Session 7

Application of Seed Treatments, Coatings, Pelleting and Other Techniques

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LARGE-SCALE SEED PRIMING TECHNIQUES AND THEIR INTEGRATION WITH CROP PROTECTION TREATMENTS

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ABSTRACT

Priming, a treatment of seeds in which they are hydrated sufficiently to allow the preparative events for germination to take place but insufficiently hydrated to allow the radicles to emerge, followed by drying before sowing advances and synchronises germination. In turn seedling emergence is more predictable; it is advanced and more synchronised, giving earlier growth. Three main priming techniques have been developed to successfully treat both large and small-seeded species; solid matrix priming (SMP) using materials such as calcined clay, polyethylene glycol (PEG) priming in bioreactors and drum priming. Provided comparisons are made for seeds achieving the same water potential during treatment, the effects on germination and seedling emergence are identical. It is possible to integrate these 'physiological' treatments successfully with the application of crop protectant chemicals to seeds and with seed pelleting techniques. Priming provides a means to introduce biocontrol agents on to seeds though to date the potential of this has been demonstrated largely only for SMP.

INTRODUCTION

Seed treatment is an ancient technology and the soaking of seed in dung for short periods prior to sowing, and 'pelleting' in dung, have been reported at regular intervals by writers down the ages from Roman times. Such treatment has been claimed to increase establishment and provide nutrients, particularly trace elements, so increasing yields on poorly manured soils. Despite this, physiological treatments of seed have not been widely exploited in commerce in contrast to the pervasive uptake of crop protectants applied to seeds. The commercial use of physiological seed treatments has been restricted largely to the alleviation of dormancy, a problem of limited significance amongst cultivated agronomic and vegetable crop species.

However, in the early 1970s Heydecker *et al.* (1973) showed that a treatment of seeds, called priming, in polyethylene glycol (PEG) advanced germination and emergence and reduced the time over which the seedling population emerged in the field. The potential of this treatment to improve crop establishment and reduce variation in plant size was widely appreciated and the benefits have been confirmed (see Bradford, 1986 for a review) using seeds primed on a small scale in Petri dishes (Brocklehurst & Dearman, 1983) or in small bubble columns (Darby & Salter, 1976). As a result of this and the interest of seed companies in the technique, substantial effort has been directed recently into large-scale priming using a variety of methods.

The purpose of this paper is to outline the mechanism of priming, the basis for improved crop response, the systems that are currently or have been developed for large-scale priming and how these processes can be integrated

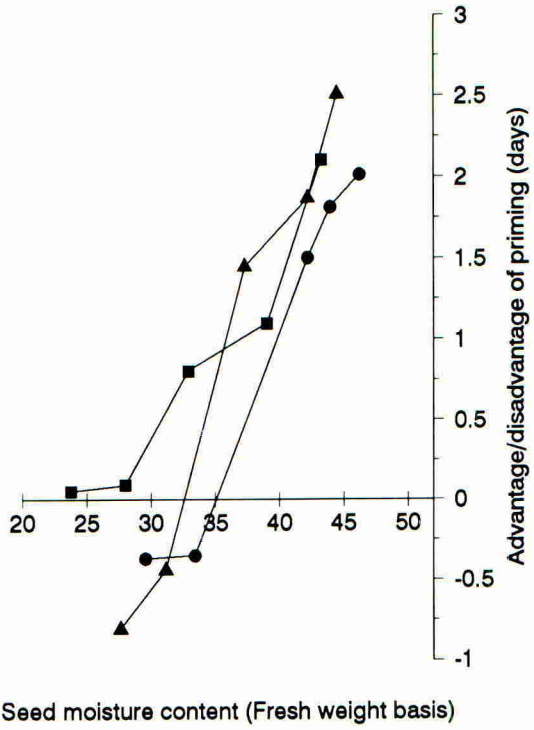

FIGURE 1 Relationship between response to priming and seed moisture content for leek (•), onion (▲) and carrot (▪) (after Gray *et al.*, 1990).

with current technology for applying crop protectants to seeds.

MECHANISM OF PRIMING

Essentially, in a seed priming regime seed water potential (ψ) is maintained at a level sufficient to initiate metabolic events in phase II of the germination process (Bewley & Black, 1978) but which prevents radicle emergence. Measurable germination responses to priming are obtained at seed moisture contents of approximately 30% and the response increases linearly over the range 30% to 45-50%, the precise upper limit depending upon species (Fig.1; Gray *et al.*, 1990). A detailed analysis of the water relations of priming seeds is given in Bradford (1986, 1990). The maintenance of the seed water potential below the threshold necessary for radicle expansion allows the slower germinating seeds in the population to 'catch up' with the faster germinating ones giving, once the 'restraint' to germination is removed, more synchronous and more rapid germination. There is much debate about the biochemical changes such a treatment might produce and whether 'repair' mechanisms are stimulated but there is little evidence that they are intrinsically different from those occurring during normal imbibition in water. Even if differences do exist there is little evidence that these are reflected in differences in seedling relative growth rates between populations of primed and unprimed seeds (Brocklehurst *et al.*, 1984).

RESPONSES TO PRIMING

The main benefits of priming are to advance and synchronise the germination of seeds in a population. The precise effects depend upon the seed moisture status and the temperature of priming (Fig.2). As the temperature at which seeds are primed falls, the response to priming increases for the same number of 'day degrees' of priming but, accompanying this, there is an increase in the proportion of abnormal seedlings. The 'crossover' point where the maximum response to priming and minimum level of abnormal seedlings occurs, in leek, for example, is 10 d priming at 15°C.

Whilst reports in the literature invariably record earlier seedling emergence from priming it is not invariably more synchronous even though germination is. This is due to a number of factors principally that, in the field, priming often secures the emergence, after a time, of weaker seedlings from poorly germinating seeds which usually would not survive from untreated seeds. This extends the period over which all seedlings emerge. In addition, some species, eg Umbelliferae, exhibit a wide range of variation in embryo size which will contribute to asynchronicity of germination and seedling emergence. However, priming does increase the predictability of percentage seedling emergence over a wide range of conditions and sowing occasions (Finch-Savage, 1990) and in this way contributes to uniformity of the crop through its effects on plant density and, in turn, on mean plant size. A summary of the effects of priming on seed germination and seedling emergence is given by Bradford (1986) and Khan (1992). The earlier emergence from primed seed advances growth and, provided harvests are made during the exponential phase of growth, 'yields' are higher from primed than untreated seeds (Brocklehurst & Dearman, 1983). However, at maturity, effects of priming on total plant weight, after eliminating the effects of the treatment on plant density, are small (see Bradford, 1986; Brewster *et al.*, 1991). An unexpected consequence of priming has been the finding that the rate of loss of viability of the seeds is increased relative to untreated seeds (see Tarquis & Bradford, 1992). However, the benefits of priming can be maintained over a period of two years in onion, leek and carrot with suitable storage temperatures and scheduling of seed treatment and sowing times (Gray, unpublished data).

LARGE SCALE PRIMING TECHNIQUES

The maintenance of a specific ψ during phase II is the basis for all the techniques currently being developed for large-scale priming. Three main techniques are used in commerce. These are solid matrix priming (SMP) developed in the USA (Taylor *et al.*, 1988; Eastin, 1990; Khan, 1992), PEG priming (Nienow & Brocklehurst, 1987), and drum priming (Rowse, 1991, 1992) both developed in the UK. Provided similar levels of seed ψ are achieved in each system the subsequent effects of priming by different methods on seedling emergence are virtually identical (Gray *et al.*, 1992).

Solid matrix priming

The use of PEG, with its low oxygen solubility (dO_2) and high viscosity has not proved to be suitable for large seeds and it is not possible to obtain high seed: PEG ratios to make the system economic. As a result, efforts have been made to use solid materials. The solid materials used for priming, ideally, should be capable of generating a low water potential, produce few solutes and have high 'flowability'. Materials made from leonardite shale,

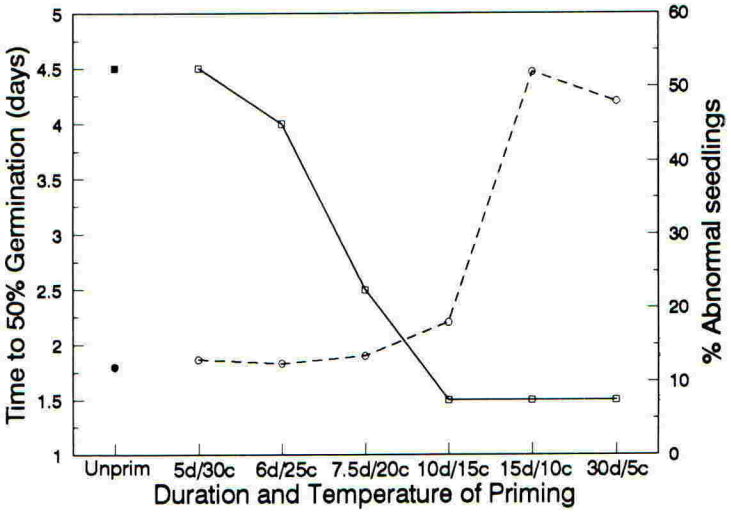

FIGURE 2 Relationship between advancement in germination from priming and the number of abnormals produced in leek. (□), time to 50% germination; (○), percentage of abnormal seedlings.

exfoliated vermiculite, diatomaceous silica and expanded calcined clay are commonly used for various methods of solid matrix priming (Taylor *et al.*, 1988; Khan, 1992). These materials are capable of generating water potentials ranging from -0.4 to -1.5 MPa. The ratio of solid material to seed in solid matrix priming described by Taylor *et al.* (1988) is typically 1.5:1 whereas in the system described by Khan (1992) it is typically 0.2 to 0.4:1. In some procedures the priming material is removed before sowing and in others it is left on the seeds. A disadvantage of the method is the lack of precision in control of ψ in the material and the seed and hence in 'repeatability' of the priming effect.

PEG priming

Two types of vessel are used for PEG priming, a bubble column and a stirred bioreactor. Details of the systems used are given in Nienow and Brocklehurst (1987), and Gray *et al.* (1992). With bubble columns it is possible to achieve greater gas liquid mass transfer coefficients (k_La) than with stirred bioreactors at equal energy input (Fig.3) and there is less risk of damage to seeds by abrasion in such systems compared with stirred bioreactors where high impeller speeds are needed to maintain dO_2 above 80% (Nienow & Brocklehurst, 1987). However, if oxygen enriched air is used (Bujalski *et al.*, 1989) then stirred bioreactors are more cost effective, since lower rates of enriched air sparging are possible, 0.02 to 0.05 vvm (volume of gas per volume of liquid per minute) as compared with 1.2 vvm for bubble columns. Nevertheless, both systems can be operated to give reliable responses to priming. However, in some species e.g. onion, even under these conditions variable responses to priming have been obtained and indicate that k_La from PEG to seeds was limiting even when dO_2 was between 80 and 100%. By using oxygen enriched air, dO_2 values can be increased to 150% and improved, more reliable responses to priming have been achieved with onion (Bujalski and Nienow, 1991), with leek (Bujalski *et al.*, 1991a) and with

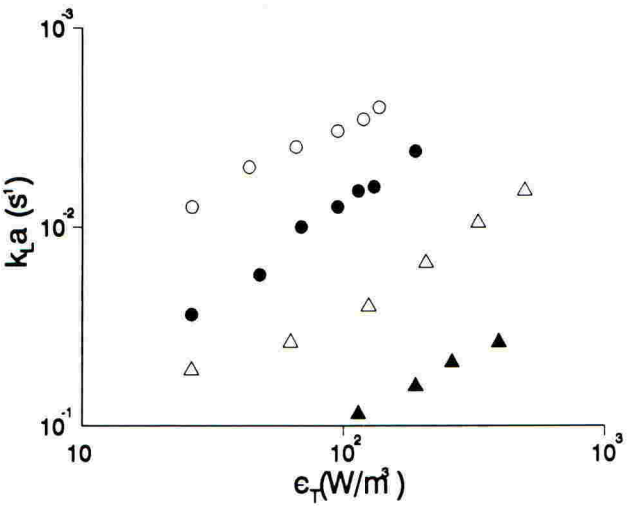

FIGURE 3 Relationship between k_La/s and specific energy dissipation rate (ϵ_T) for water (open symbols) and PEG 6000 (closed symbols) (-1.5 MPa) in bubble columns (circles) and stirred bioreactors (triangles).

carrot (Bujalski *et al.*, 1991b) but not with some flower species (Finch-Savage, 1991). At present, PEG 6000 is widely used but there would be engineering advantages in reduced power input and in obtaining higher dO_2 values by using lower molecular weight PEGs. Priming with PEG 600 and 6000 (see Gray *et al.*, 1992) give similar responses and there are no adverse effects on plant growth from the lower molecular weight PEG. As PEG 600 is a liquid, there could be additional advantages in enabling simple control systems to be devised for maintaining prescribed ψ of the PEG in bioreactors. A major problem with PEG priming arises from the need for and cost of disposal of PEG. It is possible, despite massive increases in microflora, to re-use PEG (Petch *et al.*, 1991) as no adverse effects on germination or seedling emergence responses have been noted with two cycles of use, though after three a slight reduction in seed viability was detected. Whilst this may reduce costs of treatment it may not fully compensate for the costs of final disposal of PEG.

Drum priming

The drum priming technique, developed at Wellesbourne (Rowse, 1991, 1992) involves the hydration of seeds over a period of 24 to 48 h in a drum revolving at 1-2 cm/sec. Mixing of seeds is very uniform and seeds at the end of this period are plump but surface dry. The degree of hydration is determined by a simple calibration test for each lot and a computer is used to calculate the rate of wetting and control of water supply. The seeds are then tumbled for between 5 and 15 days. The technique is now operated under licence.

Drying techniques

Drying of the seed after priming is an essential pre-requisite for storage and handling. Several systems are used based on forced air drying through a thin layer of seeds or in fluidized beds (Maude *et al.*, 1988). The

latter has the advantage that drying can be combined with the application of pesticides. Using these techniques and with temperatures within the range 15-20°C and airflow rates in fluidized beds of 0.34 m/sec to 0.05 m/sec, repeatable results without loss of the benefits of priming have been obtained (Bujalski *et al.*, 1991b). However, drying the seeds after treatment does reduce the advantage in earliness resulting from priming though this amounts to 0.5 to 1 d, equivalent to the time needed for the seed to imbibe water fully.

INTEGRATION OF SEED PRIMING WITH CROP PROTECTION AND OTHER TREATMENTS APPLIED TO SEEDS

If priming or other physiological treatments of seed are to be widely taken up and their potential developed, it is necessary that they can be integrated effectively with seed treatment using crop protectant chemicals and biological agents.

Solid matrix priming

In the SMP priming system described by Khan (1992), prior or concurrent treatments with fungicides have advanced seedling emergence and proved effective in controlling disease (Khan *et al.*, 1992) and Khan & Ptasnik (1992) have effectively primed seeds after treatment with insecticides. In a few cases the prolonged seed treatment period with priming has been exploited effectively to introduce biological agents to control disease, eg 'damping off' from *Pythium ultimum* using *Trichoderma* (Harman & Taylor, 1988; Harman *et al.*, 1989) and *Pseudomonas fluorescens* (Callan *et al.*, 1990).

PEG and drum priming

Seeds routinely treated with Benlate-T have been primed in PEG successfully (Maude *et al.*, 1992; Bujalski & Nienow, 1991; Finch-Savage *et al.*, 1991) but for *Alternaria dauci* infection such treatment only partially reduced infection as did the addition of iprodione or thiram to the PEG during the priming process (Maude *et al.*, 1992). In both situations further dusting with iprodione after treatment and drying or alternatively application of it in a polymer film coat as the final stage in treatment was necessary to control the disease fully. Such combined treatment increased plant stand and yield. The feasibility of following PEG priming by both drying and the coating of the seeds with pesticide in a single operation yet retaining the benefits of priming have been demonstrated (Table 1: Bujalski *et al.* 1992). It has also been shown that, for tomato, onion, leek, carrot, parsnip and lettuce, priming can be fully integrated with modern seed pelleting techniques without loss of the benefits of PEG and drum priming (Gray, unpublished data; Valdes & Bradford, 1987). Khan & Taylor (1986) have reported that PEG can be directly incorporated into the pelleting material, improving the rate and final percentage germination, possibly as a result of a priming action.

CONCLUDING REMARKS

The benefits of priming in terms of earliness of emergence and more reliable seedling establishment (Finch-Savage, 1990) are well appreciated and, despite the increased cost of the seed compared with untreated lots, primed seeds are in widespread use for a number of species. With flower seeds, which often exhibit erratic seed germination as a result of dormancy, the benefits

of priming are substantial and several companies in the USA and EC offer primed seeds for sale. With vegetables, primed celery and lettuce seeds, which give better germination at thermodormancy-inducing temperatures, have been available for some years from at least two companies. Details of the techniques used have not been published though details of the Quick Pill technique are available (Jacob, 1982). More recently, the introduction of the HRI drum priming technology, through licensing arrangements with the British Technology Group, has led to the commercial sale on an annual basis of several hundred kilograms of primed seed of onion, leek, carrot and parsnip in the UK.

TABLE 1. Effects of priming, drying and coating treatments on seedling emergence of leek (Bujalski *et al.*, 1992)

Priming method	Drying method	Coated with	Mean emergence time(days)	Spread of emergence 5-95%(days)	Percentage emerged seedlings
Bioreactor	Thin-layer	-	2.0	4.7	84
Filter paper	Thin-layer	-	2.3	4.9	89
Bioreactor	Spouted-bed	-	2.3	5.2	76
Bioreactor	Spouted-bed	binder	2.5	4.7	83
Bioreactor	Spouted-bed	thiram+binder	2.3	5.7	78
Untreated		binder	4.9	7.1	85
Untreated		thiram+binder	4.8	7.5	79
Untreated			5.0	7.3	81
LSD (p=0.01)			0.45	2.0	14.1

A major outlet for primed seeds is in the plant raising industry where control of the post sowing environment can be readily achieved so maximising the benefits. For vegetable transplants and bedding plants raised in modules the improvement in 'cell fill' and seedling uniformity is clearly evident and improves the appearance and performance of the product. There is increasing evidence of the use of primed seed sown directly in the field but it is necessary to sound a note of caution for the success of such treatments. Finch-Savage (1990) has shown that although, on average, over a number of successional sowings primed seeds performed better than untreated seeds this was not always the case for every sowing. This is because changes in the seed bed, notably the availability of soil moisture at the time of radicle emergence do not always coincide for both primed seeds and the untreated seeds which germinate later. To maximise the benefits from primed seed in the field it is necessary also to optimise the post-sowing environmental conditions. This can be achieved readily in outdoor seed beds and there could be therefore considerable scope to examine the possibility of priming for hardy ornamental and tree species.

Good progress has been made in integrating priming technology with existing seed treatment technology for applying crop protectant pesticides (Talavera-Williams *et al.*, 1991) and with pelleting, without loss of seed viability or the benefits of priming. It is also possible from simple tests to predict in advance the likely response to a given priming treatment or, alternatively, the particular priming conditions can be adjusted to maximise

the response for each seed lot (Rowse, pers. comm.). Currently, several techniques are used to prime seeds and each has its advantages. PEG-priming can be now routinely carried out on 10 kg batches of seeds for a wide range of species and it would be possible to contemplate priming much larger batches since the scale-up relationships for large bioreactors are well known (Talavera-Williams *et al.*,1991). However, operations on such a large-scale pose problems for the disposal of PEG and this may limit the commercial growth of such a system compared with drum priming which, theoretically, can be carried out using seed lots ranging from 1g up to 100kg or more. Furthermore, it can be used for treating large seeds, currently treated using SMP techniques. For some species which have seed coat inhibitors, eg celery, and which require a pre-treatment, priming of seeds can be accomplished more quickly by PEG than drum priming.

