root fly 48 days after planting. At time of transplanting (April 15) plants had a different age as indicated on the X axis. Seeds were coated with fungicides only (■) or with fungicides and chlorpyrifos (□). *A second control included a chlorpyrifos granulate treatment after transplanting in* combination with fungicide coated seeds (▩) (After Kosters and Hofstede, 1994).

## BIOCONTROL

Over the last 10 years a new line of seed treatments— biological seed treatments— has been introduced on the market. The research into suppression of diseases in the soil by the use of natural enemies, called antagonists, has driven the application on seeds, as they are a natural carrier to bring these antagonists into the soil. In a number of crop-disease combinations the same level of protection can be reached as with agrochemicals. The continuous work on selection of more effective strains, and the use of genetically modified antagonists have resulted in even more effective protection.

S&G Seeds started the research into biologicals in 1989, and in 1994 BioCoat for radish seeds was introduced in the Netherlands. This coating is highly effective against *Fusarium* species, a disease that cannot be controlled except with expensive soil steaming or environmentally undesired Metamnatrium treatment. Experiments have shown that by using biocoated seed the population of the microorganism, *Pseudomonas fluorescens*, builds up during the season resulting in improved protection (Fig. 3).

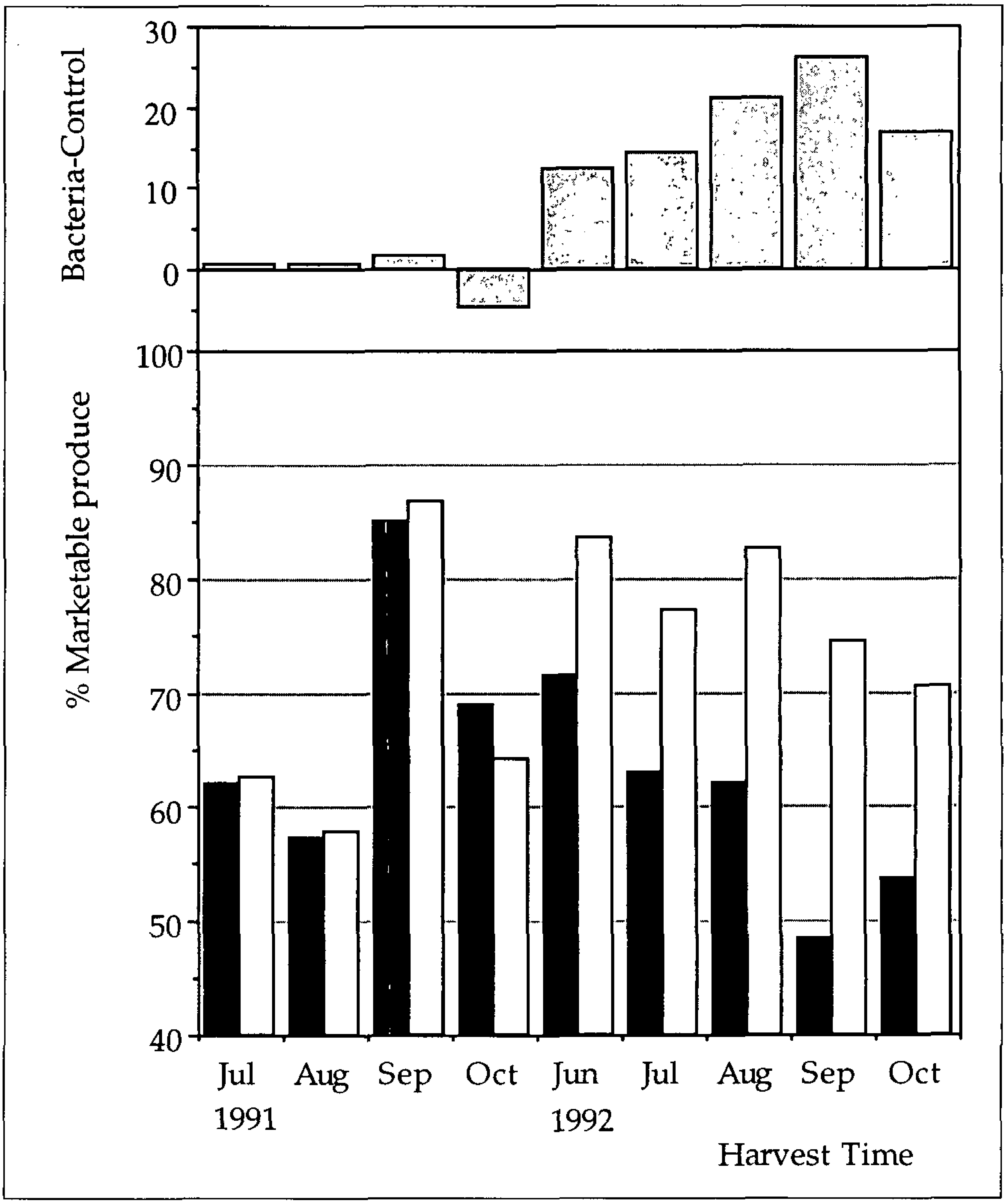


**Figure 3.** The effect of BioCoat on percent marketable produce of radish grown in a greenhouse. During subsequent sowings the yield of coated seeds (□) was compared with control seeds (■). In the upper section the difference in percent marketable yield is indicated (After Leeman et al., 1995).

