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HDC Project Report

'Seed quality in bedding plants'

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Final report to the Horticultural Development Council

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Background and objectives

Commercial pressures on the pot and bedding plant industry have created the need to adopt cellular tray systems for plant raising. However, for many species poor seed quality makes direct seeding uneconomic. This poor seed quality often results from seed retaining the characteristics typical of wild species such as, dormancy, a wide range of seed maturity at harvest, and a limited temperature range over which seeds can germinate rapidly. Much of this variation in seed quality is therefore physiologically determined and may be improved by seed technology and by optimising germination conditions. To test these possibilities a programme of work involving more than 100 experiments was carried out. The aim of the work was to determine the germination responses of seed from seven bedding plant species to a range of environmental conditions and then to develop practical treatments to improve seed performance. The treatments included both physical separation techniques and chemical dormancy breaking and seed advancing techniques. Six of the bedding plants (Primula, Impatiens, Salvia, Verbena and African and French marigolds) used in this study were identified in a UK grower survey as having major seedling establishment problems in practice. The seventh bedding plant Petunia, was identified as having few establishment problems and was therefore included for reference. The species and cultivars used in this study are commonly used in the UK.

Most growers have facilities with a limited range of options for environmental control for germination and in addition, there is a need to produce plants from many species, cultivars and seed lots at the same time. One purpose of this study was therefore to determine whether robust general recommendations for the most suitable environmental conditions during germination could be made which would apply to a number of species.

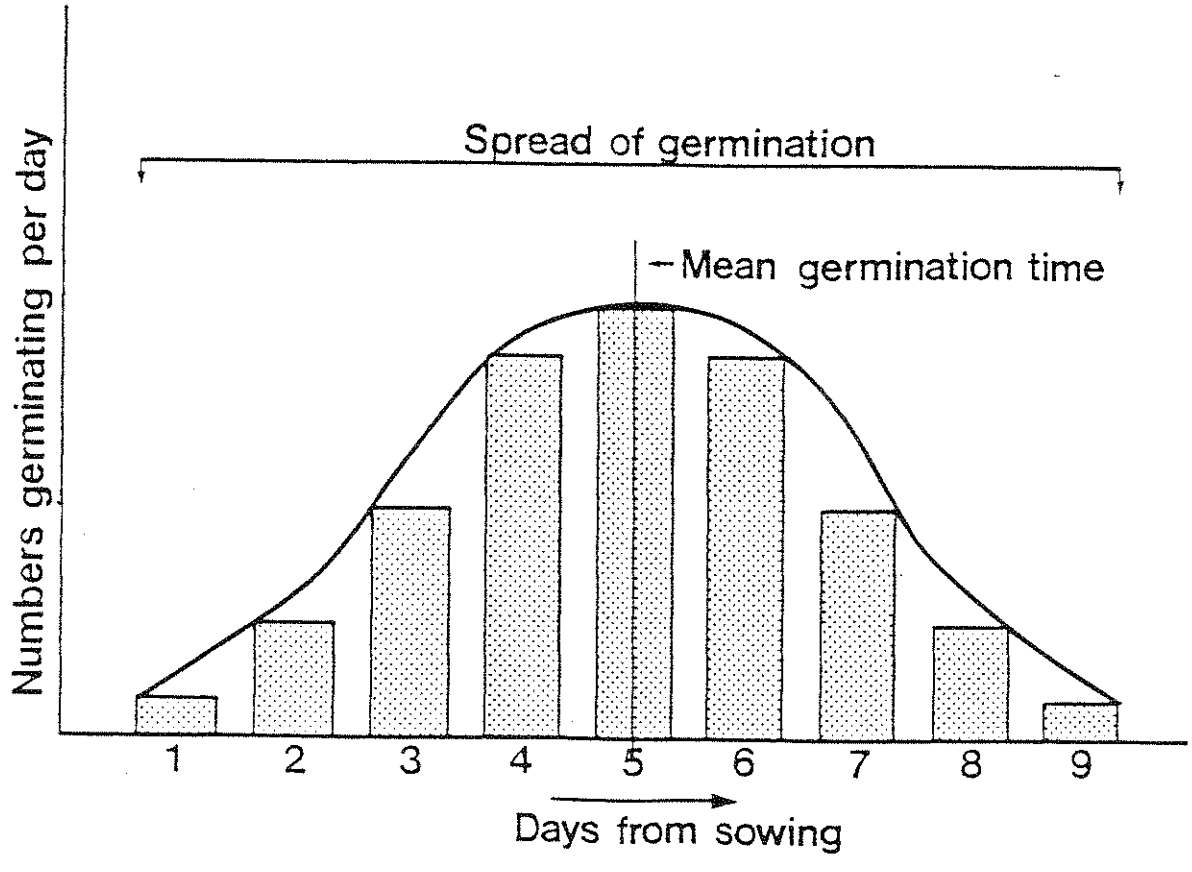
Clearly improvement in seed quality in commerce will result from improved seed production techniques, from treatment of seeds or a mixture of both approaches. Many seed treatments have been tested and