The preference for one particular method may also be influenced by the development of other seed treatment technologies, for example the application of micro-organisms to control disease. It is claimed that one of the advantages of solid matrix priming is that the material used can provide also a base for the beneficial activity of protective micro-organisms and some progress is being made using both antagonistic fungi and bacteria. No comprehensive studies have been carried out using biological agents in PEG or drum priming but it has been shown that *Enterobacter agglomerans* can be film-coated onto onion seeds and is effective in reducing the incidence of neck rot (Maude, pers. comm.). This suggests that the particular conditions offered by SMP priming are not necessarily essential to the development of successful biological disease control systems for seeds and that successful systems could also be associated with PEG or drum priming.

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THE DEVELOPMENT OF QUALITY SEED TREATMENTS IN COMMERCIAL PRACTICE - OBJECTIVES AND ACHIEVEMENTS

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ABSTRACT

Recent developments in seed treatment procedures are reviewed and the implications of treatment quality fluctuations are discussed.

INTRODUCTION

At the time of the first BCPC Symposium on Application to Seeds and Soil (Martin, 1988) there was much discussion of developments in seed treatment application technology, such as film-coating, and the ways these techniques might be used to deliver a wider range of chemicals and biologically active materials to crops (Clayton, 1988a,b; Halmer, 1988; Suett, 1988). The aim of this paper is to provide an update review, from the perspective of the seed and seed treatment industries, of recent technical developments and trends, with particular reference to issues of the quality of application. Because these industries and their markets have fragmented and complex structures, which differ in virtually every country and crop, it is only possible in this paper to discuss themes of progress and change in a general way.

Seed treatments have historically tended to be regarded within the seed industry as a necessary but secondary production step in the process of the breeding, production and sale of varieties. In practice, the treatment of seed presents the industry with special challenges in production logistics and inventory management. Often the time available is short. In some crops, the seed itself may be only recently produced - in Europe, for example, autumn sown cereals and oilseed rape are cleaned, processed and treated within about a 10 week period following harvest. Even where processed seed is available in good time to the seed company, sales orders from the farmer may not be finalised until a relatively late date. In some cases a range of varieties must be considered in possible combination with alternative seed treatments, perhaps with different application rates or even formulations. Considerable problems would arise if the wrong quantities of treatments were prepared. In general, therefore, treatments - especially those with higher value - tend to be produced to order, rather than speculatively, to minimise the amount of unsold surplus carried over at the end of the season.

It is common to consider seed production in terms of the high-volume or agricultural crops (small grain cereals, maize, pulses, oil seeds, cotton, grasses and sugar beet), and the low-volume or minor crops (chiefly horticultural vegetable and flower species). Continuous throughput equipment is used to treat high volume crops, whereas in general batch treaters are used for the low volume crops. Arguably, in practical terms, cereals merit a category of their own, because of the large quantities involved: at least 15t/h is desirable for cereal treatment in fixed installations, and some facilities achieve 40t/h, though lower rates are acceptable for other crops. Sugar beet also is a special case, in Europe and the USA, because it is mostly treated, on a batch basis, through pelleting or encrusting processes.

A substantial proportion of agricultural crop seed treatment worldwide is carried out on farmer-saved seed (with the notable exception of the hybrid crops, maize and sugar beet) - to a greater extent where yields are low, such as Southern Europe and the American Midwest - either using the farmer's own equipment, or by specialist mobile treating operations, with throughputs much slower than static equipment. In many countries, farmers' own machines used are of a basic design in which liquids or powders are added to seed metered directly into the auger - "planter box application".

As a generalisation, the most advanced seed treatment technology is employed in Europe and North America, though standards are variable. Technology is less developed in Eastern European countries and South America. In the majority of Africa and Asia (excepting Japan) and the Middle East (with certain exceptions), where there is neither the economic strength or infrastructure to support seed treatment technology, the majority of seed is farmer-saved, and treatments are applied using the simplest techniques.

DEVELOPMENTS IN APPLICATION TECHNOLOGY

Application standards

The requirements for application of seed treatments are often stated along the following lines.

Loading efficiency

The correct target dose should be reliably applied to the seed bulk, and maintained on the seed up to the point of sowing.

Drillability

Materials should be securely attached to the seed surface, and non-tacky, so as not to impair flow in the hopper and coulter tubes or the action of the seed drill itself.

Uniformity

Materials should be distributed uniformly from seed to seed. The meaning and implications of this principle are more complex than may first appear, and this point will be discussed in greater depth later in the paper.

Effect on seed quality

It is important that seed treatments have well defined and minimal effects on the physiological quality of seed. Application methods must be safe, causing minimal mechanical damage and maintaining seed moisture at acceptable levels for storage. The germination and vigour of varieties are of particular importance for module- or space-planted crops like vegetables and sugar beet, where rapid and uniform crop establishment is important in ensuring yield and harvest quality. In these crops too, seed treatments may now need to be integrated with commercial priming techniques, so as not to lose the germination enhancement benefits (Gray, 1994).

Application to pelleted and encrusted seed

Most pelleted and encrusted seeds are treated with a fungicide, and in some species an insecticide also - notably sugar beet and some vegetables in Western Europe. The main purpose of encrusting and pelleting is to alter the dimensions of seed to add weight or permit space planting through a variety of seed drills and sowing mechanisms. Coated seed must therefore meet integrity, weight, size and shape standards, usually specified by grading

through round hole and slotted sieves.

Handling safety

Aside from directly indicating poor application, dustiness may be of particular concern to those who handle seed treated with insecticides, or with materials that have irritant effects.

Appearance

Cosmetic appearance is an important factor in the perception of quality, especially when the pesticide or coating adds substantially to the cost. Visible dustiness apart, appearance is also the most obvious indicator (though not always a true reflection) of uniformity of distribution of the applied material between and on individual seeds. An attractive features of film-coating is the characteristically more or less continuous covering of the seed surface, and pelleted and film-coated seed is commercially produced in a range of appealing colours, with polished or pearlised finishes.

The impact of Operating Regulations and Quality Standards

The seed industry has to operate under increasingly rigorous regulatory standards, governing both the environment as well as health and safety in the workplace. Regulatory changes are part of a general trend affecting industrial production which has been identifiable over the past two decades, particularly in developed countries. The rate at which these changes are occurring, and the form they take, varies between countries, with "green pressures" perhaps strongest in Scandinavia, Germany, Holland, the UK and California. In the UK, for example, operators of seed treatment equipment now need to pass through a certification procedure, as will in the near future those who sell treated seed. Companies treating seed must also handle the increasingly expensive and difficult disposal of treatment waste products, such as contaminated dust and water from cleaning equipment, and the safe disposal of empty pesticide containers.

At the same time, there are the beginnings of a trend within the seed and agrochemical industries to seek voluntary accreditation under Quality Management System standards (ISO 9000, or BS 5750 in the UK) which, through external audit of operational procedures, are aimed at assuring the customer of product and service quality. Also in view for industry in general is the creation of standards for Environmental Management Systems (e.g. BS 7750), through which companies can establish and minimise the environmental impact of their operations, on a voluntary basis.

FORMULATIONS AND BINDERS

The trend continues towards liquid formulations, whose advantages include ease of mixing, relatively low sedimentation rates, decreased loss in loading, and safety to the environment. Liquid formulations, usually water-based true solutions or flowable suspensions or slurries, now are preferred in all European countries and by commercial treaters in North America and Australia. However, powders are still predominantly used for on-farm treatments in the US. Differences in practices exist. In France, Belgium, Holland, and Denmark, for example, because of the equipment installed in seed treatment plants there is a preference to use formulations in a dilute form, sometimes with film-coating polymers, whereas in the UK concentrates containing at least 50% solids are used for direct application to seed.

Film-coating was first developed for vegetables, and now has become a standard method in all major markets for applying treatments, typically fungicides, to these species. The most readily apparent characteristics of film-coating, in comparison with "conventionally" treated seed, are the absence of dust, and uniform coverage between and on individual seeds, and improved flow through the drill.

There has also been a concerted move in recent years in the French market to film-coat low-value treatments onto high-volume crop seeds, notably oilseed rape, sunflower and maize. Similarly, film-coated cereals, oilseed rape and grasses are now available in the UK. In large part this seems to have been done for reasons of brand-image, rather than improved biological efficacy. (Indeed it is worth mentioning here that, in general, there seems to be no evidence that an even coverage of active ingredients over the surface of each seed is of any particular advantage to the biological efficacy of a pesticide treatment.) The high aesthetic standards adopted involve the use of relatively high amounts of film-coating binders, which are applied both through modified conventional continuous-throughput machines, or specialised equipment (Bazin *et al.*, 1992a). With the recent advent of treatments at high rates that need to be applied with relatively large volumes of liquid - notably the registration in France of imidacloprid for maize and sunflower seed, applied at 700 g and 1150 g formulation/100 kg seed respectively - film-coating methods involving drying become technically necessary to achieve the best application standards.

Film-coating is also widely used in western European markets to apply treatments onto previously pelleted sugar beet seed. Though the range of products used in each country is relatively small, there are a large number of possible permutations of pellet size, with fungicides (thiram or iprodione, and hymexazol) and insecticides (carbofuran, methiocarb, furathiocarb, carbosulfan, imidacloprid, or tefluthrin) at various rates (Fauchere, 1992), throughout the market as a whole. In particular, some of the insecticides are applied at high levels, to replace soil-applied granules (Dewar, 1992), and add substantially to the cost of the seed. However, because of the nature of the pelleting process, and the relatively late ordering of varieties and treatments by growers, there is not enough time in practice to produce all the required combinations on each variety of seed, without resorting to costly overproduction. Film-coating, in addition to providing an efficient, uniform and safe application method, gives pelleters a high degree of flexibility in producing to order the exact required amounts of different treatments.

Polymer binders for seed treatment, with film-forming abilities, are available from specialist suppliers, co-formulated with colorants (dyes, pigments and opacifiers) and plasticizers to improve film coverage, in liquid or powder forms, suited for different crops. Filler or absorbent "drier" powder materials to add bulk or reduce stickiness are also available. Though film-coating tends to be equated with "polymer coating", a similar coating quality can be achieved for some seeds - like onion, carrot or sugar beet - at moderate weight increases using encrusting techniques.

SEED TREATMENT EQUIPMENT

The design of equipment

Most present day treatment machinery is designed to meet the several operational criteria discussed above. These can be summarised (Jeffs &

Tuppen, 1986; Clayton, 1993) as follows:

accuracy and uniformity of application
ease of operation
the ability to handle a range of formulations and seed species absence of seed damage
easy clean-down to prevent cross contamination between seed bulks
high throughput.

Enclosure of treatment chambers and packing units to prevent contamination of the workplace with dust and sprays is now standard. Most modern equipment is automated to some degree, often with sophisticated - and expensive - features to prevent operator mistakes, including safety interlocks and alarms designed to ensure operations occur in the correct sequence, and only when all components are present. In large processing plants, controls may also regulate the automatic delivery of seed from holding bins, or to gear treatment throughput to the rate of packing.

High-throughput conventional seed treatment equipment

A review of machinery was conducted by Jeffs & Tuppen (1986), and Clayton (1993) reviewed the range of equipment currently available for treating agricultural seeds, listing the major machinery models, and their design features and capabilities, of which the following is a summary.

Almost all recent developments in treatment equipment have been on continuous-throughput systems, designed for use with liquid formulations. In these designs, the accuracy and uniformity of treatment application depend on the principles and accuracy of seed and liquid metering used, on how liquid is distributed on to the seed, and on the degree of secondary re-mixing.

Liquid metering

In newer machines, liquid flows are controlled through forms of metering pump or volumetric dosing jar systems. Application to the seed itself is typically by rotary atomisers, often cup-shaped spinning discs, or less commonly though air or airless nozzles.

Seed metering

The counterbalanced weigher bucket principle is common in older continuous throughput designs, but in newer machines higher and more even seed throughputs are achieved using the variable regulating collar system, in which seed flow over a cone is restricted by a collar seated around it.

Secondary Mixing

Almost all machines incorporate a remixing stage, most commonly using horizontal or inclined augers, with various diameters and configurations of internal mixing baffles/flights depending on seed type, or with brushes for fragile seed like pulses or maize.

Horizontal drums of different designs with a gentle mixing action, incorporating direct liquid spray systems, are used to treat species such as cotton, soya and maize that are susceptible to damage.

Film-coating equipment for low volume crops

The film-coating process uses specialised equipment to spray seeds with relatively large volumes of formulations and polymer binders, with simultaneous drying, so that the seed moisture content remains virtually unchanged throughout the treatment. Typically each seed goes through several cycles of spraying and drying within the coating equipment, and is effectively

treated with several layers of the coating materials. It is therefore possible to apply different, perhaps chemically incompatible, solutions sequentially. Depending on seed size, a critical minimum amount of time and fluid is required to film-coat satisfactorily. The key to high quality coating lies in the means and efficiency of seed mixing.

Low volume crops, and pelleted sugar beet, tend mostly to be treated on a single- or continuous- batch basis - though seed bulks may amount to several tonnes each. For film-coating vegetable seed, companies consider it appropriate to have batch equipment capable of treating a range of quantities, from 100 g or less to several hundred kg.

Spouted Beds

The earliest seed film-coating equipment was based on stirred fluidised bed principles (Halmer, 1988; Clarke, 1988). Even coverage depends on mixing seed at greater than the fluidisation point and, because of the irregular shape of many seeds, flow in the bed tends to be turbulent and erratic. Capacities are typically about 5-20 kg seed, though some commercial systems achieve continuous throughput by using fluidised beds operating in series (Horner, 1988). Scaling up beyond this point in a single batch requires a disproportionate increase in the amount of air required, which is costly. Indeed, the air flow necessary to circulate seed can cause abrasion in some species (Drew, 1989) leading, as quantities increase, to potential reduction of seed quality, or cosmetic imperfections in the coating.

Drum coaters

Fluidised bed coaters are in widespread commercial use, but the trend within the vegetable seed industry in recent years has been to use batch drum coaters, which achieve comparable results. This process is carried out in a rotating cylindrical pan equipped with spraying units, with dry warmed air drawn in through perforations in the drum wall (Halmer, 1988). The design and configuration of stirrer blades is important to ensure even gentle mixing of seed of different shapes and size, so that all seeds are equally presented to the spraying system. Because of the flow behaviour of seed in the mass, it is necessary to build a range of coaters to handle different batch capacities. In practice, individual batch drums seem to have an upper size limit of about 350 kg seed, depending on seed size. However, larger capacity batch coaters using longer drums can be produced, using a design that joins shorter drums together, so that seed is more or less constrained within each successive section, and lateral movement through the drum is minimal.

Film-coating equipment for high volume crops

Because the quantities of liquid involved in the conventional treatment of seed are relatively small, it is not necessary to dry off the applied water: either seed "self-dries" or absorbent "drying" powders may sometimes be used. Film-forming binders are often incorporated in the liquids used in conventional treatment - which is in the technical sense film-coating, though the cosmetic results may or may not be a conspicuous coated layer. However, where the amounts of material and/or binder - and hence the volume of liquid - to be applied reaches a certain point, it becomes necessary to remove some water by drying. Commercially this can be achieved by modifying existing equipment or by adding an extra drying stage (Currey & Clayton, 1987).

In recent years, continuous throughput "true" film-coaters have begun to be developed commercially (e.g. Bazin *et al.*, 1992b), based on the principle of spraying with simultaneous drying. At present, only a limited assessment of the equipment is possible. Most designs are based on perforated

drums with integral spray systems, thus resembling batch drum coaters in some respects. To deliver coatings with good loading and uniformity characteristics, these machines must ensure that seed is mixed thoroughly during its short dwell-time in the drum. As the volumes to be applied to a given seed throughput increase, the faster spray rates require higher flows of drying air, at high temperatures in some designs, which is liable to cause turbulence and may distort spraying patterns and loading efficiency.

MEASUREMENT OF LOADING EFFICIENCY AND UNIFORMITY

Analytical procedures

The standard of application is directly measured by the analytical recovery of active ingredients from representative samples of commercial lots both in terms of bulk chemical loading - on a number or a mass of seed basis - or on individual seeds to determine the seed-to-seed distribution of material. Chromatographic techniques, such as tlc, glc and now most commonly hplc, are widely used as analytical tools by the agrochemical industry, by seed treatment companies and by Institutes, both for research purposes and quality monitoring of seed treatment. In the UK, for example, because of their close historical link in the provision and maintenance of much of the cereal treatment machinery, there is a well established system in place through which the major agrochemical companies receive samples of treated bulks for recovery analysis.

Chromatographic analysis is costly and time consuming, and therefore impractical for direct quality control purposes in most treatment facilities. There is thus an advantage in developing methods that give quick, if somewhat approximate, results for on-site use. Koch & Spieles (1988) proposed using measurements of fluorescence from the dye present in cereal seed treatment formulations as an indirect method of treatment distribution. Dyes have been incorporated routinely in German seed treatment formulations for some time, and this allows such checks to be carried out simply, such as the surveys made by Koch & Spieles (1989) and Rietz (1989). Ciba have developed a validated seed loading analysis kit (SLAK), based on the dye-formulation principle, for use in on-site quality control by seed treaters (C. Martin *pers. comm.*): this system is now in commercial use in the UK for the recently approved fenpiclonil cereal seed treatment.

Pesticide recovery analysis from treated seed can be complicated by the interaction of active ingredients with each other, with coating techniques and with storage duration. Certain active ingredients can be partly degraded during extraction to their component moieties, such as benomyl to carbendazim, or some carbamate insecticides (e.g. carbosulfan, furathiocarb) to carbofuran. Much analytical investigation has been carried out on treatments applied to pelleted sugar beet seed within that industry. Huijbrechts & Gijssel (1989) showed that the actual concentrations of active ingredients recovered from pellets differed from the applied doses, as a result of decomposition, irreversible absorption or conversion to other active ingredients. Interactions with certain carbamate insecticides were found to affect the analytical recovery of the fungicide hymexazol, although no clear correlation was seen with differences in biological efficacy of the latter (Pussemier *et al.*, 1994). For some materials, such as thiram and hymexazol, there is also a decrease in recovery after periods of storage in air-dry conditions, and the degree of decrease can vary between different pelleting processes (Heijbroek *et al.*, 1993).

Sampling Considerations

Product quality analysis relies on the general principle that the sample being examined is truly representative of the whole. Commercial seed bulks are not always completely homogeneously mixed after processing and conditioning, and accordingly the seed industry operates under internationally-agreed procedures for the representative sampling of bulks for Seed Certification purposes. Bulk homogeneity can also be affected by differential settling of seeds of different size and shape, during packing and distribution to the farmer or in the seed drill itself, or by storage conditions such as humidity and temperature. It therefore becomes more difficult to obtain representative samples at points further on in the distribution chain. Agreed sampling protocols will need to be developed as measurements of the recovery of applied active ingredients at the buyer level become standard practice. Agreement will also be needed on the appropriate numbers of seeds to be used for the determination of seed-to-seed uniformity. A CIPAC method for the determination of uniformity of application of liquid seed treatment formulations will indeed soon be published.