Although the market is increasingly aware of the importance of reduction of the use of agrochemicals, and biological seed coatings offer a good alternative for chemical seed treatments, it is not expected that many more examples of biological seed treatments will come on the market soon. This is due to the higher costs of the coating compared to conventional treatments and the strong trend in the industry for cost reduction. Once again the public opinion on the use of chemicals in crop protection will play a decisive role in the future.

## SEED QUALITY

The standard approach to test seed quality is a "paper test" — germination on water-saturated filter paper. The methods used for the different crops are described in the official rules of the International Seed Testing Association (1985).

The important advantage of these tests is that they supply a reproducible indication of the potential quality of a seed batch. That is, within the statistical variation that is normally expected in a test of 4X 50 or 2X 100 seeds it gives the percentage normal seedlings germinated under optimal conditions. The international seed trade has agreed upon germination standards used for different classes of seeds.

However, it is well known that the paper test is less useful when it comes to predicting germination under practical conditions. The often variable conditions of open-field-sown crops — but also for crops sown in the greenhouse — make a paper test an unreliable indicator for field emergence. Research in this field has led to standardized tests for usable plants on soil. Such a test comprises 2X 100 seeds sown in soil blocks and germinated under standardized conditions. Again, within the statistical variation it is a reliable assessment of the percentage of usable plants. A