developed to improve seed performance of a wide range of species. As a result of research at IHRW on vegetable seeds, methods for improving seed quality in these species are now being widely adopted. However, few studies have been made with seeds of bedding plant species and therefore a further purpose of this present study was to investigate the potential for these seed technology techniques to improve seed quality in the bedding plant species identified.

During this study treatment protocols developed on a small scale were adapted to systems capable of commercial scale operation. These same protocols could also be used for on site treatment using smaller-scale apparatus. The performance of seeds given these treatments was then assessed in a range of conditions that could be experienced during seedling production in good commercial practice.

Definition of terms used

A population of seeds shows a characteristic pattern of germination. Initially a few seeds germinate per day, but with each passing day more seeds germinate until a maximum is reached and then the number germinating per day declines with further days after sowing. This change in numbers germinating each day follows the characteristic bell-shaped curve shown below:



From the curve we can by addition of the numbers germinating per day obtain the total number germinated or 'percentage germination'. We can also estimate the rapidity with which seeds in a lot germinate by calculating the 'mean germination time'. We can also estimate the variability in times to germination in the population by calculating the 'spread of germination'(ln variance days). This estimate of 'spread of germination' increases as the time over which the population of seeds takes to germinate increases. These same characters are also used to describe seedling emergence from compost.

Summary of results

Germination responses to environmental conditions

The germination responses of seven bedding plant species to a range of temperatures and water potentials, both with and without light were investigated. The species were; Primula acaulis, Impatiens wallerana, Salvia splendens, Verbena X hybrida, Petunia X hybrida, Tagetes patula (French marigold), and Tagetes erecta (African marigold). In the light all species except Primula exhibited maximum percentage germination over the range 10-25°C. In Primula the optimum temperature range was 15-20°C. Mean germination time was greatly affected by temperature in all except Tagetes species which germinated in less than 5 days over the range 5-30°C. The other species showed optima at 20-30°C except Primula which showed an optimum at 20°C. Germination of both Primula and Impatiens was enhanced in the presence of light. In general mean germination time increased and percentage germination decreased with decreasing water potential (less available water) of the germination medium.

The development of seed treatment protocols

Several seed grading and selection methods were evaluated and the results reported. For example, one novel approach showed a clear relationship between the colour of Verbena seeds and subsequent performance because seed colour was related to seed maturity at harvest. The potential therefore exists to 'colour sort' these seeds to improve quality. Approaches were made to 'Gunsen's Sortex Limited', who make 'colour graders', to see if Verbena seeds could be sorted using their machines, but technical difficulties were encountered and any solution would entail substantial redesign of existing equipment.

The effects of Gibberellic acid ($GA_{4/7}$) and benzyladenine (BA) alone

and in combination were tested on all but Tagetes species. $GA_{4/7}$ fully overcame the light requirement for germination in Primula and improved germination of Impatiens in the dark. Impatiens germination was further enhanced by combining $GA_{4/7}$ with BA. These plant growth regulators (PGRs) had no beneficial effects in initial experiments on the other species tested . The results of these experiments were used as the basis for developing PGR soak treatments.