Practical performance of seed treatment equipment

There is relatively little published on the performance of conventional seed treatment equipment. Early studies (Griffiths, 1986) revealed that overall loadings and seed-to-seed distributions of cereal grain treatments were very variable, and on average achieved less than 50% of target. The practical situation in the UK now is much improved according to a recent survey (Suett *et al.*, 1994). These authors have reported that, in analyses of 21 batches of barley seed commercially treated with ethirimol (as Ferrax), 18 batches had mean loadings greater than 75% of target, and there was also a high degree of consistency between samples taken during the processing of 14 of them. In all batches, approximately 90% of individual seeds held 50-150% of the target, expressed on a weight basis. Distribution appeared to be similarly variable in commercially treated grain in Germany where, in two surveys made using the dye-fluorescence analytical method, (1) 80% of seed lots treated with various seed dressings were found to have individual seed loadings within 50% of the mean dose (Rietz, 1989), whereas (2) half the lots had CVs >50% higher than 50% (Koch & Spieles, 1989).

Film-coating through batch coaters is capable of a greater degree of uniformity. In commercial systems with film-coated pellets or vegetable seed, it is reported that the almost all seeds have individual loadings within 30% of the mean dose (Halmer, 1988; Horner, 1988).

As already mentioned, much attention is now being paid by the buyers of treated seed to recovery analysis from pelleted sugar beet sown in certain Western European countries. Sugar companies and growers' representatives in Holland, Belgium, France and the UK now routinely analyse pesticides applied to commercial seed bulks. This is done to meet concerns that required doses have in fact been applied - both to ensure optimal biological protection for the crop, and to assure the end-user that the often expensive treatments have been applied in full measure. Analytical methods have been developed, and their repeatability has been established by inter-laboratory ring tests involving the pelleters (Heijbroek *et al.*, 1993). Indeed, over the past few years, sugar beet pelleters have moved to the point of routine in-house recovery analysis, for quality control and assurance purposes.

Batch analytical recovery is not at present a prominent quality

assurance factor in other crops. However, increasing attention to treatment quality by farmers is foreseeable as high-performance high-cost treatments become available, and perhaps as food-processors and supermarket chains seek to assure themselves about all aspects of produce quality. The far-reaching consequence of this trend could be a situation where pesticide loadings on seeds, determined by recovery analysis, become an additional condition of trade between the seed industry and its customers.

PRACTICAL LIMITATIONS ON ACHIEVING UNIFORMITY

How important is uniformity?

Theoretical considerations

It is generally accepted on theoretical grounds that all individual seeds in a treated bulk should as far as possible carry the same loadings of active ingredients. A *priori*, an equal distribution would be thought necessary to give the same degree of protection to each plant, especially with AIs that have a systemic mode of action and where crops are sown at wide spacings so that each seed is isolated from its neighbour. It should also minimise the risk of phytotoxicity. Erratic loading and seed-to-seed distribution of pesticides could have complex effects on pest and disease control, depending upon the nature of the AI, its mode of action and the soil type (Griffiths, 1986).

In practice however, seed size naturally varies to some degree within every bulk of seed, even after size-grading, and it is therefore inevitable that treatment doses applied to individual seeds will differ. Suett *et al.* (1994) report up to 20% CV in individual barley seed weights, and up to 45% CV in individual ethirimol loadings, within commercial batches. Even with commercial pelleting, though the range of seed size tends to be narrowed, seed drills can satisfactorily accommodate fairly wide size ranges: currently in Europe for example, diameter tolerances for sugar beet pellets are 1.00 or 1.25 mm above a minimum of 3.50-3.75 mm, depending on the country (Fauchere, 1992). This means that, at the extreme, seed or pellet surface area can differ by 50% or more from the smallest to the largest seed in the batch. Westwood *et al.* (1994) have shown that, in a batch of pelleted seed in which 63 out of 100 individuals had loadings within 22% of the mean, individual seed loading was highly significantly covariant with weight and surface area.

Most registered seed treatment rates are expressed on the basis of a weight or volume of formulation per weight of seed. However, the number of seeds for a given weight can differ greatly from batch to batch, or variety to variety. This makes it illogical to argue on the grounds of optimal efficacy that all seeds in a given batch must receive the same dose, if that individual-seed dose will be different from one batch to the next. This situation does not arise when treatment doses are expressed on the basis of a weight per number of seeds. Such "unit" rates are used in most European countries for the treatment of sugar beet seed, but this would not necessarily be a likely or practical proposition for other high-volume crops.

There is little doubt that it should be of concern if distribution is grossly uneven or skewed, but the situation is not so clear where %CVs are about 50% or less. Koch & Spieles (1989) propose that the proportion of cereal grains carrying between 75% and 125% of the correct amount of dressing is the most important parameter in assessing the quality of seed treatment.

Relationship to biological efficacy

There is a surprising lack of published evidence about the relationship between the degree of uniformity and biological efficacy, no doubt partly because it is a difficult matter to investigate experimentally. Suett & Maude (1988) found marked differences in the uniformity of uptake of chlorfenvinphos by individual seedlings of film-coated cabbage, carrot and onion seed. Along similar lines, Westwood *et al.* (1994) report marked differences in the concentration of imidacloprid in sugar beet cotyledons during early seedling development from seeds of different sizes.

Suett & Maude (1988) and Jukes *et al.* (1994) have developed an experimental approach that involves mixing together, in different proportions, film-coated samples that have been prepared on a batch of seed: this is done in such a way as to make up sets of experimental treatments, in which the biological efficacy of any given bulk-loading level of active ingredient can be tested at different degrees of seed-to-seed uniformity. These authors have shown that radish film-coated with chlorpyrifos or chlorfenvinphos and sown at various seed spacings, exhibited the same degree of control in conditions of severe infestation of cabbage root fly in the field, despite having seed-to-seed variabilities ranging from about 15% to 65% (as %CV). The effect was evident over a wide dose range: though the overall degree of protection was reduced at lower doses, performance of the seed treatment was unaffected by the uniformity of dosing within each mean dose level. The authors speculate that this can be best explained in terms of the tolerance distribution of the pest population in response to the insecticide dose on the seed population taken together. Minimising seed-to-seed distribution in order to optimise biological efficacy therefore may not always be necessary beyond the point already achieved in commercial practice, and at least not in the case of the control of cabbage root fly on radish.

Clearly, more research is needed about the degree of uptake of active ingredients from pesticide-treated seed, and the interaction between a pest or disease organism and the developing crop, before the importance of a high degree of uniformity can be properly assessed.

THE PROSPECTS FOR QUALITY SEED TREATMENTS

It is possible to see a long term trend in the quality of seed treatment application technology - from powder to liquid formulations, and from conventional application to film-coating. It is technically possible now to deliver as much quality in the application of a particular seed treatment as the farmer or the seed treater is prepared to pay for. What this amounts to varies between crops, and from country to country. Where the seed itself has a high value, the seed treater may be able to readily absorb the costs of applying even low value treatments using quality coating techniques.

The use of seed treatments, and the methods to apply them, are always vulnerable to changes and fluctuations in the agricultural climate. The effect of the recent reforms in the CAP, for example, has been to switch financial support for farmers from crop prices to farm incomes, on the basis of rotational set-aside of arable land. Crop economic inputs have thus been placed under greater pressure. One consequence has been to further increase the proportion of farmer-saved seed in crops like cereals and oilseed rape. Another is that it becomes more difficult for the farmer to justify using relatively expensive seed treatments when buying seed, especially where yield improvements are likely to be small. In this market situation the seed

merchant may not be able to justify the cost of using the highest quality coating techniques to apply treatments. A degree of technical compromise may then become necessary, to apply treatments in conventional rather than more expensive specialised equipment - a trend seen recently in the UK with coated cereal and oilseed rape products.

New high-performing seed treatments must offer a sufficient added value to both the farmer and the agrochemical and seed industries, in order to develop as an economical proposition, and they are likely to be costly. As such seed treatment products are introduced, agrochemical companies will need to ensure product efficacy, and control product liability, by safeguarding the quality of application. This is a situation that is easiest to manage in distribution systems where seed is treated by producers, merchants or specialist coating service companies - where application quality can be assured by formal agreements, such as Bayer's "Quality Charter" for the recent introduction of imidacloprid seed treatment. The trend in high value seed treatment technology is clearly towards efficient application of expensive AIs in factory situations, using techniques such as film-coating.

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THE INFLUENCE OF SEED TREATMENT UNIFORMITY ON THE BIOLOGICAL PERFORMANCE OF CHLORFENVINPHOS AND CHLORPYRIFOS

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ABSTRACT

Radish seeds were treated with insecticides at 3 dose levels and 4 levels of between-seed uniformity and were field-sown at 3 different spacings. Damage by cabbage root fly larvae was influenced by dose and seed spacing but not by the level of treatment uniformity.

INTRODUCTION

To optimise the biological efficacy of seed treatments, dosing of individual seeds should be as uniform as possible. However, in a field study with insecticide treated radish seed, similar high levels of protection were achieved with treatments having wide-ranging between-seed uniformities (Suett & Maude, 1988). That study, with a single insecticide and single crop spacing, had limited implications. The results of a more extensive investigation, using reduced doses, different seed spacings and two insecticides, are presented in this paper.

MATERIALS AND METHODS

Radish seeds were treated with chlorfenvinphos and chlorpyrifos at various doses. Seed batches were then mixed in different proportions in order to achieve mean target doses of 3, 6 and 12 g AI/kg and target between-seed uniformities of 15, 25, 38 and 50 %CV. Each of these 24 treatments was field sown at spacings of 2.5, 5 and 10 cm.

Seed treatment

Radish seeds, cv French Breakfast (2.75 - 3.00 mm diameter), were film coated at Horticulture Research International, Wellesbourne (HRI-W) in a fluidised-bed unit (Maude & Suett, 1986). Chlorfenvinphos (50% AI wettable powder, Shell Agrochemicals UK Ltd.) and chlorpyrifos (25% AI wettable powder, Dow Agriculture UK Ltd.) were applied at target doses of 1, 2, 3, 4, 5, 6, 8, 10, 12, 16 and 20 g AI/kg. A polymer sticker (polyvinylacetate, Vinamul formulation R18160) was used at a rate of 25 g/kg for all applications. Each treatment was applied over 15 min at a bed temperature of 30°C.

Seed Mixing

In order to achieve a range of between-seed uniformities at the different mean dose levels required, batches of seeds at different doses were mixed in the fluidised-bed unit at 25°C for 1 minute. The compositions of the required mixtures were calculated using a model which assumed a normal distribution of seed doses within each batch and, on the evidence of previous studies, an inherent level of between-seed treatment uniformity of CV = 15%. Table 1 shows the composition of mixtures required to give target levels of variation. The doses a, b, c, d, and e were 1, 2, 3, 4 and 5 g AI/kg to give a mean

TABLE 1. Composition of seed mixtures required to achieve different levels of dose uniformity, expressed as percentage coefficient of variation (%CV).

CV (%)	Seed dose (% in mixture) a	b	c	d	e
15	0	0	100	0	0
25	0	15	65	20	0
38	5	20	25	25	25
50	20	20	20	20	20

mixture dose of 3 g AI/kg and were increased proportionally to give mean doses of 6 and 12 g AI/kg.

Residue Analysis

The mean doses of the seed batches treated initially were determined by extracting 3 replicate samples of 100 seeds per treatment with methanol (100 ml). The mean doses and between-seed variabilities of each mixture were assessed by extracting 50 single seeds per treatment with methanol (1 ml per seed).

Solution concentrations were determined by hplc using a Spectra Physics model 8810 pump with a 25 cm Spherisorb ODS II cartridge column. For chlorpyrifos the mobile phase was water + methanol (5 + 95, 1.3 ml/min) and for chlorfenvinphos the mobile phase was water + methanol (15 + 85, 1.5 ml/min). Retention times were 3.4 min and 3.3 min respectively. Detection was by Cecil 2112 variable wavelength uv detector at 220nm. All samples were injected automatically using a Spectra Physics 8775 autosampler. Peak areas were measured by a Spectra Physics 4270 computing integrator and were quantified by comparison with external standards.

Field performance

The experiment was established on a light sandy-loam soil at HRI-W in July 1988. Separate areas were allocated to each of the 3 seed spacings so

TABLE 2. Insecticide doses achieved in initial batches.

Target dose (g AI/kg)	Achieved dose g AI/kg (± sd) Chlorfenvinphos	Chlorpyrifos
1	1.27 (0.04)	0.90 (0.01)
2	2.14 (0.22)	1.90 (0.07)
3	3.01 (0.11)	2.88 (0.02)
4	4.49 (0.12)	3.79 (0.02)
5	5.42 (0.15)	4.50 (0.02)
6	6.60 (0.15)	5.91 (0.01)
8	9.50 (0.33)	7.78 (0.00)
10	11.24 (0.35)	9.36 (0.10)
12	12.60 (0.39)	11.42 (0.04)
16	14.32 (0.25)	14.80 (0.06)
20	23.10 (0.47)	18.89 (0.08)

that comparison of treatments would not be affected by possible differences in attractiveness of different plant densities to cabbage root fly. Each area contained 3 replicate blocks of 6 randomised insecticide/dose combinations. Within each of these plots, 4 treated and 1 untreated sub-plot were randomised, each sub-plot comprising a single row of 130 seeds. Treatments were arranged in a split plot design with uniformity variates as sub-plots. Each plot therefore contained all 4 variabilities of a single dose of one insecticide.

The seeds were hand-sown to a depth of 2 cm on 11-14 July and the mature plants, excluding the first 20 and last 20 in each row, were harvested on 11-12 August, 5 weeks after sowing. Roots were washed and assessed for the presence or absence of damage caused by cabbage root fly (*Delia radicum*) larvae. Crop stand was assessed at harvest by comparison of the numbers of roots in the samples taken for damage assessment.

TABLE 3. Mean doses (g AI/kg) and between-seed uniformities (% CV) achieved at the different target doses.

Dose (g AI/kg)			% CV		
Target	Chlorfenvinphos	Chlorpyrifos	Target	Chlorfenvinphos	Chlorpyrifos
3	2.44	2.94	15	14.4	15.8
3	2.50	3.06	25	36.1	29.0
3	3.27	4.42	38	42.5	41.9
3	2.96	3.67	50	49.9	60.0
6	6.24	6.47	15	15.3	17.2
6	6.31	6.28	25	21.6	25.0
6	7.91	6.33	38	34.8	42.0
6	6.56	5.92	50	47.2	65.3
12	9.95	12.5	15	21.1	11.5
12	10.7	13.6	25	28.3	27.6
12	14.6	16.0	38	47.3	30.3
12	13.4	12.8	50	50.7	42.7

RESULTS

Seed analyses

The mean doses of the initial batches of chlorfenvinphos and chlorpyrifos treated seeds were within 30% and 11% respectively of target doses (Table 2). The mean doses of the subsequent mixtures are shown in Table 3. Between-seed variabilities of the mixed seeds ranged from 14.4% to 50.7% for the chlorfenvinphos treated seeds and 15.5% to 65.3% for the chlorpyrifos treated seeds. Mean insecticide loadings and between-seed variabilities were within 25% of target in 21 out of the 24 mixtures. Results are therefore presented on the basis of the initial target doses and %CV.

Field performance

Analysis of variance of the numbers of roots harvested from each treatment (Table 4) confirmed that there were no significant differences

TABLE 4. The mean numbers of radish roots at harvest.

Target dose (g AI/kg)	Target CV (%)	Mean number of roots Chlorfenvinphos	Chlorpyrifos	Untreated
Untreated				91
3	15	89	89	
3	25	94	98	
3	38	87	93	
3	50	94	95	
6	15	86	92	
6	25	88	92	
6	38	87	92	
6	50	84	93	
12	15	86	92	
12	25	91	89	
12	38	89	92	
12	50	86	92	

p = 0.05) in crop-stand between any of the treatments and the untreated radish. There was therefore no evidence of phytotoxic effects even at the largest dose of the more phytotoxic chlorfenvinphos (Thompson *et al.*, 1980).

There was a high level of insect infestation with the proportion of attacked roots in the untreated row in each plot ranging from 62-90% at 2.5 cm spacing up to 69-95% at 10 cm spacing and the random nature of this attack between untreated subplots suggested that they may not be a reliable estimation of the level of attack within a plot. Data from untreated subplots was therefore not used as a baseline when comparing data from the treated subplots. Nevertheless, the split plot experimental design meant that comparisons between levels of treatment uniformity were the least likely to be affected by different levels of insect attack across the experiment. The percentage of unattacked roots at the different doses, uniformities and spacing are shown in Figure 1. Analyses of variance using an angular trans-

TABLE 5. Comparison of insecticide performance at 3 seed spacings by the estimated percentage reduction in the numbers of cabbage root fly larvae.

		Estimated % reduction in numbers of larvae (± sd)		
Seed spacing (cm)		2.5	5.0	10
Insecticide	g AI/kg			
chlorfenvinphos	3	81.9 (6.8)	78.6 (8.7)	70.4 (10.2)
chlorfenvinphos	6	92.3 (5.3)	90.6 (6.0)	87.5 (9.5)
chlorfenvinphos	12	92.9 (5.1)	95.8 (6.0)	96.6 (2.8)
chlorpyrifos	3	75.2 (14.2)	74.8 (15.1)	58.9 (7.5)
chlorpyrifos	6	80.3 (11.0)	80.6 (12.9)	71.5 (10.2)
chlorpyrifos	12	92.9 (5.5)	85.4 (6.7)	79.0 (10.4)

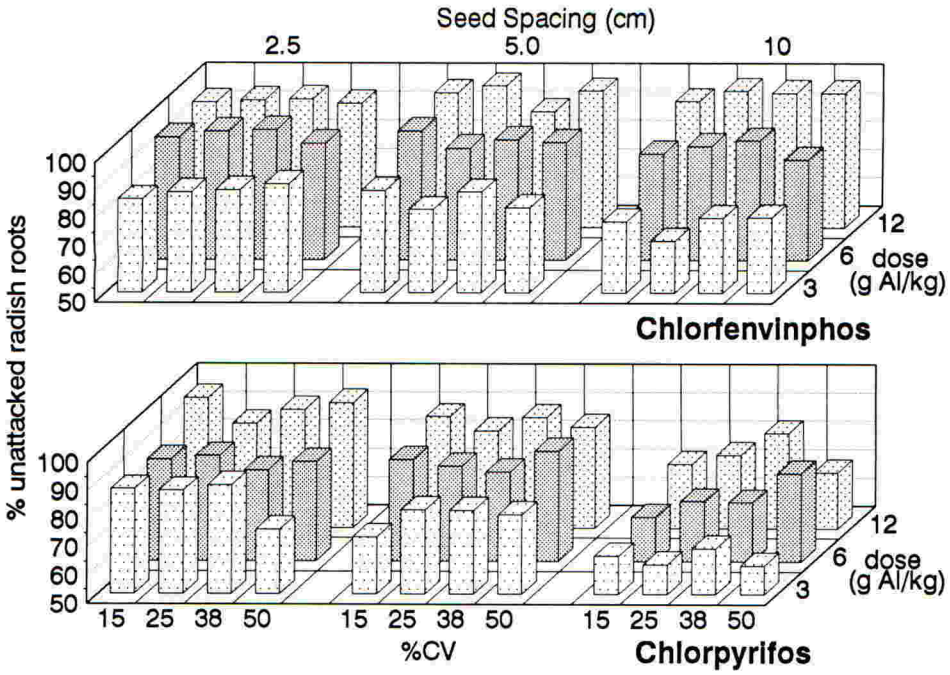

Figure 1. The % of unattacked radish roots at 3 seed spacings, 3 doses and 4 levels of seed treatment uniformity.

formation on the percentage of attacked roots in each subplot showed that, within each spacing, chlorfenvinphos performed significantly better than chlorpyrifos ($p < 0.05$) and that larval attack decreased with increasing dose. However, there was no effect of, nor interaction with, treatment uniformity ($p = 0.05$).