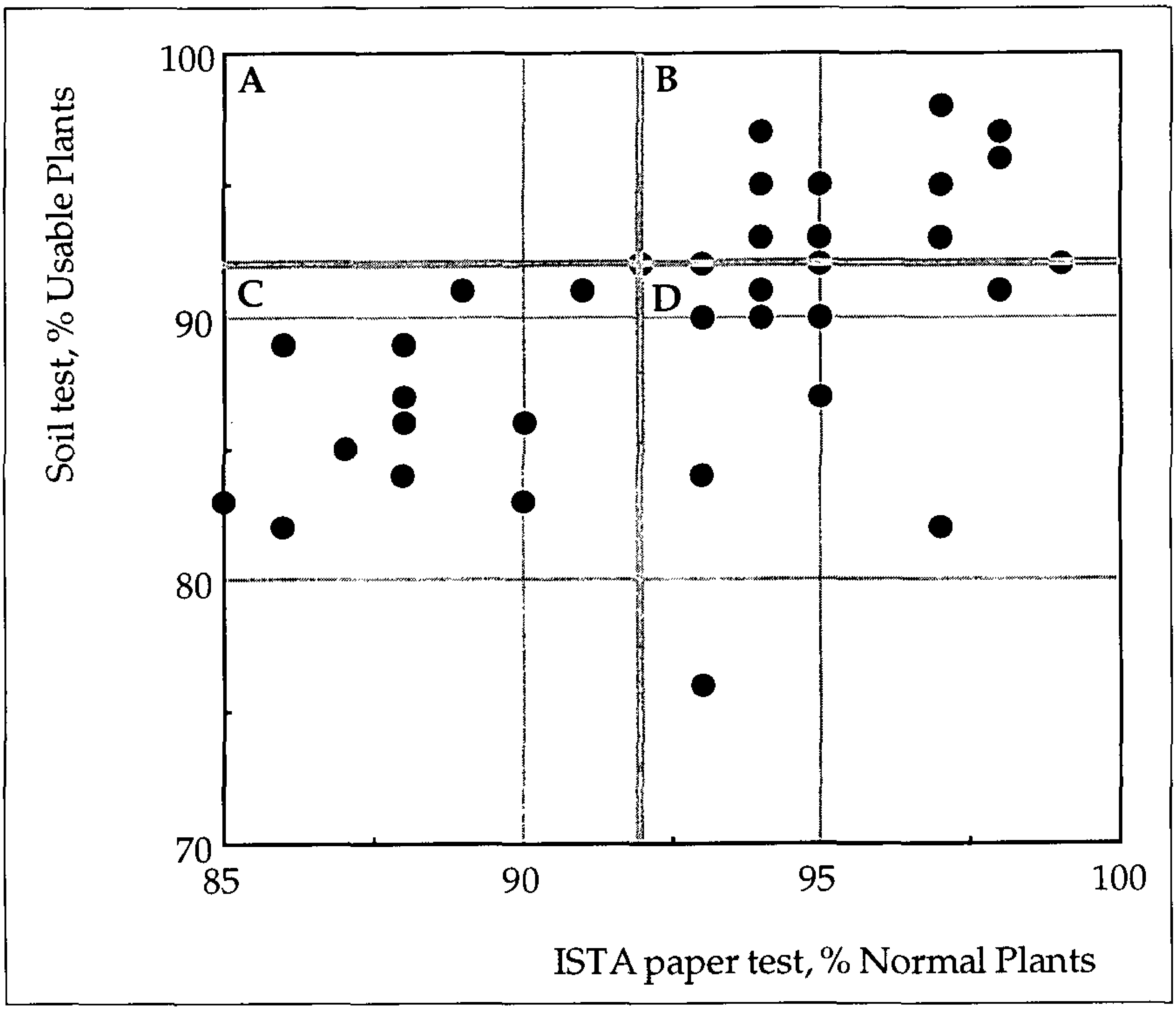


**Figure 4.** A comparison of the germination performance in an ISTA paper test and a percent usable plants-soil test. Each data point represents one seed lot. Note a significant number of seed lots in quadrant D, indicating 92% or more usable plants in the ISTA test but less than 92% usable plants in the soil test. Note also that no seed lots are present in quadrant A (Bruggink, S&G Seeds, unpublished results).

comparison between the paper test and the soil test shows that the soil test can be more discriminating and can better identify the high quality seed lots (Fig. 4).

A soil test quantifies usable plants, looks at uniformity and, to a lesser extent, speed of germination. Speed of germination, or germination rate, is the critical factor that translates into "vigor"; the characteristic that makes a seed less sensitive to adverse germination conditions like low temperature. Speed of germination can best be measured by daily counting of germinated seeds incubated on paper. Formulas (Orchard, 1977) have been developed to calculate the germination rate of a seed lot using the daily countings.

In conclusion, the most valuable information a grower can have is the percentage usable plants obtained in soil under specified conditions, and information related to the germination rate, expressed in a vigor index. This kind of information is as yet not typically available for growers who buy seed, but it will be in a few years. Special product forms like Sterling® seed, introduced in Europe for open-field vegetables by S&G Seeds, makes the need for such information greater. In Sterling® seed the vigor index is on average twice that of standard seed. Due to the higher vigor index Sterling® seed results in much better plant stands in early season sowings of field crops like carrot and chicory (Huygens, 1996).

## IMPROVING VIGOR

Sterling® seeds have been primed to improve the vigor. The idea to prime seeds was originally proposed by Heydecker (1973), a scientist from Nottingham University. Heydecker introduced the concept as the incubation of seed in an osmoticum, preferably polyethylene glycol 8000, a high-weight inert molecule, to control the seed water content. This technology has been used for a number of years but in the 1980s innovations in the technology were published. Taylor (1988) described a method to control the water content by means of a matrix made of vermiculite, perlite, or similar materials. Rowse (1988) published an even simpler method called drum priming. In this system the seed is put into a drum and a calculated amount of water is slowly added by means of nozzles. Recently Rowse (1996) published still another method, a combination of PEG and drum priming. The drum comprises an outer layer that contains a PEG solution, and an inner drum that is made of semipermeable material, such that the seed in the inner drum can take up water from the PEG solution without coming into contact with the solution itself.

All methods are based on the principle that the water potential of the seed during the incubation is strictly controlled. This is important because the rate of metabolism preparing the seed for radicle protrusion — the germination per se — depends on the moisture content in the seed and the temperature during the incubation. The best results of a priming treatment are obtained when the progression of pre-germination development is allowed to proceed as far as possible without the occurrence of radicle protrusion. Radicle protrusion is a critical step in the process because the seed then becomes prone to desiccation damage.

The typical result of a priming treatment is a 100% increase in seed vigor (Van der Toorn, 1990). However, an important drawback of primed seed is the limited shelf life of these seeds. Therefore S&G Seeds has developed a method to increase shelf life in primed seeds (Schipper et al., 1995). With this method the seeds can be easily stored, not only longer than conventionally primed seeds, but also under conditions similar to untreated seeds (Fig. 5).