The effects of a wide range of fungicide and PGR soaks and osmotic priming, both alone and in combination, on the germination of five of the bedding plants were tested. Germination results are reported from seeds air-dried after treatment. The bedding plants used were Primula, Impatiens, Salvia, Verbena and Petunia. Due to the large number of treatments tested these treatments were carried out on a small scale and tested in germination boxes. In general priming treatments reduced mean germination time of all species. PGRs applied in a 48h soak at 5°C increased percentage germination of Verbena seeds in the light and Primula and Impatiens seeds in the dark. These same PGRs enhanced the benefits of osmotic priming these species when added to priming solutions. In each of these cases, the most effective of the range of treatments tested is identified. With the exception of Salvia seeds which could not be dried following treatment without damage, significant benefits were shown with all other species for seed treatments that have commercial potential.

Large scale seed treatment and seedling establishment

A more limited range of the most effective combinations of osmotic priming / PGR / fungicide treatment protocols were developed on a larger-scale in aerated solutions. These experiments were carried out on four of the bedding plants; Primula, Impatiens, Verbena and Petunia. Combination priming treatments reduced mean germination time of all species and increased percentage germination of Primula and Impatiens seeds in the dark compared to that from untreated controls. In cellular trays, seedling emergence time was reduced in all species by priming. These benefits were enhanced by the addition of PGRs to the priming solution. PGRs were more effective when added to the priming solution than when applied as a pre-soak. In general, oxygen enrichment of the priming solution reduced seed performance unless PGRs were also present in the solution. The most effective treatment combinations were:

Primula, oxygen enriched priming with gibberellic acid ($GA_{4/7}$, 10^{-5}M); Impatiens, priming with $GA_{4/7}$ (10^{-4}M) and benzyladenine (BA, 10^{-6}M); Verbena, priming with $GA_{4/7}$ (10^{-4}M); and Petunia priming alone. Seeds of all species were pre-soaked in Iprodione solutions and osmotic potentials of priming solutions and treatment durations are also specified in the reports. Some examples of the earlier seedling emergence and increased percentage emergence from primed seeds sown in cellular trays are illustrated in plates 1-6. Further experiments also investigated seedling emergence of both treated and untreated seeds at a range of compost temperatures and moisture contents.

Summary of main points

1. The germination response to environmental conditions varies considerably between species, but good performance (although not necessarily optimum performance) is possible from all the species tested in a very limited range of temperatures (c. 20°C) and compost moisture contents.

2. Significant benefits can be achieved by seed selection techniques and chemical seed treatments, however both approaches are species specific. The bases of a range of treatment protocols have been outlined in this report and now require commercial development and testing.

3. Under near optimal conditions there are worthwhile gains from using seed treatments to increase plant stands, reduce seedling emergence time and to reduce the spread in times to emergence depending on species. However, although seed treatments improved seed performance under many conditions the results suggest that seed treatments will not completely eliminate the adverse effects on emergence of non-optimal environmental conditions that might be experienced in bedding plant seedling production.

4. The improvement of seed quality through seed technology is beneficial, but further major improvements will depend upon improved seed production practices.

Further details

Detailed descriptions of the experiments and the results have been grouped together for clarity into three separate reports. The reports cover: germination responses to environmental conditions (Report 1); the development and testing of a range of seed treatment protocols (Report 2); and the 'scaling up' of selected seed treatments and their effect on

seedling establishment in cellular trays (Report 3). Further information is given in annual reports written at the end of years 1 and 2 of this three year study.

REPORT 1: Germination responses of seven bedding plant species to environmental conditions and gibberellic acid.

Summary

The germination responses of seven bedding plant species to a range of temperatures and water potentials, both with and without light are described. The species were; Primula acaulis, Impatiens wallerana, Salvia splendens, Verbena X hybrida, Petunia X hybrida, Tagetes patula, and Tagetes erecta. In the light all species except Primula exhibited maximum percentage germination over the range 10-25°C. In Primula the optimum temperature range was 15-20°C. Mean germination time was greatly affected by temperature in all except Tagetes species which germinated in less than 5 days over the range 5-30°C. The other species showed optima at 20-30°C except Primula which showed an optimum at 20°C. Germination of both Primula and Impatiens was enhanced in the presence of light. In general mean germination time increased and percentage germination decreased with decreasing water potential of the germination medium.