For each plant spacing, the mean of all the untreated plots was used as a baseline in the estimation of the percentage reduction in the numbers of cabbage root fly larvae (Wheatley & Freeman, 1982) by the various treatments measured over all the uniformity treatments and the results are presented in Table 5. All treatments (except the smallest dose of chlorpyrifos at 10 cm spacing) reduced the numbers of larvae by more than 70% and chlorfenvinphos at 6 and 12 g AI/kg and chlorpyrifos at 12 g AI/kg (except at 10 cm spacing) reduced numbers of larvae by more than 85%.

DISCUSSION

The study supported the earlier suggestion (Suett and Maude, 1988) that large variations in insecticide loadings on individual seeds have relatively little effect on the mean efficacy of a treatment against cabbage root fly. Although the performance of both insecticides was influenced significantly by the mean dose level, as well as by plant spacing, performances within each of these variables were unaffected by the uniformity of dosing within each mean dose level. It had been suggested that the failure of the initial study (Suett & Maude, 1988) to reveal differences in performance resulting from treatment uniformity differences might be ascribed to the similarly high

efficacies of the 15 and 30 g chlorpyrifos/kg doses used. The present study showed that, even at doses as small as 3 g AI/kg (<1% of the recommended linear rate), the effects of treatment uniformity differences were negligible despite a significant reduction in the overall efficacy of the mean dose. It was evident also that the effects of uniformity differences were not being suppressed by interactions between adjacent seeds, since mean uniformities performed similarly at all three spacings.

The lack of effect of differences in treatment uniformity can be explained, at least partially, by considering the tolerance distribution of the pest population (Finney, 1971) in conjunction with insecticide dose response. The experimental observations can be justified mathematically on the basis of the underlying mechanisms described previously (Phelps & Thompson, 1983). Thus the expected number of attacked roots in a row is the sum of the probabilities of attack of individual roots. For any given mean dose, therefore, the increased probability of attack on roots receiving low doses is compensated for by the decreased probability of attack at high doses. Numerical simulations based on appropriate response curves for the present study confirmed that the range of CVs tested would have little effect on practical performance.

The study showed once again that effective control of soil-inhabiting insect pests can be achieved using greatly-reduced doses of insecticides. It would now seem also that non-uniformity of treatment may not threaten the efficacy of insecticidal seed treatments as much as had been feared.

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THE LIFE CYCLE OF A SEED TREATMENT FORMULATION DEVELOPMENT

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ABSTRACT

In addition to a short introduction to the development of seed treatment formulations, the life cycle of an active ingredient and its formulations are presented. The development cycle, starting from an early stage of screening up to market introduction, is discussed using a new seed treatment product as an example. Interactions between departments involved in this development, such as process development, analytical development, toxicology, registration, sales, product development and relationships to third parties, is illustrated.

INTRODUCTION

The history of formulation development for seed treatment is strongly influenced by the development of new technologies and attempts to increase user safety. In addition to presenting the benefits of seed treatment, and the special characteristics of seed treatment formulations, the paper will put special emphasis on the factors during the life-cycle, which could have an unpredictable influence on the progress of the development of a seed treatment formulation. Furthermore, an estimation of the time schedules for the development of an active ingredient for seed treatment, from discovery up to first sales, will be illustrated.

HISTORY AND BENEFITS OF SEED TREATMENT

Since ancient times, plant protection agents have been used to control pests which attack crops, stored foods, domestic livestock, arable lands, domiciles, and the human body. Homer (c.1000 B.C.) refers in the Odyssey to the "pest-averting sulfur" and Cato (c.200 B.C.) describes the boiling of bitumen (asphalt) to produce insecticidal fumes which controlled pests in vineyards. The ancient Egyptians employed fumigation to reduce infestation in stored grains. From the beginning of agriculture, farmers were always looking for methods to protect the seeds for the crop.

For many years, it was common practice to use mercury compounds, but this has since been banned, due to the ecological and toxicological risks. In the last few years, seed treatment has become an important segment of the plant protection market, and many agrochemical companies started to set up development groups, with special emphasis on the development of formulations and application technologies for seed treatment uses.

In comparison with conventional chemical treatments, seed treatment offers many advantages. Whereas in other methods of controlling seedborne diseases, large amounts of products had to be sprayed or otherwise applied, seed treatment makes it possible to reduce the amount of active ingredient which is applied. With new methods, the required amount of active ingredient can be reduced by up to 90%, compared with conventional application.

Being in close contact to the seed kernel itself, the active ingredient is located di-

rectly at the place where it is needed and forms a type of 'survival bag' for the young seedling. This can control early season diseases and soil pests, as well as seedborne infections, and may allow the farmer to reduce the number of foliar sprays. Last but not least, due to sophisticated new formulation technologies and new methods of application, the risk of the farmer being exposed to products is reduced, as well as the risks for contamination of the environment. Seed treatment can clearly be considered as a very safe method for man, as well as for nature.

Seed Treatment Formulation Types

With the increased need for safe formulations, formulation types and the methods for application for seed treatment, have become more and more sophisticated.

The first and oldest types of formulations for seed treatment were all powder based formulations. Dust formulations for seed treatment (DS) are the most common types of classical formulations. They consist of an active ingredient and some inorganic carriers. The application of these dusts is very inconvenient for the user and the quality of the treatment is poor, because much of the product is lost during the process of application. This type of formulation is still of importance in some less developed countries, where modern application machinery is too expensive, or not available. The first step towards safer formulation types was the development of wettable powders for seed treatment (WS), where the addition of special additives made the preparation of water based slurries possible. The dust is reduced and the application properties improved, resulting in less abrasion, and significantly less risk of contamination for the operator.

Modern formulations are all liquid - mainly water based - formulations, although the oldest types are true solutions (LS). In this case, the active ingredient is dissolved, for example in water. Whenever possible, organic solvents are avoided due to the potential risk of phytotoxicity to the seeds. In cool climates, where cold stability could be a problem, solvents are chosen very carefully, in line with ecological safety aspects.

Emulsions (ES), which contain respectively small liquid droplets, flowables (FS), which contain finely ground solid particles, and capsule suspensions (CS), which contain small polymer balls, filled with active ingredient, are all stabilised by the same special surfactant systems. Emulsions are prepared by using special mixing equipment, where knives, rotating at a very high r.p.m., produce small particles. Capsule Suspensions are formed by a chemical reaction at the interface of small emulsion droplets of liquid or dissolved active ingredient, which are formed in a preliminary step, where a fine membrane, forming the wall of the polymer balls, is produced by interfacial-polymerisation with the surrounding media. By adjusting the ratio of the polymerisation components, the thickness of the polymer walls, and thus the release characteristics, can be varied.
By encapsulation of furathiocarb for example, the toxicity of the formulation PROMET® 400 CS can be reduced, in comparison to that of the active ingredient, from an LD_{50} of 30 mg/kg to an LD_{50} of 3000 mg/kg (rat) - significantly increasing the safety for the user.

The formulation to be chosen for a particular active ingredient is a function of the physical properties of the active ingredient, as well as a function of its uses. Different application machinery used for various types of seeds may neccesarily require different types of formulations, or at least different formulation properties.

THE BOTTLENECK IN DEVELOPMENT

The screening for potential active ingredients for fungicides and insecticides for seed treatment starts at a very early stage in research, where thousands of new compounds are screened, with the aid of several standard tests, for their activities against the main dis-

eases and pests. Only a small proportion show sufficient potential activity to proceed to the next stage, where a closer study is made of the new compounds. After a second evaluation, active ingredients are selected for testing in the field. Only a few dozen are left at this stage, about which time, chemical research is looking for the first routes of active ingredient production, and special research formulations are prepared for the first time. At the next stage of development, chemical production processes are developed and optimised.

Only a handful of active ingredients a year reach the final development stage, and even fewer of these are released eventually for sales. At this time, a formulation and packaging concept is established. After collecting enough data, registration is initiated. Complete product dossiers are submitted to the competent authorities, which include studies on toxicity, environmental behaviour, safety and ecological aspects. To save development time, different investigations have to be carried out simultaneously. For example, formulation development may have to commence before the manufacturing procedure for the chemical itself has been optimised fully.

TIME SCHEDULES

The complete development of a new product takes about ten years. During this period, work is carried out simultaneously in research and development, analytics, chemistry and product development. Toxicological studies and registration procedures are also ongoing. These studies and registration are largely independent of product development but tox and registration could have a profound influence on the life-time of the product.

Factors which affect formulation

Adverse ecological behaviour, toxicological results and sometimes formulation issues may influence, or even cause a sudden halt in development. But development is not always stopped - sometimes formulations may have an effect on this decision. There are possibilities - as mentioned before in the LD_{50}-reduction of the PROMET® formulation, where, by using adequate formulation technology, the toxicological effects could be minimised. This entails experiments with special formulation technologies, such as encapsulation.

If changes in manufacturing procedures of the active ingredient become necessary, due to environmental or cost aspects, these might cause problems in formulation development. Even slight changes in the specification, such as the spectra of by-products, might cause incompatibilities with special surfactant systems, making the development of new formulation variants necessary.

Last but not least, changes in the quality of the components used in the different formulations, might be an additional source of problems in the life-cycle of a formulation. If, for example, a manufacturer of a special additive decides to change the specification of one of his products, this might lead to difficulties in formulation development. It is even more complicated: some suppliers will not disclose the composition of their surfactants. If the supplier then subsequently decides to change, either the composition or the production process, difficulties in product development can occur.

The fenpiclonil example

An example of the interactions between chemical and product development, as well as the relationship to suppliers of auxiliaries, has been the development of fenpiclonil - BERET® - flowables. A new chemical class of fungicides, the phenylpyrroles, was introduced for seed treatment, using new and sophisticated chemical processes, as well as

modern formulation types.

Continuous improvements of the chemical process, resulting from the learning progress in handling that new class of fungicides, led to an active ingredient with very high purity. In the meantime, product development planned to produce several tons of formulation. A scale-up production in the pilot plant using the new AI quality, led to severe thickening of the flowable. An intensive testing program revealed that the active ingredient, which had unexpectedly high purity, interacted with the antifoam agent, and this caused the thickening. By changing the antifoam agent, re-testing the physico/chemical stability and re-testing the application properties of the product, as well as supplying the necessary documents, the product could be produced on time. Only application properties had changed slightly, due to the use of a minor amount of additive (<0.5 %).
Finally, the manufacturer of the new antifoam agent guaranteed a shelf life of only 6 months for his product. When out-of-date antifoam-agent was used in manufacturing, separate small additive droplets appeared on the surface of the formulation. This was not well received by the customers. This problem was solved by changes in the specifications of the additive and careful checking-procedures of the new antifoam batch.
A second adaptation in the manufacturing process of the active ingredient, which allowed recycling of the organic solvent used as medium of reaction, had no negative side effects in formulation development.

CONCLUSIONS

The above examples clearly demonstrate factors for success and the necessity for total communication of all involved parties, during the whole development life-cycle of a product, in order to achieve a fast and successful market introduction.

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TEMPERATURE EFFECTS ON OSMOTIC PRIMING OF LEEK SEEDS

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ABSTRACT

Leek seeds were osmotically primed in polyethylene glycol solutions in priming bioreactors sparged with air. Combinations of a range of temperatures from 5 to 30°C in steps of 5°C and priming durations from 5 to 30 days were used to give 6 treatments each of thermal time of 150 day-degrees. During the treatment samples of seeds were removed at about 30 day-degrees intervals including a final sample of fully primed seeds. These samples were surface dried only and were assessed by a germination test. The reminder of the fully primed seeds were dried in thin layers for 2 days in an air flow at 15°C and then tested for germination. These seeds were retested after 3 months in store.

There were no differences in percentage germination between the different temperature/time treatments or compared with untreated seeds. However, only seeds treated at temperatures lower than 20°C showed significant improvements in terms of reduced germination time; the range of temperatures from 5 to 15°C gave the best priming performance which was almost equal for both surface dried and dried seeds, with the 15°C treatment being the only one to reduce the spread of germination times. These effects were retained in the dried seeds during a storage period of 3 months but the proportion of abnormal seedlings increased significantly, especially for the longer treatments.

INTRODUCTION

Osmotic priming of seeds in polyethylene glycol (PEG 6000; -1.5 MPa) solutions increases the rate and synchrony of germination (Heydecker, 1977; Heydecker and Coolbear,1977) and may also improve emergence characteristics, plant fresh weight and final yield for a number of species (Bradford, 1986). The literature on priming (Heydecker and Coolbear,1977; Bradford, 1986) mainly reports the effects of priming and of drying seeds using small scale, laboratory methods. These include priming in Petri dishes, on filter paper moistened with suitable PEG (or salt) solution, with thin-layer drying in near-ambient air temperatures, either on the bench in an open environment or in temperature-controlled drying cabinets. However, recently there has been significant development of methods for priming and drying large quantities of seeds (Nienow and Brocklehurst, 1987; Nienow et al, 1991;

Bujalski and Nienow, 1991; 1992; Bujalski et al., 1991b; 1992). The effects of priming in different bioreactors and drying in various ways on the storage potential of leek seeds following conventional storage have also been assessed (Maude et al., 1993a, b).

This paper describes the priming of leek (*Allium porrum* L.) seeds in stirred bioreactors and the influence of the temperature and duration of priming on the intermediate and final treatment effects. All treatments were subjected to priming temperature and duration equivalents of 150 degree-days (0°C base). This approach was adopted on the basis of analogy with the response of seed germination to constant heat sum (also called thermal time) (Bierhuizen and Wagenvoort, 1974) and to constant temperature and osmotic potential i.e. the hydrothermal time to germination concepts (Gummerson, 1986). 150 day-degrees was selected because of the success of priming carried out for 10 days at 15°C (Gray et al., 1991) and because such heat sum constitutes only about 70% of the amount of a thermal time found to be necessary for leek seed germination at constant temperature (Bierhuizen and Wagenvoort, 1974), thus preventing seed from undesired germination during the priming process.

MATERIALS AND METHODS

Seeds and Storage

Leek seed cv Verina raised at Luddington EHS in 1988 was used. Seeds were kept in a seed store at 10°C and 40% r.h. prior to use and after completion of the treatments.

Germination tests and seedling assessments

In all experiments, four replicates, each of 50 seeds from each treatment, were laid out as a randomised block on a Copenhagen tank at 15°C under 16 h light/8 h dark regime. Germination was counted daily for 14 days then seedlings were removed and assessed under a magnifying lens for normal and abnormal development (Beckendam and Grob, 1979).

Statistical analysis of the data

Germination and presence of abnormal seedlings were calculated as a percentage of the number of seeds sown. Spread of germination times was expressed as log variance of time to germination. The data were subjected to analysis of variance and, where appropriate, the angular transformation of the data was used for the analysis.

Priming

Seeds (140 g) were osmotically primed in 1.4 l PEG 6000 solutions (at concentration of 100 g seed/l) in bioreactors sparged with 700 ml air/min. The PEG concentration was adjusted to give solutions of -1.5 MPa osmotic potentials (Michel, 1983) the respective treatment temperature. A range of temperatures (5 to 30°C in steps of 5°C) and priming durations (5 to 30 days), giving the thermal time of 150 day-degrees, was tested. Seeds were kept in suspension by the action of a double impeller system (bottom impeller pumping upwards and the upper one downwards) at 400 rpm. This geometry (baffled vessel, two impellers of

diameter equal to half of the vessel diameter, pumping in the opposite directions, variable speed motor capable of running in either direction) gives the greatest flexibility for seed suspension (Chapman et al., 1983) and also good results for air dispersion (Kuboi and Nienow, 1982). The dissolved oxygen level in the priming liquid was kept above 70% saturation throughout the treatment periods, thus ensuring consistent priming responses (Bujalski et al., 1991a; 1993). Samples of about 300 seeds were removed at approximately 30 day-degree intervals throughout the treatment period with a final sample taken when the seeds were fully primed. All of these were surface dried only and were assessed immediately for germination. The reminder of fully primed samples (120 g each) were dried in thin layers for 2 days in an air flow at 15°C to their original moisture content. These seeds were then tested for germination and the test was repeated after the seeds had been kept for three months in a seed store.

RESULTS AND DISCUSSION

There were no differences in percentage germination between comparable temperature-time treatments at either the intermediate (data not shown) or final sample assessments. Only seeds treated at 30°C for five days and dried showed a significant ($P<0.05$) decrease in germination and the three months storage had no further effect (Table 1).

TABLE 1. Effects of thermal time of 150 day-degrees during priming treatments at different temperature/time combinations on dried seeds germinated immediately and after three months storage.

Priming treatments	Tested					
	Immediately after priming and drying			After 3 months storage		
	%G	Spread (hrs)	%A	%G	Spread (hrs)	%A
Untreated seeds	97(82)	6.65	11	97(82)	6.65	11
30°C for 5 days	91(72)	6.47	13	91(73)	6.51	13
25°C for 6 days	95(77)	6.79	12	97(81)	6.32	9
20°C for 7.5 days	95(78)	6.67	13	94(76)	6.42	24
Untreated seeds	96(78)	6.34	15	96(78)	6.34	15
15°C for 10 days	95(77)	5.35	20	97(82)	5.69	27
10°C for 15 days	95(79)	6.24	21	95(77)	5.95	27
5°C for 30 days	94(76)	6.93	24	94(75)	5.87	33
LSD ($P<0.05$)	3.9(6.3)	0.532	5.7	3.9(6.3)	0.532	5.7

%G = % germination; Spread = log (variance of germination times); %A = % abnormals; (angularly transformed data in brackets).

The development of the response in terms of reducing the mean germination time due to priming at different temperatures as a function of thermal time is shown in Figure 1.

Treatments carried out at 25 and 30°C produced almost no priming effect, the reduction in the mean germination time being accounted for by the fact that these samples which were surface dried only had the advantage over the controls of being almost fully imbibed when set for the germination test.

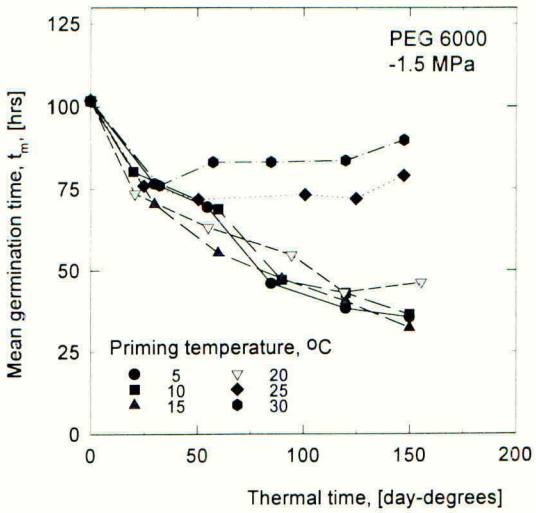

FIGURE 1. Priming responses of leek seeds vs. thermal time.