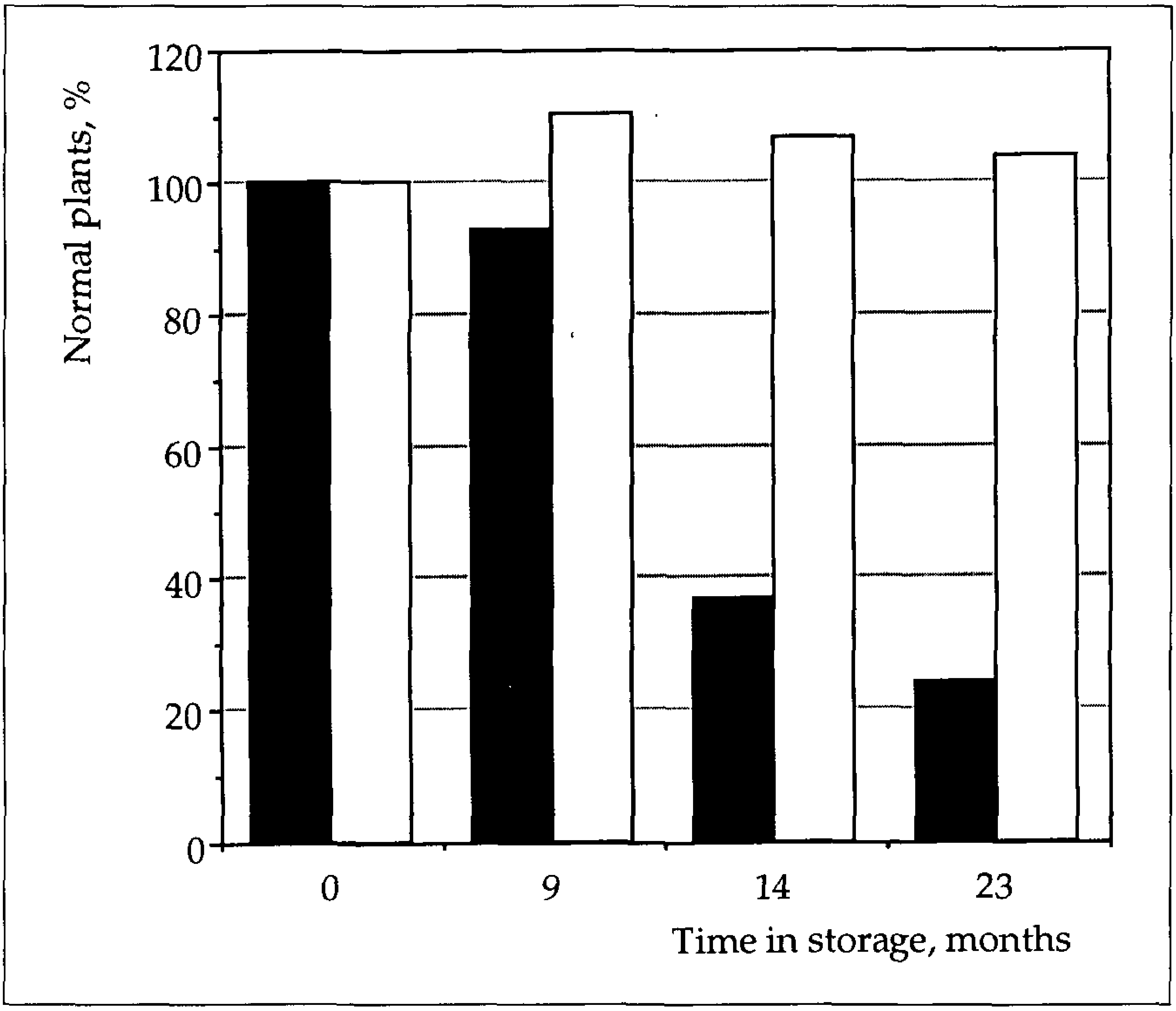


**Figure 5.** The effect of a shelf-life induction treatment on primed Pansy seeds. The seeds were primed at t=0 and either dried back immediately (■) or treated to induce shelf life (□) and subsequently dried. Seeds were stored at 18C in sealed packets. Normal plants are expressed as percentage of germination at t=0 (After Schipper et al., 1995).

The technology used to restore the shelf life of primed seeds is related to the induction of desiccation tolerance in germinated seeds. Primed seeds are held under conditions that confer a stress, preferably a combination of temperature and moisture stress. When a primed seed batch contains 35% (f.w.) moisture content at the end of the priming period, it may then be incubated at 30% moisture content and at a temperature of 32C to increase shelf life.

## IMPROVING PERCENTAGE USABLE PLANTS

Priming does not necessarily improve the percentage usable plants obtained under standard optimal soil conditions. Therefore, next to physiological enhancement a lot of research and development is allocated to seed separation methods. The goal of this research is to develop methods to separate viable seeds from less viable or nonviable seeds, so that seed batches can be obtained with 100% usable plants.

The efficiency of a separation method (SE) may be expressed by the formula:

$$SE = (Qo-Qi)/W$$

where Qo = % usable plants of outlot, Qi = % usable plants of inlot, and W = % of lot that is rejected during processing. For example, a seed lot with a germination of 80% is processed and gives a seed batch which is 60% of the original seed lot and has a germination of 85%. The efficiency of the separation process was (85-80)/(40) = 0.125. A typical seed-cleaning method, like calibration or graduation, has an efficiency of 0.1.

The reason for low efficiencies of conventional seed separation equipment is the absence of a causal relationship between physical seed characteristics used for the separation and the physiological quality.

The parameter with the highest correlation with the quality is the density of seeds. To address the potential of density separation, Taylor et al. (1982) developed a separation in mixtures of chloroform and hexane. A typical density separation has an efficiency of 0.3, meaning a 10% increase in percentage usable plants and a seed loss of about 30% (Fig. 6). The method has been commercialized by Franken, a seed-processing company in the Netherlands.

For some years the Dutch seed industry has been working at the use of X-ray imaging as a seed separation method. The idea is based on the relationship between specific embryo morphology characteristics and the resulting young plant quality (Van der Burg et al., 1994). This type of relationship has been worked out in detail, and the required hardware and software has also been designed. The bottleneck in the application of this technology is in the complicated equipment that has to be designed for the singulation and positioning of large numbers of seeds in the vision system, the limited capacity, and the selection hardware.