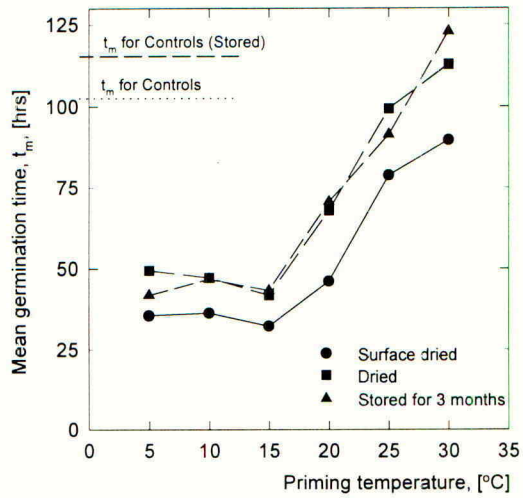

FIGURE 2. Responses for primed seeds either surface dried, dried and dried and stored.

There were significant ($P<0.001$) differences between treatments in mean germination times for fully primed seeds, ranging from about 34 hrs for seeds treated at 5 to 15°C and

surface dried to 112 hrs for those primed at 30°C and dried (Figure 2). Similar effects were obtained after three months storage (Figure 2). The spread of germination times (log variance values) was significantly reduced only for seeds fully primed at 15°C which was 4.66 when surface dried (data not shown) and this effect was retained after drying and storage (Table 1). The long treatments at 10°C and 5°C showed significant increases in abnormal seedlings after drying and also further increases after the storage period. There was also a small increase after storage for the 15°C and 20°C treatments (Table 1).

CONCLUSIONS

The reduction in mean germination time by priming was constant and greatest for equivalent thermal time treatments at temperatures less than 20°C, with the overall optimum response at a temperature of 15°C due to the reduction in the spread of the germination times. However, all these treatments also resulted in an increased proportion of abnormal seedlings, especially after storage. The longer the treatment period, the more severe was the deterioration. The effect of storage accords well with earlier studies (Maude et al., 1993a, b). However, the problem here appeared more severe and occured without storage for the longer treatments, possibly because of the prolonged shear and mechanical forces of the impellers acting on the seeds.

Clearly, though seeds can be successfully primed in bulk, prolonged low temperature treatments can be deleterious and the effect also magnifies the reduction in storage life. On the other hand, high temperatures do not lead to effective priming. This work suggests that there is an optimum working temperature for bulk seed priming.

ACKNOWLEDGEMENTS

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THE PHYSIOLOGICAL ADVANCEMENT OF SUGAR-BEET SEEDS

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ABSTRACT

Since sugar-beet yields are limited by the amount of solar radiation intercepted, particularly during May and June, treatments to stimulate earlier seedling emergence should be advantageous. However, earliness of sowing is limited by exposure to cool weather which vernalizes the plants and induces 'bolting'. A treatment which both advances and devernalizes seeds has been developed which allows sowing to be brought forward safely by about 10 days. Annual experiments since 1988 show that sugar yield was increased by 0.19 t/ha as a consequence of seed advancement giving more rapid emergence and by 0.042 t/ha/day as a result of earlier sowing, In practice, the improvement which was produced by advancing and devernalizing beet seeds was *c* 0.35 t/ha, about 5% of the average national yield. A 3-year study indicated that advanced seeds can be stored for at least 3 years without any major reduction in their performance.

INTRODUCTION

Two main factors determine the earliest date at which the sugar-beet seeds should be sown in the UK. Firstly, if seeds are sown too early the developing seedlings can be exposed to cool temperatures which induce bolting in the growing crop. This creates a weed beet problem and can result in considerable yield loss (Longden, 1991). Data from the 1970s indicated that most bolting resistant varieties should not be sown before 20 March (Jaggard *et al*, 1983) and although current varieties are slightly more bolting-tolerant, this continues to be a guideline for sugar-beet farmers. Secondly, cold, wet conditions in early spring can reduce the proportion of seeds which will produce established plants. These factors combine to give crops in which the ability to intercept solar radiation in May and June is restricted, thus limiting yield. Consequently, seed advancement treatments have been sought which will accelerate seed germination and seedling development without introducing the risk of bolting and flowering in the growing crop. Early work by Longden (1971), based on hardening techniques used on carrot seeds, demonstrated the potential to shorten the period between sowing and germination. Although the effects on yield were not examined, positive responses of developing seedlings indicated the potential benefit for the UK crop if bolting could be controlled. Between 1984 and 1989 seed treatments were developed at Broom's Barn Experimental Station which both devernalized seeds, thereby reducing the number of bolters, and improved seedling establishment (Durrant & Jaggard, 1988).

DEVELOPMENT OF THE SEED ADVANCEMENT TREATMENT

Initial methods of advancement, which involved steeping seeds in water followed by incubation with NaCl solution, caused germination and hypocotyl extension to occur sooner than with either untreated or water-steeped seeds in laboratory tests. Seeds given a 6-day advancement treatment and sown in early March 1984 emerged about 12 days earlier in the field than untreated seeds, plant establishment was higher and bolting was reduced from 33 to 27% (Durrant & Jaggard, 1988). Subsequent experiments testing the effect of seed water content, duration of treatment and incubation temperature showed that, under restricted moisture conditions in the absence of NaCl, seeds could be advanced for at least 5 days at 25°C without deleterious effects on germination or hypocotyl growth (Durrant & Mash, 1990).

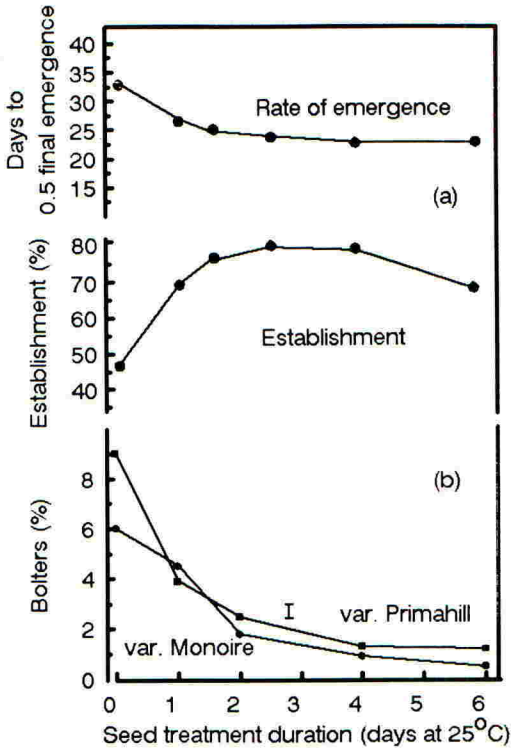

FIGURE 1. Relationship between seed treatment duration at 25°C on a) plant establishment and time required for half of the final number of seedlings to emerge from a 13 March sowing in 1987 and b) the number of bolters on 15 October from a 17 March sowing in 1986. (Durrant & Mash, 1990).

Based on the results of experiments carried out in 1986 and 1987 (Figure 1), an advancement treatment of 4 days was identified as being necessary for maximum benefit in terms of improved emergence and establishment and decreased bolting. The prolonged, high temperature devernalization treatment makes use of the principles of hydro-thermal time (Gummerson, 1986). The seeds are physiologically active during the high temperature treatment but do not germinate because their water content is close to the base water potential for germination.

EXPERIMENTS WITH ADVANCED SEEDS

The advancement treatment used consisted of steeping sugar-beet seeds in an agitated 0.2% (w/v) aqueous suspension of thiram at 25°C for 8 h, partially drying to 124% of the original weight, incubating at 25°C for 88 h and then air-drying (ADV). Control seeds were steeped in thiram for 8 h then air dried (TS). The ratio of seeds to thiram suspension was 1:4 (w/v). The TS treatment is analogous to the current commercial treatment and the ADV treatment has now been slightly modified for commercial testing.

Field experiments were carried out between 1988 and 1991 with seeds of the varieties Amethyst (1988/90) and Celt (1991), pelleted by Germain's (UK) Limited. Over the 4 years, 11 sowings were made (Durrant *et al*, 1993). Overall, seed treatment had little effect on the proportion of seeds giving established plants but establishment increased consistently as sowing was delayed in March. Advancement consistently reduced the time between sowing and emergence; this was about 9 days from early March sowings and between 1 and 4 days when seeds were sown in early April The benefits from advancement showed considerable seasonal variation but, on average, ADV seeds needed 4 fewer days for half the seedlings to emerge than TS seeds. Results from a similar experiment in 1993 are presented in Figure 2 in which, although the advancement treatment provided a maximum benefit of about 3 days earlier emergence from March sowings, the consistency of the advancement effect overall was well demonstrated.

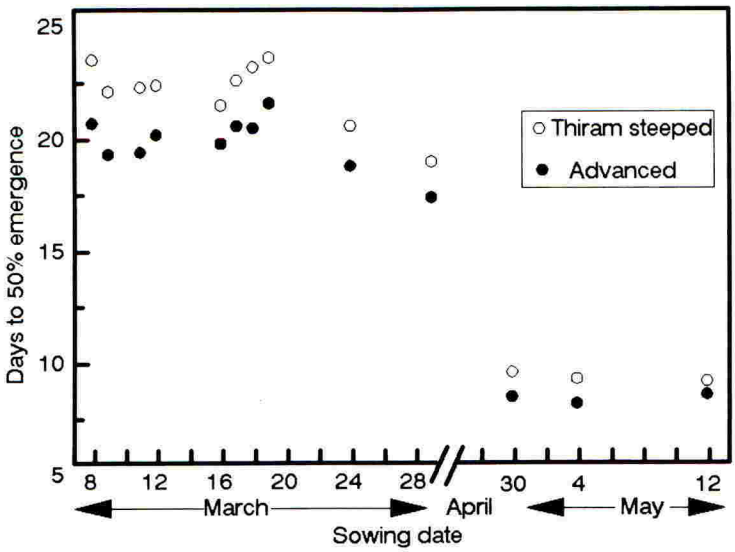

FIGURE 2. The effect of seed advancement on the number of days to 50% emergence from a range of sowing dates in 1993 (data courtesy of Germain's UK Ltd.).

The range of years, seed treatments and sowing dates had large effects on the proportion of land covered by leaves. Seed advancement increased ground cover by between 1% and 6% and the ability to sow advanced seeds earlier without the risk of bolting provided an extra benefit in this respect, as shown for 1990 (Figure 3).

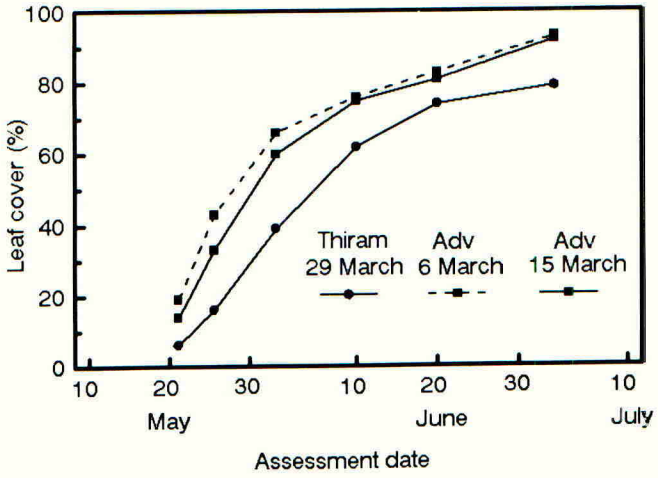

FIGURE 3. Effect of combination of early sowing and seed advancement on leaf cover, 1990

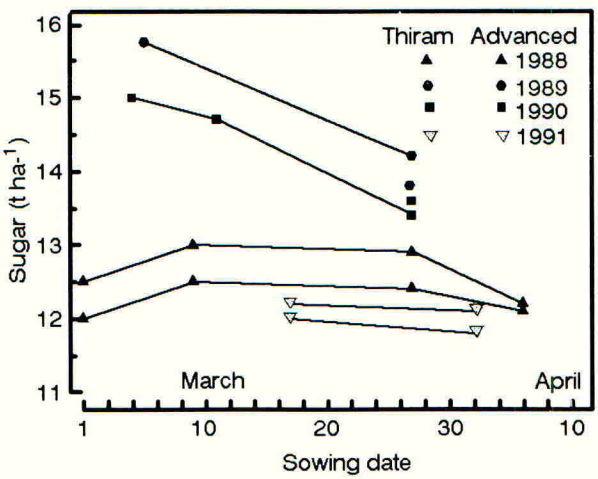

FIGURE 4. Effect of seed treatment and sowing date on sugar yield, 1988-1991.

The amount of solar radiation intercepted by the crop in May and June (1988-1991) ranged between 155 and 485 MJ/m^2; this related closely to the effects of seed treatments and sowing dates on canopy development by the end of May. In 1988, when TS seeds were sown on 2 March or 9 March, 20% and 9% of the plants respectively bolted by late October; this figure was halved by the advancement treatments, In other years, very few plants bolted from any of the seed treatments, presumably because of mild conditions during the spring.

Different relationships between sowing rate and sugar yield occurred (Figure 4). In 1989 and 1990, yield was increased substantially by progressively earlier sowing of

advanced seed whereas this achieved little effect in 1988 and 1991. In 7 of the 8 comparisons, yield was larger from ADV than from TS seeds, although in individual comparisons the effect was never large enough to be significant at the 5% probability level.

COMMERCIAL TRIALS

In 1991, seeds of 5 commercial varieties were given scaled-up TS and ADV treatments, pelleted and tested in 8 trials drilled between 4 March and 2 April; the majority were drilled earlier than the UK national crop. As in the small scale trials, ADV seed of all varieties emerged more rapidly than TS seeds at the first two assessment dates, with no major adverse effects being observed at final establishment (Thomas *et al*, 1993). Three replicated trials in 1992 compared advanced and standard seeds drilled earlier than currently recommended as against a normal drilling date. No significant differences in yield were found between ADV and TS seeds at either drilling date but at 2 of the sites sugar yield was increased significantly by earlier drilling. When averaged over the 3 trials there was an increase of approximately one tonne of sugar/ha for crops drilled at least 10 days earlier than normal

STORAGE OF ADVANCED SEED

TS and ADV seeds kept in sealed polythene bags at room temperature were tested for laboratory germination and field emergence after 9 and 36 months of storage (Thomas *et al*, 1993). As an average over the 4 varieties tested, germination remained consistent at 97-98% throughout the study. Seed vigour, as measured by the number of day degrees above 3°C required to produce hypocotyls 2 cm high, was not impaired during the first 2 years of storage. After 9 months of storage ADV seeds emerged faster and seedling establishment was greater than from TS seeds sown in the field on 16 March. However, after 3 years of storage the ADV advantage was smaller, mainly due to decreased performance of 1 of the 4 varieties. In general, ADV seeds required 7 to 15 d°C less than TS seeds for half of the seedling hypocotyls to grow to 2 cm in standard laboratory tests. Results from late spring sowings during the third year of storage showed no significant difference ($p = 0.5$) in emergence percentage between ADV and TS seeds and all seedlings were normal.

CONCLUSIONS

The potential advantages to be gained from sugar-beet seed advancement are two-fold. Firstly, advancing the seeds to complete part of the germination process before sowing reduces the time for seedlings to emerge as compared with thiram-treated seeds. On average, this effect increased sugar yield by 0.19 t/ha (0.048 t/ha/day). Secondly, 'devernalization' of the seeds allows earlier sowing, so increasing yield for every day gained during March by about 0.035 t/ha/day. The number of days likely to be gained by advancing the earliest safe sowing date from 20 March to about 11 March will depend on whether or not the soil is friable and dry enough to be worked by machinery.

The average sowing for sugar beet in the UK during the 1980s was between 19 March and 4 April. Bringing forward the current recommendation for the earliest safe date to sow to 11 March would, on average, bring the mean date of sowing forward by 9 days, each worth 0.035 t/ha of sugar, a total of 0.315 t/ha. Thus the likely sugar yield improvement due to the advancement treatment is 0.315 t/ha, plus the benefit from advancement *per se* of 0.19 t/ha, an overall increase of 0.5 t ha^{-1}.

Although the combination of the advancement treatment and the improved opportunity to sow the crop early are, on the basis of experimental evidence, likely to be worth an extra 0.5 t/ha of sugar, it is unlikely that all of this will be achieved in practice. In similar situations the yield which arrives at the sugar factory gate is approximately 70% of what would be predicted as present in the middle of the fields (Scott & Jaggard, 1992). Using this correction, the treatment should be worth an extra 0.35 t/ha of sugar to the grower and processor, which is about 5% of the average national yield.

ACKNOWLEDGEMENTS

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THE ETHIRIMOL CONTENT OF COMMERCIALLY-TREATED CEREAL SEEDS

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ABSTRACT

Analysis of >750 samples of treated seed showed that most mean doses of ethirimol were within 20% of target and that, within batches, >90% of samples contained the mean dose ±10%. The results of between-seed variability and loading retention studies are also presented.

INTRODUCTION

More than 3 million ha of wheat and barley are grown currently in the UK and it is estimated that at least 85% of these crops receive a seed treatment prior to sowing (Davis *et al.*, 1990). A comprehensive survey of commercial seed treatments more than 20 years ago revealed considerable variations in loading accuracy and uniformity (Lord *et al.*, 1971) and prompted the industry to examine treatment efficiencies. However, despite many subsequent modifications to the range of available pesticides and formulations, as well as to application machinery, there has been no major assessment of the impact of these major developments on treatment efficiency.

This deficiency was recognised by the BCPC Seed Treatment Working Party, who initiated recently two 6-month studies of commercial seed treatment quality. Some of the results of these studies are presented in this paper.

METHODS

The studies were done at Horticulture Research International, Wellesbourne, during July - December 1990 and April - September 1992. The treatment selected for study was Ferrax (Zeneca Agrochemicals), a liquid formulation applied to winter and spring barley seeds at a rate of 500 ml product/100 kg seeds and which contains ethirimol (400 g/l), flutriafol (30 g/l) and thiabendazole (10 g/l). Samples were taken from 5 types of treatment machine at 13 plants in different regions of the UK. In 1990, 367 samples were taken from 14 treatment runs. In 1992, 292 samples were obtained from 7 runs and a further 120 samples were taken at a single site from 1-tonne sacks in which treated seeds were being stored prior to bagging. Between-seed treatment variability was also assessed and the physical stabilities of treatments were measured in drop tests and by passing treated seeds through a drill unit.

Seed sampling

Samples from treatment machines were taken either from the stream of seed as it left the treatment chamber or from the tops of filled sacks prior to sealing. Individual sacks on pallets were sampled centrally using a spear. The 1-tonne sacks were sampled by taking four replicate samples from the top, middle and bottom of each sack. The samples, approximately 10 g, were taken and retained in plastic tubes, 80 x 20 mm, which were sealed immediately after sampling. Between-seed variability was determined by analysing 25 individual, weighed seeds from 2 treatment runs in 1990 and from 2 runs in 1992. Drop tests were done in 1990 and 1992 and were based on the procedure of Jeffs (1973); a sample of seeds (200 g) was dropped 100 times down a 40 cm-long plastic tube on to a wire mesh and a 10 g subsample was removed after every 10 drops. The influence of the drilling procedure on loading retention was assessed in 1992 by transferring the contents of a 50 kg sack of treated seed into the hopper of a 25-outlet Ransomes Nordsten Liftomatic Model 300 seed drill and activating the drill. Samples were taken from the sack before opening, from the hopper and from all 25 outlets, 6 of which were selected for analysis.

Analytical methods

It was established at the outset that the objectives of this study would be achieved by determination of only ethirimol, which was the principal component of the formulated product. Ethirimol was analysed by hplc using a Hypersil ODS column. The mobile phase was phosphate buffer (pH 8.0): methanol: acetonitrile (4:3:3) and the eluant was monitored at 220 nm. The sample extractant comprised buffer: methanol: tetrahydrofuran (3:4:3). Samples were weighed then extracted by transferring the contents of each sample tube, with rinsing, to a 200 ml Duran bottle and tumbling with 50 ml extractant for 30 min. Extracts were diluted x 5 with mobile phase solution prior to analysis by hplc. The stock standard solution (1.00 mg ethirimol/ml) was checked against a freshly-prepared stock solution every 4 wk and working standard solutions were shown to be stable for at least 1 wk after dilution. The analytical procedure was monitored by incorporating a control sample into the study, one portion of which was analysed for every 20 samples received. By the end of the 1990 study, 30 control subsamples had been analysed.

RESULTS

Results of the analyses of the 30 control samples analysed during July - December 1990 were highly consistent. Ethirimol levels ranged from 1520 - 1740 mg/kg and, with a CV of 3.5%, were all within ± 8% of the mean loading of 1650 mg/kg.

Samples from machines and sacks

Table 1 summarises the analyses of the batches of treated seeds sampled in 1990 and 1992. In most of the batches the ethirimol contents of the individual samples were highly uniform. Thus, in 14 of the 21 batches, at least 90% of the samples contained the mean dose ± 10% and, in 6 of these, all of the samples were within this dose range. The overall uniformity of treatment was reflected by the coefficients of variation which, with the exception of batches P and V, were all <8%. Batch P was particularly anomalous, with 8 of the 20 samples containing 990 - 1070 mg/kg and the remainder containing 1600 - 1810 mg/kg. The overall mean loadings of the

TABLE 1. Ethirimol loadings on seeds taken from machines or 50 kg sacks

Year + sample code		No of samples	Mean load mg/kg	Mean load % of target	Range mg/kg	% CV	Samples containing ± 10% of mean load, %
1990	A	30	1870	93.5	1730-1970	2.7	100
	B	54	1830	91.5	1600-2060	6.0	89
	C	23	1640	82	1480-1750	3.7	100
	D	24	1520	76	1260-1620	5.7	92
	E	29	1780	89	1620-2000	5.7	97
	F	28	1230	61.5	1160-1380	3.7	96
	H	21	1570	78.5	1400-1700	6.2	100
	L	37	1840	92	1700-1950	3.5	100
	M	14	1580	79	1490-1690	4.1	100
	N	36	1420	71	1240-1620	6.4	94
	P	20	1430	71.5	990-1810	24.5	0
	S	22	1550	77.5	1350-1790	7.2	73
	T	12	1610	80.5	1520-1690	2.9	100
	V	17	1550	77.5	1300-1950	10.2	73
1992	BB	27	2040	102	1710-2230	5.8	97
	CC	60	1630	81.5	1340-1860	7.5	91
	DD	27	1930	96.5	1350-2130	7.8	85
	EE	31	1770	88.5	1390-2070	7.9	83
	FF	83	1720	86	1550-1920	6.1	96
	GG	29	1770	88.5	1400-2080	7.4	82
	HH	35	1950	97.5	1770-2240	6.8	90

individual batches ranged from 1230 - 2040 mg/kg. BB was the only batch in which the mean dose exceeded the target dose for ethirimol of 2000 mg/kg and a further 5 batches had mean doses within 90% of target. Twelve of the remaining 15 batches contained 75 - 90% of the target dose.

Samples from 1-tonne sacks

The overall mean ethirimol loading on the 120 samples from the ten 1-tonne sacks was 1970 mg/kg, equivalent to 98.5% of target. In individual sacks, mean doses ranged from 94.5 - 113% of target. The mean loading of 2030 mg/kg on samples from the tops of sacks were significantly greater ($p < 0.01$) than those in the middle and bottom of the sacks (1940 and 1930 mg/kg respectively).

Between-seed variability

The results of the analyses of single seeds (Table 2) are expressed as mg/kg and are based on the mean 100-seed weight determined for each batch. The weights of individual seeds ranged from 28 - 67 mg and there was a 2.0 - 2.4-fold weight range within each batch, the coefficient of variation ranging from 16 - 21%. Ethirimol loadings on individual seeds were much more variable, with coefficients of variation ranging from 29 - 45%. There were 3 - 7-fold ranges of dose within batches, with some seeds coated with the equivalent of almost 3 times the target dose. Nevertheless, in all batches approximately 90% of the seeds held 50 - 150% of target.

TABLE 2. Mass and ethirimol content of individual seeds analysed in 1990 and 1992. Each sample comprised 25 single seeds

Year	Sample	Seed mass, mg			Ethirimol content, mg/kg		
		Mean	Range	% CV	Mean	Range	% CV
1990	1	51.3	33.2-66.4	16.5	1670	860-6120	45.6
	2	50.9	33.8-66.6	16.0	1840	1040-5400	41.8
1992	3	51.3	28.3-67.4	18.9	2080	1100-3790	28.7
	4	43.7	24.8-60.9	21.1	2470	1080-5950	39.6

Physical stability

Data from the drop tests done in 1990 and 1992 are shown in Figure 1 as proportions of the initial loadings of 1420 and 2170 mg/kg (1990 and 1992 respectively). The results from the two tests were similar, with both of the initial loadings declining by 10, 20 and 30% after 10, 30 and 60 drops respectively. Subsequent losses were small and, after 100 drops, approximately 65% of the initial doses remained.

Changes in seed loadings at different stages of the drilling procedure are shown in Table 3. There were no significant differences ($p=0.05$) in the mean loadings of seeds taken from the top, middle and bottom of a single 50 kg sack. Although the overall mean dose declined by 3% following transfer from the sack to the seed hopper and by a further 4.8% between the hopper and the outlets of the drill unit, neither of these single-step differences were significant at the 95% confidence level. However, the overall decline of the initial mean dose from 1950 mg/kg to a mean of 1800 mg/kg on the seeds emerging from the drill outlets was significant at this level of confidence.

TABLE 3. Ethirimol loadings (mg/kg) on seeds before, during and after passage through a seed drill

Sack			Hopper			Drill outlet		
Position	mg/kg	CV %	Position	mg/kg	CV %	Outlet	mg/kg	CV %
Top	1920	5.6	1	1780		1	1870	
Middle	1920	4.1	2	1910		5	1780	
Bottom	2000	3.6	3	1980		10	1820	
Mean	1950	4.4	4	1970		15	1770	
			5	1800		20	1770	
			Mean	1890	4.9	25	1780	
						Mean	1800	2.4

DISCUSSION

This survey showed that there had been a marked improvement in the quality of commercial seed treatments since the earlier extensive studies of Lord *et al* (1971). However, it was still evident that the majority of seed treatment plants were failing to achieve the target dose of fungicide. In some cases, eg samples F, N and P, mean doses of ethirimol were so much below target that they clearly reflected serious deficiencies in the treatment

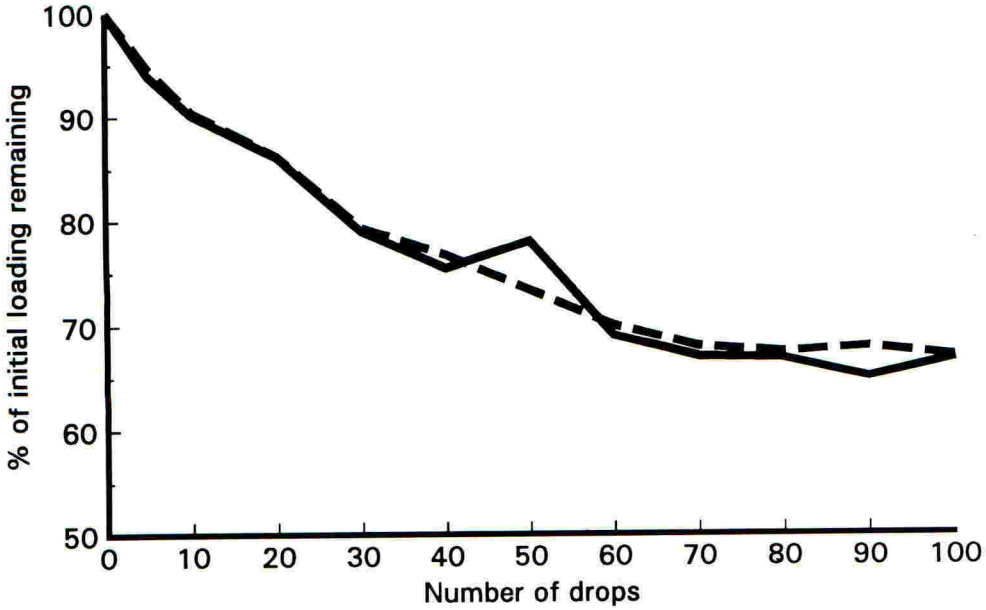

FIGURE 1: Decline of ethirimol loading on seeds in retention tests in - - - - - - - 1990 and in _____ 1992

procedure. Nevertheless, despite the overall low dosing, the mean doses of the majority of treatments were well within recommended guidelines of 70% (Slawson, 1994) or 75% (Koch and Spieles, 1989) of target.

This generally satisfactory achievement of treatment accuracy was associated with a much improved level of mean dosing uniformity between individual samples in each batch, with the great majority of samples containing within ± 10% of their respective mean doses. Although measurements of the loadings on individual seeds (Table 2) revealed CVs of up to 45%, there was already a marked inherent variability in the sizes of individual treated seeds. It seems unlikely, therefore, that even the most precise application could achieve variabilities significantly smaller than 25% CV. Under such circumstances, the production of seeds with between-seed loading variabilities of only 29 - 45% CV is no small achievement, especially at typical rates of throughput of 15 - 20 tonnes/hr. Furthermore, the proportion of each batch containing ± 50% of the target dose was always >90%. This compared favourably with the 80% of single grains from 67 seed lots which Reitz (1989) found were within this range. Precise definition of specifications for between-seed uniformity have yet to be established in the the UK. It is possible that different criteria may have to be established for different purposes. For example, uniformity requirements for effective eradication of a seed-borne pathogen are likely to be more stringent than for systems in which the seed is used simply to transport active ingredients into the soil. Furthermore, recent studies have shown that the efficiencies of insecticide seed treatments against field populations of cabbage root fly were influenced little by the level of between-seed treatment uniformity (Jukes *et al*, 1994). Clearly there is still much to be learned about this aspect of dosing variability before realistic guidelines can be established.

The results of the retention studies are encouraging. The drop test used in the present studies subjected the seeds to a much more rigourous examination than that imposed by the 3 or 6 drops recommended previously in Germany and the UK respectively (Kohsiek and Jeffs, 1986). Nevertheless, even after 100 drops, 65% of the initial dose of ethirimol remained on the seeds, little short of the 70% minimum proposed for the UK (Slawson, 1994). The mean dose on seeds emerging from the seed drill was equivalent to 90% of the target, suggesting that, with liquid seed treatment formulations, it might be realistic to recommend at least 10 drops for studies of retention.

Despite the general failure to meet the specified target dose, the treatment plants which cooperated in this study were, on the whole, achieving a level of seed treatment quality which should ensure optimum control of target pathogens. Nevertheless, it remains of some concern that even a 10% discrepancy between target and achieved doses would have entailed the "loss" of >4kg of a.i. for every 20 tonnes of seed being treated. Although the consequences for treatment efficacy may be insignificant, the associated environmental and safety implications are likely to demand that more attention is given to this aspect of the treatment process.

The above data are also being examined in order to establish the accuracy and reliability of different sampling frequencies and to correlate these with batch size and sampling point (Hewett and Suett, in preparation).

ACKNOWLEDGEMENTS

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THE EFFECT OF PELLET WEIGHT ON THE DISTRIBUTION OF IMIDACLOPRID APPLIED TO SUGAR-BEET PELLETS

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ABSTRACT

The quantity of imidacloprid applied to individual pelleted seed of sugar beet was variable, ranging from 0.6 to 1.8 mg per pellet. This variation was partially due to small differences in pellet size, which led to proportionally larger differences in surface area. The higher doses of imidacloprid on larger pellets caused significant slowing of emergence in the laboratory, but did not reduce final emergence. The presence of imidacloprid in the leaves was greater from larger seeds 19 days after sowing at the 2-leaf stage, but not before or after that stage.

INTRODUCTION

The technology for applying small quantities of pesticide to individual seeds has improved immensely in recent years (Maude, 1990), largely by adopting techniques used in the pharmaceutical industry. However, distribution on individual seeds can still be variable, especially when pesticides are applied to the surface of the pelleted seed. Some of this variation is caused by small differences in seed pellet size leading to proportionally larger differences in surface area. This in turn can lead to large difference in the amount of pesticide applied to individual pellets (Suett & Maude, 1988), which can result in under or over dosing. The consequences of the former may be insufficient activity of the pesticide, leading to pest attack, and the consequences of the latter may be phytotoxicity.

Imidacloprid (1-[6-chloro-3-pyridinyl] methyl 4-5 dihydro N-nitro(1-imidazol-2-amine), commercially known as Gaucho (Bayer plc), is a new systemic insecticide which gives good control of soil and foliar pests of sugar beet when applied to the pelleting material surrounding sugar-beet seed (Altmann, 1991). The rate of application to sugar beet which has been approved in France, Belgium, the Netherlands, Finland and, this year, in the UK is 90 g AI per unit (1 unit = 100,000 seeds). This constitutes a relatively high proportion (approximately 4%) of the total pelleting material surrounding the seed, and may be responsible for the slowing of emergence (Heatherington & Meredith, 1992) and reduction in plant number (Dewar, 1992) observed in some trials.

The present study was carried out to determine the distribution of imidacloprid on commercially-pelleted seeds, and whether variation in this distribution caused adverse effects on the germination, emergence and survival of plants growing from them.

MATERIALS AND METHODS

Variability in seed and pellet size

Commercial raw monogerm sugar-beet seeds are botanically fruits, each containing a

true seed. The raw seeds, which are discus-shaped at harvest, are rubbed to remove excess cortical tissue, and then graded to remove too small or too large seed. The minimum and maximum diameters of seeds stipulated by British Sugar plc for use in the UK are 3.00 to 4.25 mm (J.W.F. Prince, personal communication). Pelleting the seed renders it more spherical and so much easier to sow mechanically. However, pellet size still varies between 3.5 and 4.75 mm in diameter, which means that the largest pellets are 36% bigger than the smallest. Only 5% of pelleted seed outside that range is allowed in commercial batches.

The sugar-beet seed, cv. Saxon, used in this study was either pelleted in the normal way, but without the standard methiocarb at 2 g AI per unit, or treated with imidacloprid at 90 g AI per unit. The imidacloprid was applied as a wettable powder to the outside of previously-formed pellets which had also received basal applications of thiram, partially in a steep process and partially added to the pellet (a total of 5 g AI per unit), and hymexazol at 10.5 g AI per unit. These two fungicides were applied to control the fungal diseases *Phoma*, *Aphanomyces* and *Pythium* (Asher & Dewar, 1994). The imidacloprid was bound to the outer surface of the pellet by a coloured polymer to prevent loss of active ingredient (Halmer, 1988); untreated seed received neither imidacloprid nor polymer.

To determine the variability of seed used in this study, 500 pelleted seeds from each of the untreated and imidacloprid-treated batches were weighed individually on a high-precision microbalance (LeCo-250), and their length and breadth measured using a very accurate digital calliper. The approximate surface area of each seed was calculated by using the equation for a prolate spheroid: $2\pi b^2 + 2\pi$ (ab/e) arcsin e where a = length (mm), b = width (mm) and $e = \sqrt{(1-[b^2/a^2])}$ (Korn & Korn, 1961).

Variability in application of imidacloprid

To determine the variability in application of imidacloprid to individual pellets, one hundred pelleted seeds were selected at random and weighed. Imidacloprid was extracted by placing each seed in 10 ml of acetonitrile : water (80:20), homogenising gently to break up the pellet, and left overnight on an orbital shaker. One ml aliquots from each sample were filtered through a DynaGuard filter (0.2µm) prior to analysis by high performance liquid chromatography (HPLC). After extraction the, by then, depelleted seeds were recovered from the solvent, air-dried at room temperature for 10 hrs, followed by a further 8 hrs at 30°C in a drying cabinet before being weighed. The weight of pelleting material surrounding each seed was assumed to be the difference between the two weights.

The effect of pellet size on rate of emergence

Fifty seeds from each of three different size grades (20-30 mg, 30-40 mg, 40-50 mg) from each of the untreated and imidacloprid-treated batches were sown individually in compost in 9 cm pots and placed in a controlled environment room at 20°C. The rate and extent of emergence was recorded daily for 13 days after sowing. Subsequently, 10 plants from the imidacloprid-treated batch were bulk-harvested 12, 19, 24, 31 and 41 days after sowing when plants were at the cotyledon, 1-2 leaf, 3-4 leaf, 5-6 and 7-8 leaf stages respectively. Imidacloprid was extracted from the plant tissue by placing 1 g of fresh leaf tissue from each bulk in 25 ml of acetonitrile : water (80:20), macerating for 10 min, and centrifuging (10 000 *g*) for 10 min at 10°C. The supernatant was evaporated down to 1 ml and filtered through a DynaGuard filter (0.2 µm) before analysis by HPLC.

Analytical Procedure

Imidacloprid was analysed by HPLC (Westwood & Dewar, 1993) using a Hypersil ODS 150 x 4.6 mm (ID) column. The mobile phase was water : acetonitrile (75:25) at pH 3.5, and the eluant was monitored at 265 nm and a flow rate of 1 ml per minute.

RESULTS

Variability in pellet size

Pelleted seed from both untreated and imidacloprid-treated batches varied in weight from 25 mg to almost 60 mg. The mean weight of untreated seed was 34.4 ± 5.5 mg, almost 2 mg less than the treated seed (36.3 ± 5.2 mg). The difference is attributable to the quantity of active ingredient and polymer added to the treated pellet. For both batches of seed there were highly significant positive correlations between weight and surface area ($P > 0.001$) (Fig. 1), and these relationships were of similar slope in each case, but the treated seed had a consistently larger surface area of about 1 mm^2 for the same weight of seed. Again this must be attributable to the application of the treatment and polymer. In both batches the surface area of large pellets (*ca* 50 mg) was almost double that of small pellets (*ca* 25 mg) but the majority (approximately 70%) were within ± 10% of the means.