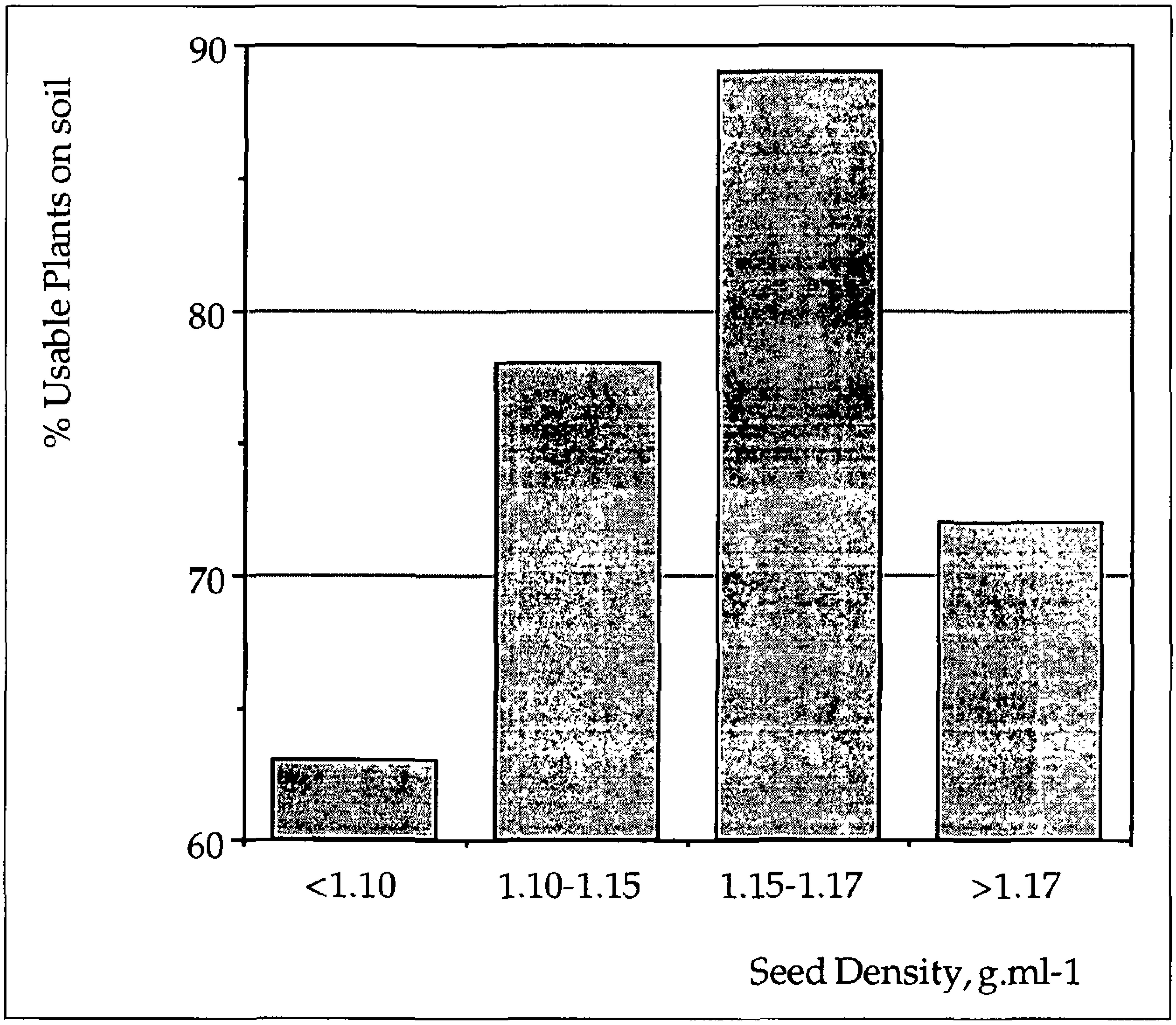


**Figure 6.** The effect of separation of a tomato seed lot in mixtures of hexane and chloroform. The separation solutions were prepared according to Taylor et al. (1982) (Van der Toorn, S&G Seeds, unpublished results).

## PREGERMINATION

Finch-Savage (1989) chose a completely different approach for the development of high-efficiency separation methods. He reasoned that since seeds in their original form cannot be separated into viable and nonviable seeds, the difference had to be induced in the seeds: that is, the viable seeds must be germinated. Subsequently, germinated seeds can be separated from nongerminated seeds.

The idea to obtain 100% usable plants by selection of germinated seeds brings up several problems. The first problem is to control the germination process. As radicle protrusion occurs, the radicle, freed from the surrounding barriers, accelerates into a very high rate of elongation and water uptake. Therefore, the window that is available for selection of an individual seed is very short. In a seed batch the actual time of radicle protrusion of the individual seeds is spread over a longer period, in most species several days. Those two factors lead to the conclusion that to obtain a uniform seed batch of germinated seeds, the separation step must be carried out frequently and without disturbing the germination process.

To shorten the period needed for separation, pretreatments like priming can be used. In addition to these pretreatments the manipulation of temperature and light can be used to control the germination process.