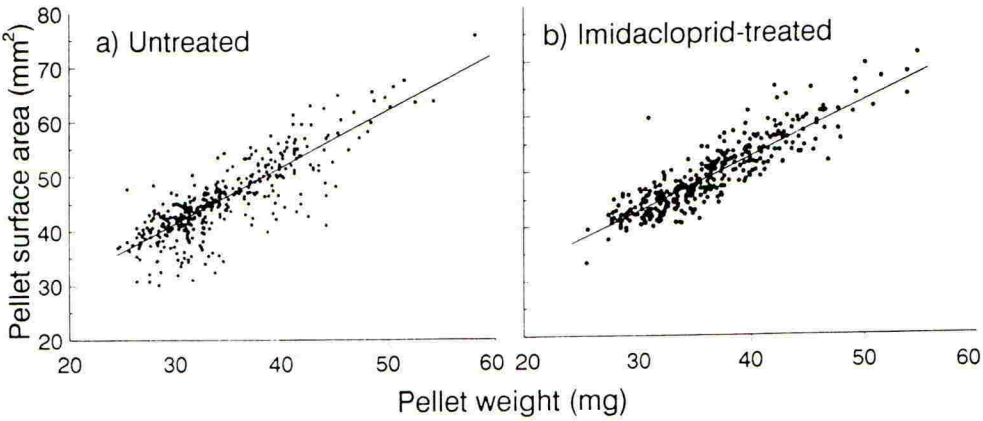

FIGURE 1 Comparison between pellet weight and surface area for a) untreated seed; y = 11.058 + 1.014x and for b) imidacloprid-treated seed; y = 12.012 + 1.014x, where x = pellet weight (mg) and y = surface area (mm^2).

Variability in imidacloprid concentration

The weights of imidacloprid-treated pelleted seeds which were subsequently extracted to determine the amount of imidacloprid varied from 24 mg to almost 50 mg. Imidacloprid concentration also varied, from 0.56 mg/seed to over 1.7 mg/seed, a 300% difference, although the majority of observations (63%) lay within 0.2 mg/seed of the mean dose of 0.9 mg/seed (equivalent to 90 g AI/unit) (Fig. 2b).

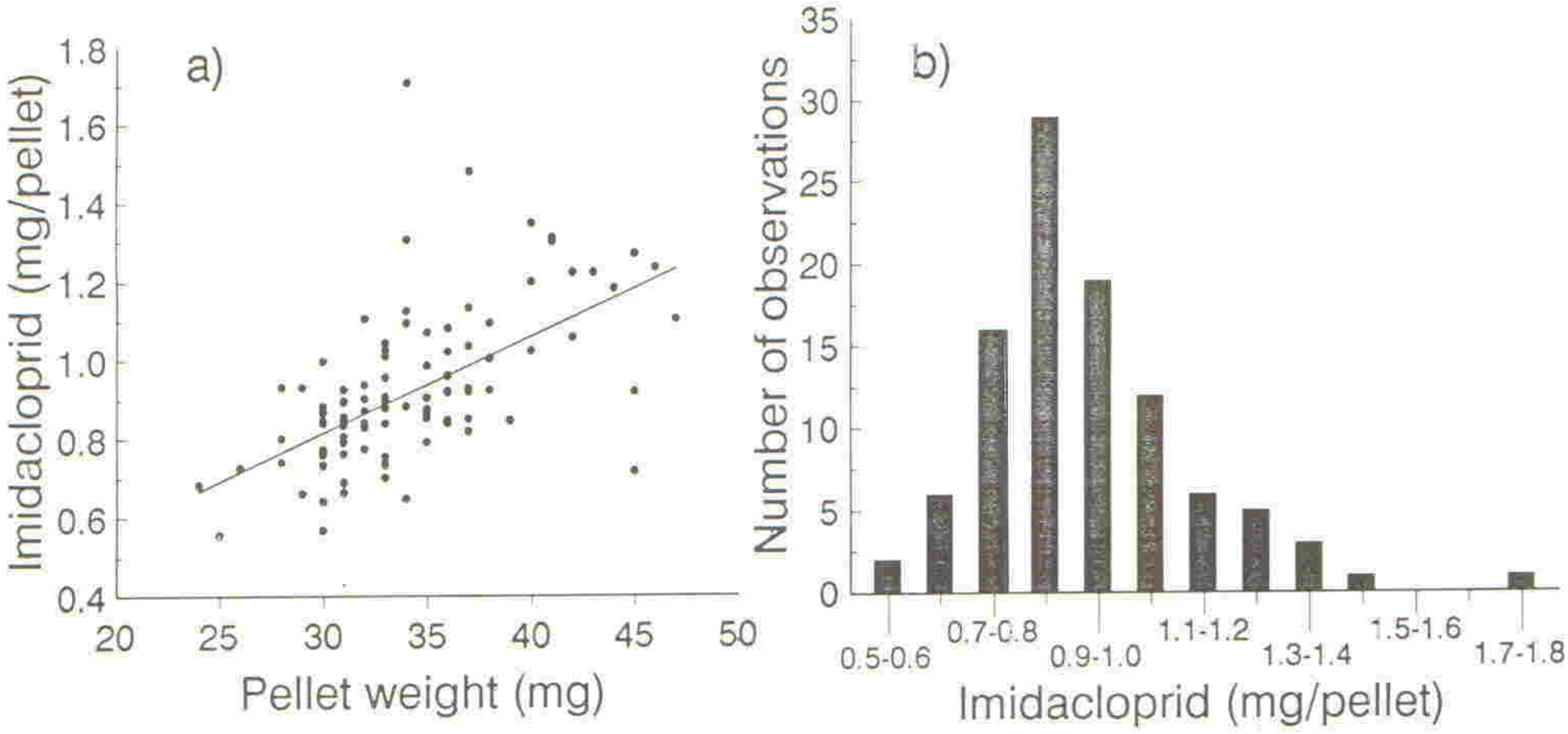

FIGURE 2 a) Comparison of imidacloprid concentration with pellet weight: $y = 10.7 + 2.412x$ when y is the amount of imidacloprid (mg/seed) and x = pellet weight (mg): b) frequency distribution of imidacloprid on sugar beet pellets.

There was a significant positive relationship between pellet weight and imidacloprid content ($r = 0.572$; $P > 0.001$) (Fig. 2a) showing that, on average large pellets (*ca* 45 mg) contained 33% more imidacloprid than the mean dose of 0.9 mg/seed and small pellets (*ca* 25 mg) contained about 22% less.

The relationship between depelleted seed size and imidacloprid concentration was only weakly correlated, with only 7% of the variance accounted for. The weight of pellet material applied to seeds was also only weakly correlated with seed weight with only 14% of the variance accounted for.

Effect of pellet size on emergence

No significant adverse effects of imidacloprid on emergence were recorded after 13 days (Table 1). There was a suggestion that emergence of seed in larger untreated pellets was much less than in smaller pellets.

TABLE 1. Effect of seed size and imidacloprid treatment on the extent and rate of emergence of sugar beet seedlings.

Seed weight (mg)	% Emergence after 13 days		Days to 50% emergence	
	Untreated	Imidacloprid	Untreated	Imidacloprid
20-30	100	96	6.1	6.9
30-40	84	94	6.3	7.4
40-50	86	94	6.7	7.4

Plants emerged consistently later from imidacloprid treated pellets than untreated over all seed sizes ($X^2 = 51.85$; $P > 0.01$) (Table 1). Within each batch emergence was significantly

faster from smaller pellets than larger ones (X^2 = 28.13, 8 d.f. and 47.92, 8 d.f. for untreated and imidacloprid-treated respectively).

Uptake of imidacloprid

There were no differences between pellet weights in the uptake of imidacloprid 12, 24, 31 and 41 days after sowing, but 19 days after sowing (2-leaf stage) at least twice as much imidacloprid was detected in the leaves of plants from large pellets compared to those from smaller pellets (Fig. 3). The apparent decline in concentration of imidacloprid with time is due to dilution within plant tissue as the plants grow larger, not to a decrease in total uptake within the plant.

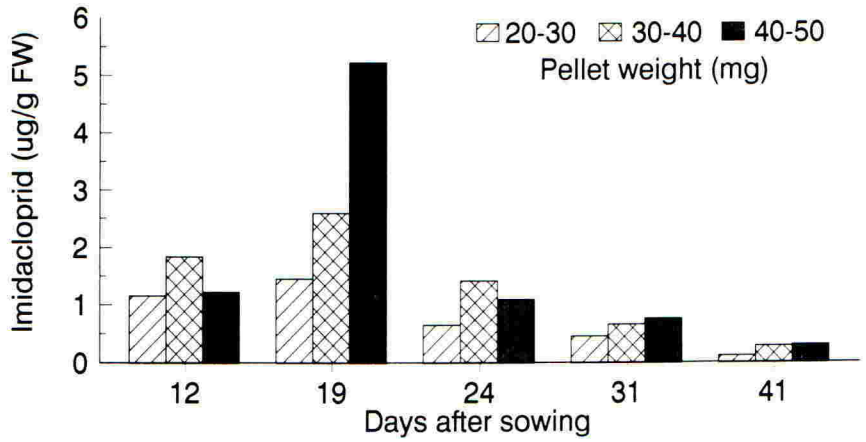

FIGURE 3. The effect of pellet weight on the concentration of imidacloprid in the leaves of sugar-beet seedlings.

DISCUSSION

Sugar-beet pelleted seed as supplied to growers in the UK varied in size from 3.50 mm to 4.75 mm in diameter, and in weight from about 25 mg to 50 mg. This resulted in a range of surface areas from about 35 mm^2 to 68 mm^2 - almost a 100% difference. It was not surprising therefore that the amount of chemicals such as imidacloprid, applied to this surface area, vary by similar proportions. This study confirms that the amount of imidacloprid on individual pellets varied by as much as 300%, although the mean value of the 100 seeds tested here was 89.1 g AI, only 1% less than the target.

The consequences of this variation, which is partially related to pellet size, are that larger pellets have larger doses of imidacloprid and that this can slow emergence significantly, although final emergence was not affected. However, larger untreated pellets were also slower to emerge and the proportion of these seeds not germinating was noticeable. Therefore these results remain inconclusive and the problem needs further investigation.

The concentration of imidacloprid in plants growing from larger pellets was only greater than that from smaller pellets on one sample occasion (the 2-leaf stage), but this could have

important consequences, especially if herbicides are applied at that growth stage. Exposure to high doses of more than one chemical at vulnerable growth stages may cause death of some plants.

ACKNOWLEDGEMENTS

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THE COATING OF CARROTS WITH CHLORFENVINPHOS

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ABSTRACT

Considerable yield losses in the cultivation of carrots are caused by the carrot fly (*Psila rosae*). It is possible to limit damage by treating the crop in the field with chlorfenvinphos. Similar efficacy is achieved with a chlorfenvinphos seed treatment, which uses only 2% of the amount of AI required for a soil or crop treatment. On the basis of the physical properties of chlorfenvinphos, and for hygienic, technological and physiological reasons, it was formulated as a wettable powder.

INTRODUCTION

From the end of May up to autumn, carrots are liable to attack by two generations of the carrot fly (*Psila rosae*). One week after laying eggs the larvae hatch out. They migrate into the main root and develop there over a period of 4 to 7 weeks. After pupation, the second generation hatches out from the middle of August. The damage is caused by the larvae which cause the carrots to taste bitter, smell unpleasant and rot. It is therefore almost impossible to grow carrots commercially without controlling this pest.

Insect control

The insecticidal effectiveness of chlorfenvinphos is well-known (Beynon *et al.*, 1968). Chlorfenvinphos (Birlane, Sapecron, Haptarax, Haptasol: Shell) blocks the enzyme acetylcholinesterase and acts as a contact and breathing poison. The pure substance is a colourless oil with a boiling point of 110°C at 0.0013 mbar and a vapour pressure of 2.2×10^{-7} mbar at 25°C. It has a water solubility of 145 mg/l at 23°C. To date, its application has been limited to field treatments with an emulsifiable concentrate or to row treatments with granules at doses up to 5 kg AI/ha. These doses may need to be even greater if prolonged control of second generation larvae is required. This paper describes studies undertaken to control first generation carrot fly larvae with a seed treatment. An essential advantage of this method is the reduction of the amount of active ingredient to only 0.1 kg per ha.

METHODS

Preparation of a wettable powder

Since the usual trade formulations of chlorfenvinphos were not suitable for treating seeds, the active substance was absorbed in a nearly pure state (96% AI) on an inert, inorganic carrier and converted into a dry powder that contained 60% AI. This powder did not contain any formulation aids such as organic solvents, emulsifiers, adhesives or antifreeze substances that might have adversely influenced the germination of seeds. It was readily stirred into an aqueous suspension together with fungicides, germination aids and binders and was sprayed on to the seeds in a technical process. After drying,

the carrier prevented the migration and penetration of the active substance on or into the seeds and also suppressed possible effects on germination. Despite the oily characteristics of chlorfenvinphos, the seeds did not stick together, thus avoiding potential difficulties during sowing.

Treatment of carrots

The treatment of the carrots was carried out in a technical installation for seed coating (Hoerner, 1985; Halmer, 1988). In this process, the aqueous suspension was sprayed on to a bed of seeds that was fluidised by warm air. This was performed in a container suitable to the amount and variety of the seeds. As they passed the spraying zone, the seeds picked up the suspension, while at the same time the warm air was drying the seeds. After dropping down the container wall the cycle was completed. Treatment continued until the calculated amount of suspension had been applied. At an air temperature of 40°C, 10 kg seed could be treated in 15 min with 4 kg of a suspension containing 25% w/w solids (fungicide, chlorfenvinphos, pigment and binder).

Analytical investigations

The analytical determination of chlorfenvinphos in a representative sample and measurements of a sufficient number of single seeds give information about the quality of the coated seeds. In numerous assessments, the mean achieved dose was found to be within 90-100% of the target dose of 25 g AI/kg. At this dose level, and with a mean seed weight of 2 g/1000 seeds, the target dose was approximately 50 µg chlorfenvinphos per seed. The distribution of AI on 100 individual seeds is shown in Figure 1.

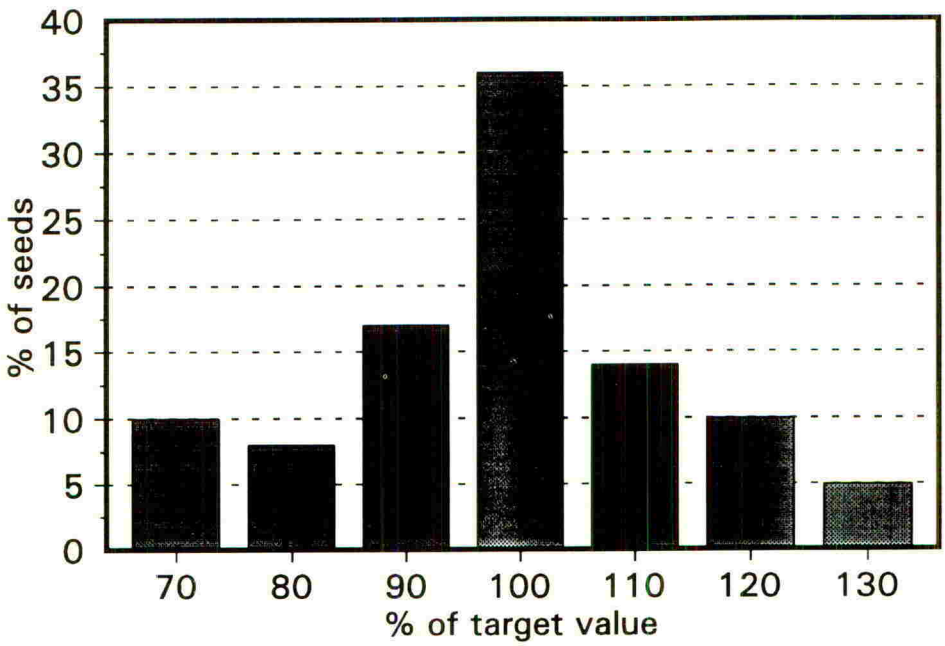

FIGURE 1. Distribution of chlorfenvinphos on 100 carrot seeds. Target value = 50 µg/seed)

All the seeds contained 70-130% of the target dose of chlorfenvinphos. The coefficient of variation (CV) was ± 17%.

Storage stability

The seeds were stored under usual conditions at 18°C for 3 years to examine the effects on germination and on the stability of the chlorfenvinphos treatment. Results showed that there was no significant decomposition of chlorfenvinphos.

RESULTS

Field trials under practical conditions indicated that the chlorfenvinphos seed treatment was very effective in reducing damage by 1st generation carrot fly larvae (Table 1).

TABLE 1. Effect of different treatments of chlorfenvinphos against 1st generation carrot fly larvae (cv. Napoli)

Treatment	% of plants infested		
	1989 sown 20 March evaluation 27 June		1990 sown 15 March evaluation 6 June
	field a	field b	field c
1. Control (untreated)	10.5	17.0	50.0
2. Surface band treatment with granules at sowing	13.0	12.5	-
3. Field treatment with EC before sowing	-	-	9.5
4. Coated seed	4.3	12.3	12.1

With a seed density of approximately 2 million seeds/ha, the amount of chlorfenvinphos applied via the seed treatment was equivalent to 100 g AI/ha, compared with 5 kg/ha with the granule or EC treatment. Analyses of carrots at harvest showed that residues of chlorfenvinphos were below the limit of detection (< 0.01 mg/kg). The seed treatment with chlorfenvinphos thus appears to be an effective and economic alternative to more conventional methods of applying the insecticide to control 1st generation carrot fly on carrots.

ACKNOWLEDGEMENTS

The analytical determinations of chlorfenvinphos were performed in the laboratory of SUET, the residue investigations were done in the Institute Fresenius, Taunusstein. We thank Prof. Kretschmer, Geisenheim for carrying out and evaluating the field trials and colleagues of the Dutch Shell Company, with whom we coordinated the work.

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INTERACTIONS BETWEEN HYMEXAZOL, FURATHIOCARB AND SOME CLAY MATERIALS USED FOR SEED TREATMENT

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ABSTRACT

The transformation of furathiocarb was studied after deposition of this pro-pesticide onto clay films in the presence or absence of hymexazol as well as other model compounds. It appeared that, in the absence of hymexazol, there was very little transformation (<2.5%) of furathiocarb into carbofuran. In the presence of hymexazol the transformation into carbofuran was much greater and increased progressively with time (up to 27%), especially with some specific clay materials such as bentonite, hectorite and vermiculite. It was also shown that model compounds structurally related to hymexazol were unable to induce this acceleration of the transformation of furathiocarb. Similar trends were observed when the clay materials were used in seed treatments, and the instability of furathiocarb was again greater when hymexazol and bentonite were used together in the same treatment.

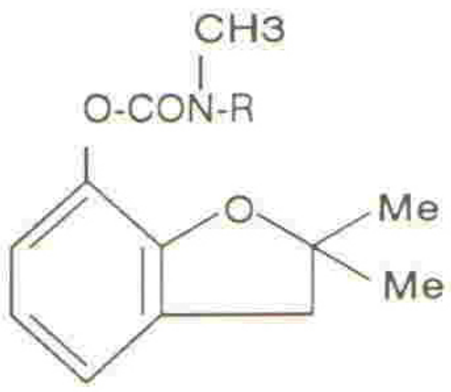
INTRODUCTION

One of the main benefits from pesticide application on seeds is the marked reduction of the application rate and, therefore, of the potential hazard for the environment. Significant progress has been achieved with the sugar beet crop where a fungicide such as hymexazol can be applied in the seed pellets, either alone or together with an insecticide such as furathiocarb. Some problems, however, may occur with this combination of pesticides. Furathiocarb, for instance, lacks stability when applied together with hymexazol on seed pellets prepared with clay materials (Huijbrechts & Gyssel, 1989 ; Pussemier *et al.*, 1990). The aim of the present study was to follow the transformation of furathiocarb into carbofuran which, although not being the active ingredient *sensu stricto*, seems to be, under certain circumstances, the major biocidal derivative. Thus the transformation of furathiocarb, on clay films and in experimental seed treatments based on the same materials, has been studied with special emphasis on the role of the clay material and of the accompanying organic compound (hymexazol or other model compounds).