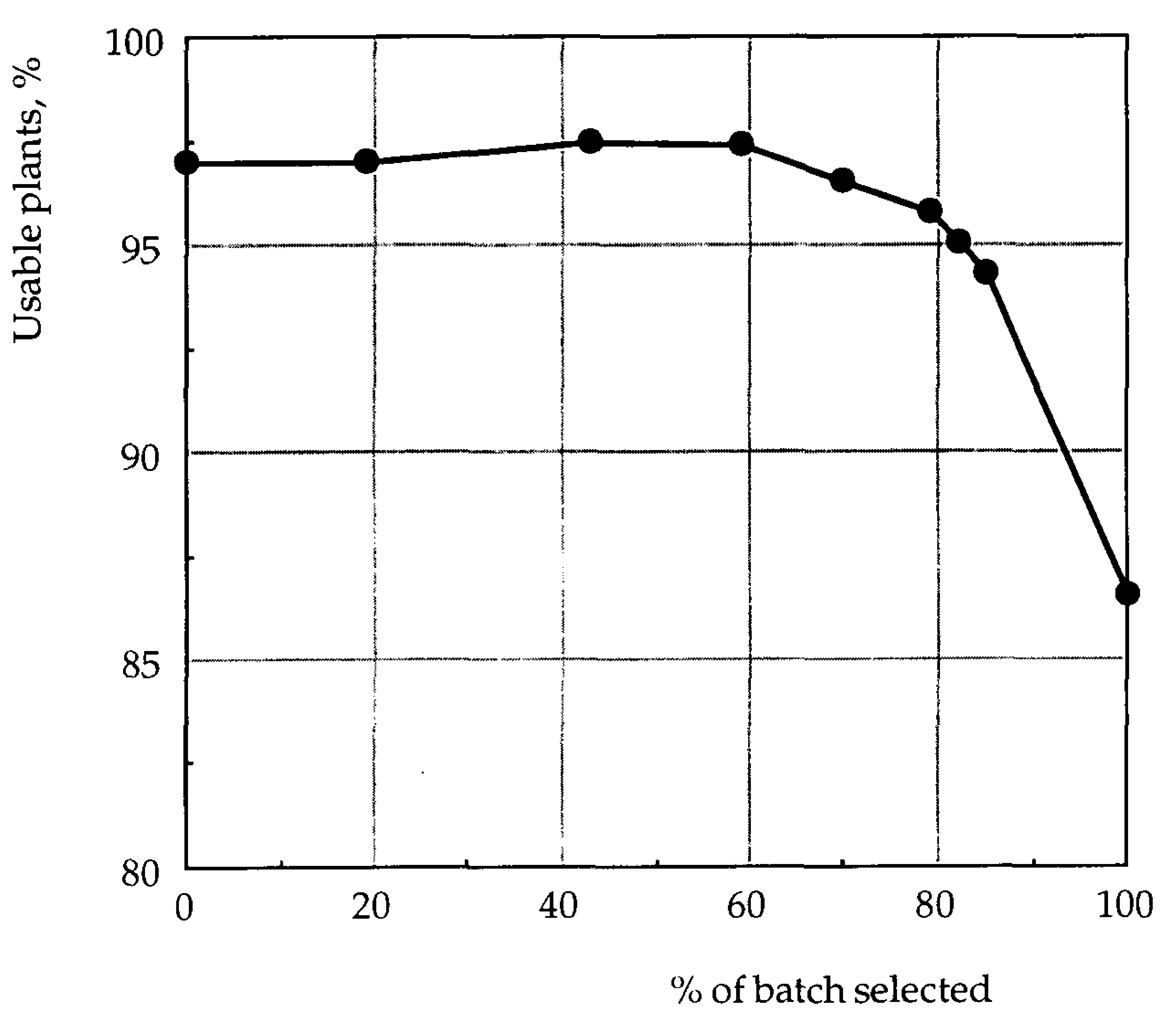


**Figure 7.** The relationship between the time of radicle protrusion and the young plant quality of Impatiens seeds. A seed lot was incubated in aerated water. Germinated seeds were removed periodically and tested for resulting young plant quality. The graph indicates that the last 30% of the seed lot is of a lower quality (Bruggink, S&G Seeds, unpublished results.)

The second problem that has to be addressed is how to separate the germinated from the nongerminated seeds. A very powerful method appeared to be the use of image analysis systems in combination with the germination systems, in such a way that seeds are permanently monitored and germinated seeds are removed and further processed.

The efficiency of separation of germinated seeds should be 1.0, but is as a rule between 0.7 to 0.8 because not all germinating seeds are used. For most crops, a relationship exists between the germination rate and the quality of the young plant (Fig. 7). The early germinators are the seeds that give the highest quality of young plants. The seeds that germinate slowly are not selected.

The third problem is the instant loss of desiccation tolerance at the moment of germination. S&G Seeds has developed a method to reinstate desiccation tolerance in the germinated seed (Bruggink and Van der Toorn, 1996). The method is based on an incubation treatment at a slightly lower water content than at the moment of radicle protrusion. The effect of the water withdrawal is a complete inhibition of radicle growth. But during this period of suspended radicle growth the breakdown of food reserves continues. As a result sucrose is concentrated in the radicle. Figure 8 shows the relationship between the sucrose content in the seed and the survival after desiccation. Next to these processes we have shown that also a group of proteins that are called Late Embryogenesis Abundant (LEA) proteins are being synthesized during the incubation (Bruggink and Van der Toorn, 1995).

The products that are based on pregermination technology are sold under the name PreMagic®. Reports from the plant raisers indicate that "it is possible to get 100 usable seedlings routinely without a lot of effort" (Shaw, 1996).

## FROM TECHNOLOGY TO PRODUCTS

The developments covered in this paper lead to a reassessment of the added value of seed technology. Seed treatments are changing into "crop protection add-ons". Priming treatments are used to provide the customer with seeds fit for suboptimal sowing conditions. New separation technology is brought into the trade to create totally new classes of seed quality. In other words, treatments are translated into products and these products are targeted to markets. This paper shows that it is possible to define five seed types with distinct features of benefit to different market segments:

- **Standard Seed.** This is the starting point of the product line, seed with a known quality, based on the market standard, and coated with agrochemicals that protect the germinating seed. Standard seed is of interest to growers that rely on a "value for money" concept and grow their crop under controlled conditions.
- **High Vigor Seed.** This seed is targeted towards high risk sowing environments, like early season sowings in Northwest Europe or greenhouse conditions in summer South-East United States. The product offers a higher reliability in emergence compared to standard seed under such conditions. The Sterling® seed marketed by S&G Seeds for open-field crops is an example of this type of seed.
- **High Percent Usable Plant Seed.** This seed is targeted to professional growers which can control the germination conditions and want to optimize the operation as much as possible. The