MATERIALS AND METHODS

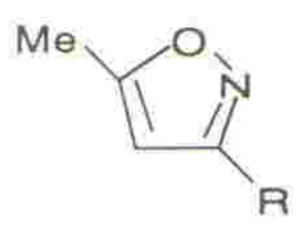
Materials

Furathiocarb, technical grade, was obtained from Ciba-Geigy, Basle. Carbofuran and hymexazol were obtained by extracting the active ingredients from their commercial formulations (Curater (Bayer Ltd) and Tachigaren (Sankyo Ltd), respectively). The identity and purity of the chemicals obtained after crystallization were confirmed by determination of their melting points.



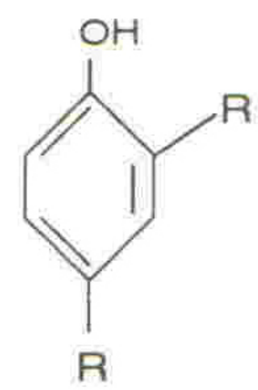
Furathiocarb (R = SN(Me)CO2Bu)

Carbofuran (R = H)



Hymexazol (R = OH)

5-Methylisoxazol (R = H)



Phenol (R = H)

2,4-Dinitrophenol (R = NO2)

FIGURE 1. Chemical structure of the selected pesticides and model organic chemicals

5-Methylisoxazol, phenol and 2,4-dinitrophenol, all analytical grade, were purchased from Janssen Pharmaceutica, Beerse. The chemical structures of all the compounds are detailed in Figure 1.

The clay materials selected were : kaolin from Eire, bentonite from Wyoming, vermiculite from Texas, and hectorite from California. Methylcellulose (Tylose from Merck), a binder widely used in the seed treatment technology, was taken as a reference material and, because of its polysaccharidic composition, was assumed to be chemically inert with respect to the pesticides.

Clay films

For the studies dealing with the transformation of furathiocarb on solid films, 2.5 g of the selected clay and reference materials were suspended in 50 ml distilled water. Two ml of the suspensions were poured into glass vials (3 cm diameter) and allowed to dry for 16 to 20 hours at 60°C. One ml of a 20 mM furathiocarb solution in methanol:water (1:1) was then poured onto the films, together, when appropriate, with hymexazol or with the structurally related compound, all of them being applied at the same concentration as furathiocarb (i.e. 0.2 mmoles per g of clay material). The films were allowed to dry again (24 hours at 60°C). To a first set of films, 5 ml of water were added just after drying, in order to extract the carbofuran produced from the furathiocarb. A second set of films was maintained dry at room temperature (18-22°C) for 7 or 14 days before performing this extraction procedure. The percentage transformation of furathiocarb was determined by measuring the amount of carbofuran produced, using an enzymatic test based on the inhibition of acetylcholinesterase (Pussemier *et al.*, 1990). The measurements were carried out on 2 or 3 replicates and the relative standard deviation coefficients were generally close to 20%.

Treated seeds.

Three hundred maize seeds (c. 100 g) were introduced into an experimental seed dressing system prepared from a cylindrical drum and a commercial painting device. The treatment was performed by spraying portions of a suspension containing the seed dressing materials into the rotating cylinder and drying the seeds with hot air (60°C). The sprayed aqueous suspension contained furathiocarb (4g/L) with or without hymexazol (4g/L) as well as bentonite (80g/L) or Tylose (12g/L). The seeds were extracted and analyzed for carbofuran after 1, 7 or 14 days storage in the laboratory.

RESULTS AND DISCUSSION

Furathiocarb transformation on solid films

The percentages of furathiocarb converted into carbofuran after 1, 7 and 14 days of contact with the clay films are shown in Table 1. The pH values shown in the same table are those measured in the aqueous suspensions obtained when extracting the carbofuran.

In the absence of hymexazol, the rate of transformation was small (< 2.5%) and there was only a very little increase with time. This limited transformation of furathiocarb into carbofuran seemed to be associated to the acidic properties of the solid materials. From the following relationship it can be seen that after one day there was a very significant correlation with the pH :

$$\%\ \text{transformation (1 day)} = 3.70 - 0.38\ \text{pH} \qquad r = -0.96 \qquad (1)$$

After 7 and 14 days, however, less significant correlations were obtained :

$$\%\ \text{transformation (7 days)} = 4.13 - 0.38\ \text{pH} \qquad r = -0.90 \qquad (2)$$

$$\%\ \text{transformation (14 days)} = 5.20 - 0.47\ \text{pH} \qquad r = -0.83 \qquad (3)$$

From these observations it is suggested that a limited acid-catalyzed transformation occurred at the very beginning, probably when the clay materials were still moistened and active as catalysts (Ortego *et al.*, 1991). Later, when the clay films were dry, there was very little additional production of carbofuran, and it seemed that the pH was no longer the main factor controlling this further transformation of furathiocarb.

In the presence of hymexazol, on the other hand, the transformation of furathiocarb into carbofuran was already important (up to 6.94%) after 1 day but clearly increased with time, reaching 20-30% for some of the clay materials such as bentonite, hectorite and vermiculite. For the organic adsorbent (Tylose) and for kaolin, which was the only tested clay material without swelling properties, the fraction transformed into carbofuran, whilst not negligible after 1 day, did not increase any further with time. It would seem, therefore, that the addition of hymexazol to the clay materials characterized by swelling properties may activate the surface-catalyzed transformation of furathiocarb.

TABLE 1. Percentages of furathiocarb transformation after application alone and in combination with other organic chemicals on various solid films (HYM = hymexazol; MeISO = 5-methylisoxazol; PHE = phenol; DNP = 2,4-dinitrophenol; BEN = bentonite; KAO = kaolin; VER = vermiculite; HEC = hectorite; TYL = Tylose)

Solid film	Chemical added	Interval after treatment					
		1 day		7 days		14 days	
		% transf.	pH	% transf.	pH	% transf.	pH
BEN	-	0.42	8.0	0.55	9.3	0.67	9.3
KAO	-	1.39	6.3	1.20	6.8	1.75	6.5
VER	-	0.93	7.5	1.18	8.6	2.39	7.8
HEC	-	0.10	9.6	0.18	10.2	0.46	9.7
TYL	-	1.14	6.5	1.81	6.8	2.13	6.4
BEN	HYM	4.07	6.2	15.36	6.3	23.52	6.1
KAO	HYM	3.81	5.4	2.06	5.3	2.90	5.3
VER	HYM	6.94	7.2	11.14	7.7	18.97	7.8
HEC	HYM	1.49	9.1	22.66	8.8	27.06	9.0
TYL	HYM	3.34	5.2	2.84	4.8	2.59	4.6
BEN	MeISO	0.60	9.4	0.63	9.8	0.69	9.4
KAO	MeISO	2.46	7.4	1.88	6.8	1.99	6.8
VER	MeISO	2.04	8.2	1.41	8.5	1.52	6.8
HEC	MeISO	0.58	9.3	0.14	10.0	0.40	9.0
TYL	MeISO	2.70	7.4	3.47	7.3	2.46	6.6
BEN	PHE	0.68	8.1	0.81	9.1	0.74	8.9
KAO	PHE	1.35	6.3	1.10	6.3	1.35	6.3
TYL	PHE	1.30	6.3	1.23	6.3	1.48	6.3
BEN	DNP	0.60	4.7	0.55	4.5	0.68	4.7
KAO	DNP	0.74	3.0	0.55	3.0	1.10	3.2
TYL	DNP	1.23	3.1	1.35	3.1	1.10	3.2

From the results obtained when using 5-methylisoxazol, phenol, and 2,4-dinitrophenol instead of hymexazol (Table 1), it was evident that these compounds, whilst structurally related to hymexazol, did not lead to any activation of the transformation properties of the clays. 5-Methylisoxazol is analogous to hymexazol (presence of an isoxazolic ring) but lacks the hydroxylgroup. On the other hand, both the phenol and 2,4-dinitrophenol compounds have a hydroxyl group with a pKa of 10.00 and 4.09 respectively (Albert & Serjeant, 1971). The former compound is thus less acidic than hymexazol (pKa = 5.5 ; Vanderheyden *et al.*, unpublished data) whilst the latter is more acidic. It thus seems that the properties of hymexazol are quite unique and cannot be linked to the aromatic or hydroxyl moieties alone.

Transformation of furathiocarb when applied on seeds

The percentages of furathiocarb transformation are presented in Table 2. It appears that, 1 day after the seed treatment, the rate of transformation of furathiocarb was very small (0.07 - 0.28% of the amount that

TABLE 2. Percentages of furathiocarb transformation after application in seed treatment with Tylose (TYL) or bentonite (BEN), with or without hymexazol (HYM).

Materials used for seed dressing	% of furathiocarb transformation after : 1 d	7 d	14 d
TYL	0.13	0.13	0.13
BEN	0.07	0.15	0.42
TYL + HYM	0.17	0.31	0.34
BEN + HYM	0.28	5.67	9.00

has been applied). Furathiocarb was more stable in the seed treatments without hymexazol. When both hymexazol and the clay material (bentonite) were applied simultaneously, the transformation rate was somewhat higher. These differences, however, increased afterwards during the storage of the seeds. Thus, after 14 days storage, 9% of furathiocarb had been transformed into carbofuran in the treatment combining hymexazol and bentonite, whereas no more than 0.13 - 0.42% transformation occurred with the other treatments.

CONCLUSIONS

The main results of this study can be summarized as follows :

1) Furathiocarb applied alone on clay films was quite stable. Limited transformation into carbofuran was observed after one day and seemed to be linked to the acidic properties of the supports. This transformation of furathiocarb in contact with the films did not increase very much after 7 or 14 days. It is thus suggested that this acid-catalyzed transformation occurred mainly in the liquid phase, during the time needed to evaporate the solvent in which the furathiocarb was added to the films.

2) When furathiocarb was applied together with hymexazol, the transformation was significant after 1 day and increased during the following days, especially with the films prepared from clays exhibiting swelling properties. With kaolin and Tylose, there was no increase of transformation with time. It is thus suggested that hymexazol was able to diffuse in the interlayer space of the swelling clays, thereby changing the catalytic properties of the clay surfaces, and eventually increasing the transformation of furathiocarb to carbofuran.

3) This increased transformation of furathiocarb to carbofuran in the presence of hymexazol was also observed after performing an experimental seed treatment on maize, as long as bentonite, a swelling clay, is added to the seed dressing mixture. It is thus recommended to avoid the use of swelling clays when treating seeds with a mixture of hymexazol and furathiocarb.

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A SMALL-SCALE LABORATORY FLUIDIZED BED SEED-COATING APPARATUS

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ABSTRACT

There is a need for a simple and efficient laboratory-sized coating machine. A fluidized bed coating apparatus developed in the Seed Science Center at Iowa State University has the capacity to coat from 100 to 500 g of seeds in 15-30 min. It is efficient, easy to operate, and suitable for coating small amounts of seed for experimental use. A fluidized-bed is formed in the coating chamber by a controlled upward flow of heated air. The coating liquid is introduced through a simple air-atomizing spray nozzle. Initial trials showed that round seed (soybean) could be coated with better success than flat seed. However, with minimum experience corn, sunflowers and other irregular shaped seeds can be successfully coated.

INTRODUCTION

Regulatory and environmental concerns combined with marketing demands have created a substantial interest in seed coating technology. Exposure of seedsmen and growers to captan and other pesticides on the seed is no longer considered acceptable. Further, production practices and techniques often result in mechanical damage, which could be corrected by coating seeds with protective materials. However, evaluation of these new materials requires greater precision than traditional seed treatments. Increasingly sophisticated equipment has been introduced to the seed industry by pharmaceutical equipment manufacturers, with experience in coating tablets, capsules, and granules with organic solvents and aqueous dispersions. Fluidized bed systems are frequently used in pharmaceutical, chemical, and food industries, and are widely used for drying of granular materials. There are many different ways to form a fluidized bed including rotary or vibrational movement, pressurized gas, impulse fluid circulation or flow, sonic vibrations, or magnetically stabilized fluidization. The vibrated fluidized bed reported by Gupta et al. (1980) refers to a shallow rectangular fluidized bed where the complete assembly is vibrated at a relatively high frequency and with a small amplitude. Kamamura and Imada (1980) used reduced pressure to

dry fluidized particles. Turcaj (1983) used a fluidized bed for drying samples of wheat utilizing a laboratory apparatus. Evans et al. (1983) reported experiments with a continuous flow fluidized bed heating system capable of treating up to 500 kg/h of wheat. Bacon et al. (1988) reported on a small scale fluidized bed seed treatment device which could coat as little as 200 seed.

Following increased interest in protecting corn, soybean and other seeds by coating, and finding commercially available equipment to be too large and expensive we designed and constructed a small-scale laboratory coating apparatus to allow precise application of coating materials to approximately 500-gm of seed.

METHODS AND MATERIALS

The schematic for the coating apparatus is presented in Fig.1. All parts are mounted on a mobile table of convenient size, e.g. 75 X 60 cm X 85 cm high. A lower shelf houses the air supply, heater, and control equipment. Air is provided by a tangential fan with a capacity of 47 l/s, fan output is controlled by a variable transformer which allows nearly infinite regulation of air velocity. The 900-watt finned strip heater is mounted within a section of 7.5-cm copper tubing through which the air passes on its way to the coating chamber. The temperature is regulated by an electronic control capable of accuracy of 0.1^{0}C from a sensor mounted below the coating chamber. Seeds to be coated are fluidized in the coating chamber, which is 75-mm ID with a stainless-steel mesh (1 x 1 mm) screen bottom. The chamber is removable to facilitate removal of the coated seed. A spray nozzle with external mixing is supplied with the pressurized air and liquid for coating. The nozzle is constructed in our laboratory using stock 6.25-mm OD copper tubing for the outer shell and 1.5-mm OD Teflon internal liquid supply line. Coating solutions are stirred with a standard laboratory magnetic stirrer. To obtain uniform nozzle delivery of the coating solutions constant flow rates are provided with a variable speed peristaltic pump with a revolution range of 6-600 RPM.

Constant uniform movement of the seeds in the coating chamber is necessary for uniform application of coating materials. The coating material is sprayed onto the seed while it is circulating in the stream of warm air. The air pressure lifts the seed and forms the fluidized bed in the coating cylinder. Movement within the fluidized mass is created by the adjustment of the atomizing air provided by the nozzle. This pressure lifts the seeds in the middle of the chamber, and after reaching the upper level of fluidized bed, the seeds travel down the outer periphery of the chamber. The number of revolutions that the seed makes per minute (the number of exposures to the coating material) is regulated by changing the velocity of air in the chamber and the nozzle pressure. It is important to have enough seeds in the cylinder to maintain uniform movement of seeds and efficient recovery of the spray solution. If the seed volume is too small, the air will follow the path of least resistance and seed circulation in the chamber will decrease. The 75-mm chamber accommodates up to 200-250 g of corn or soybean seed. The coating solution can be applied at various rates, depending on the nozzle capacity, physical

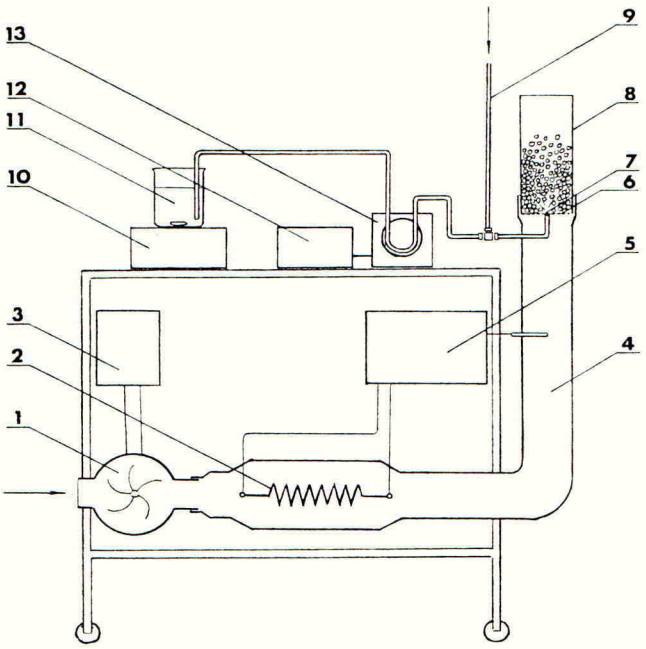

Figure 1. A fluidized bed seed-coating apparatus. 1. Fan, 2. Heater, 3. Variable transformer, 4. Pipe, 5. Temperature control, 6. Wire mesh, 7. Spray nozzle, 8. Coating chamber, 9. Regulated air supply, 10. Magnetic stirrer, 11. Coating liquid, 12. Peristaltic pump regulator 13. Peristaltic-drive pump.

properties of the coating liquid, air flow, temperature, number of revolutions of seed, and operator experience. Fast evaporation of deposited liquid in the warm air makes it possible to apply and dry the coating materials in one step.

Table 1. Coating efficiency of soybean seed as affected by seed mass and coating polymer.

Coating Polymer	**Seed Mass**	**Coating Time**	**Seed Weight gm/100 Seed**[1]
Sacrust	200 gm	12 min	27.273 a
Sacrust	400 gm	20 min	27.050 a
Polyvinylpyrrolidone	200 gm	15 min	26.711 b
Polyvinylpyrrolidone	400 gm	21 min	26.345 b
Control			25.833 c

[1] Values followed by the same letter are similar at the 5% level of probability.

Table 2. Analysis of variance of seed to seed coating variability of soybean as affected by seed mass.

Source	DF	MS	F	P
Treatment	1	35.721	8.40	0.0092
Replication	19	7.058	1.66	0.1391
Total	39			

To determine equipment performance, two batch sizes of soybeans (200 and 400 gm) were coated with either Sacrust (Sarea, Linz, Austria) or Polyvinylpyrrolidone (Sigma), the coating amount was calculated to be 6% seed weight gain. The process was replicated three times and the 100 seed weight was measured on four subsamples of each replicate to determine batch size and coating uniformity. To further evaluate the seed to seed variation 20 individual seeds of the Sacrust coated seed were soaked in 5 ml of distilled water for 15 min. The color intensity of the resulting solution was measured at 490 nm against a water blank. All statistical comparisons were calculated using the Statistix (Analytical Software, St. Paul MN).

RESULTS

Initial trials showed that round seed (soybean) could be coated with better success than flat seed (corn). The coat applied on soybean seed had uniform thickness, good appearance, and completely covered the seed. Corn seed tended to stick and the coating was initially uneven. After additional experience and changes in the rate of application, air pressure, solution concentrations, and temperature, however, successful coating of corn seed was achieved. Soybean seed can be coated in a relatively short time with good precision (Table 1). The time required to coat the different batch sizes varies but the resulting product is similar in overall coverage as indicated by the similarity in 100 seed weight. The seed to seed precision is not significantly effected by the amount of seed although the coating time is extended. Further the seed to seed coating level(Table 2) is similar within coating mass but significantly different between mass. The significance between seed mass levels is probably due to the large number of replications and the sensitivity of the spectrophotometric measurements. The germination and field performance of seed coated with the coater is a function of initial seed quality the polymer used and the seedbed environment. Under no circumstances did the coating procedure appear to influence seed performance. Most of the polymer systems that have been tested have not effected the germination performance of the coated seed.

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