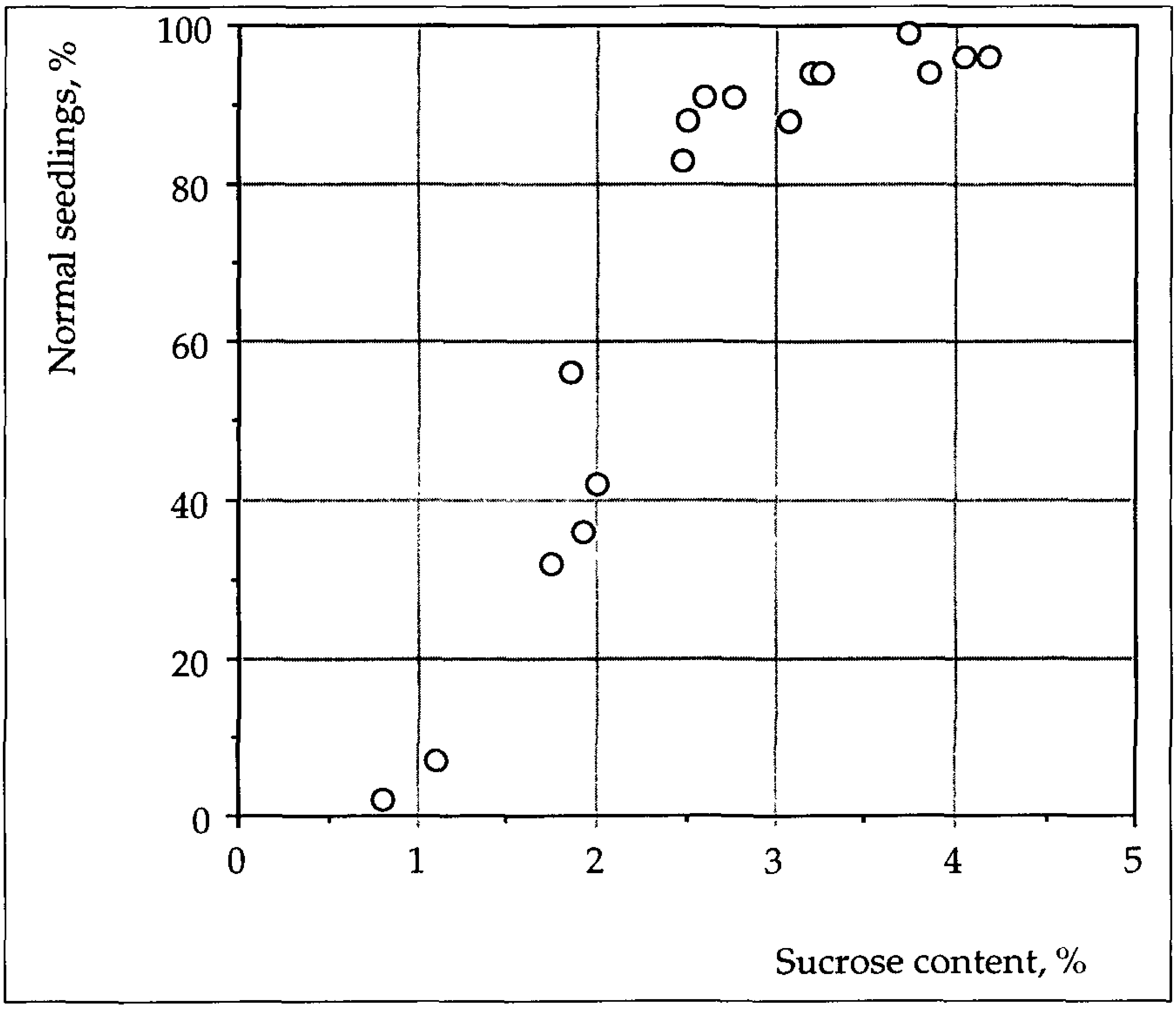


**Figure 8.** The relationship between the sucrose content and the survival of germinated Impatiens seeds after desiccation. Each data point represents a batch of germinated seeds that was treated at different moisture contents and for different periods to induce desiccation tolerance (Bruggink, S&G Seeds, unpublished results).

concept of 100% usable plants brings automated transplanting in the picture, it eliminates patching of trays before delivery, and it enables the plant raiser to make more efficient use of the greenhouse. The PreMagic® seed for bedding plants in the U.S.A. marketed by Vaughans *is an example of this type of seed.*

- **Pelleted Seed.** This seed facilitates high speed precision sowing. For some crops it is an absolute requirement, for others it is an extra that makes a more profitable operation possible. Example of this type of seed is Lettuce Splitkote marketed by Incotec.
- **Seed Plus Shield.** This seed is combined with a crop protection package that protects the young plant until several weeks after sowing. This seed type is of interest to growers who face a high disease and/or pest pressure. For these markets it offers a convenient alternative to conventional crop protection methods. Examples of this seed type include Brassica Triocoat seeds marketed by SeedCote Systems in the UK.

The different types of seed products may be combined to meet the specific grower demands. The complete transfer of technology into products yields the full potential of seed technology and creates added value both for the grower and for the seed industry.

**Acknowledgments.** I would like to thank several people from the S&G Seeds Department of Technology: Bernadette Kroon, Sietske Hofstede, and Frank de Rooij for their help on biologicals and coatings; Tonko Bruggink for his help on seed quality and pregermination, and Ruud Scheffer for his peer review of the manuscript.

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