The effects of gibberellic acid ($GA_{4/7}$) and benzyladenine (BA) alone and in combination were tested on all but Tagetes species. $GA_{4/7}$ fully overcame the light requirement for germination in Primula and improved germination of Impatiens in the dark. Impatiens germination was further enhanced by combining $GA_{4/7}$ with BA. These plant growth regulators had no beneficial effect on the other species tested.

Introduction

Commercial pressures on the pot and bedding plant industry have created the need to adopt cellular tray systems for plant raising.

However, for many species poor seed quality makes direct seeding uneconomic. This poor seed quality is often due to seed retaining the characteristics typical of wild species such as, dormancy, a wide range of seed maturity at harvest, and a limited temperature range over which seeds can germinate rapidly. Much of this variation in seed quality is therefore physiologically determined and may be improved by seed technology and by optimising germination conditions. As part of a programme of work to test this possibility and develop practical seed treatments, the germination responses of seed from seven species were studied in a range of environments. Most growers have facilities with a limited range of options for environmental control for germination and in addition, there is a need to produce plants from many species, cultivars and seed lots at the same time. One purpose of this study was therefore to determine whether robust general recommendations for the most suitable environmental conditions during germination could be made which would apply to a number of species. Six of the bedding plants (Primula, Impatiens, Salvia, Verbena and African and French marigolds) used in this study were identified in a UK grower survey as having major seedling establishment problems in practice. The seventh, Petunia, was identified as having few establishment problems and was therefore included for reference. The species and cultivars used in this study are commonly used in the UK.

In a review of temperature and light requirements for germination of ornamental species, the germination of some Primula, Impatiens, Salvia and Petunia species was shown to be enhanced by exposure to light and Verbena germination was enhanced in the absence of light (Cathey, 1969). Gibberellic acid (GA) has been shown to relieve dormancy in several flower species (Alderson, 1987) and help to relieve the light

requirement for germination of Primula species (Thompson, 1970; Miller and Holcomb, 1982) and Impatiens species (Jouret, 1977; Simmonds, 1980). A further aim of this study was therefore to determine the potential for using gibberellic acid to overcome germination problems in the bedding plant species studied here.

Materials and Methods

General experimental details

Seven bedding plant species were studied; Primula acaulis cv. Improved Biedermeier Strain, Impatiens wallerana cv. Dwarf Baby Mixed, Salvia splendens cv. Blaze of Fire, Verbena X hybrida cv. Olympia Mixed, Petunia X hybrida cv. Red Star, Tagetes patula (French marigold) cv. Spanish Brocade, and Tagetes erecta (African marigold) cv. Inca Orange. In all experiments germination (visible radicle present) was recorded on replicates of 50 seeds placed on filter paper moistened with distilled water or test solution in sealed transparent polystyrene boxes. In treatments where germination response in the dark was measured seeds were placed into germination boxes under green light and then wrapped in aluminium foil to exclude light. Germination counts were made daily initially and then at longer time intervals on seeds kept in the light (c. 100-170 μmol m^{-2} s^{-1}). When germination in the light was complete a single germination count was made on seeds kept in the dark. Percentage germination data were angularly transformed and spreads in time of germination (Orchard, 1977) were log transformed before all measured parameters were subjected to analyses of variance.

Effects of environment

In two separate series of experiments seeds of all seven species were subjected to a range of environmental conditions. In both experiments two replicates of each treatment were kept in the light and in the dark. In the first experiment seeds were placed into growth cabinets at seven temperatures, at 5±1°C intervals between 5 and 35°C. In the second experiment seeds were placed on solutions at four water potentials (distilled water, -0.1, -0.2 and -0.5 MPa) at each of three temperatures (10, 20 and 30°C). The concentration of polyethylene glycol (6000) used for each water potential was determined after Michel and Kaufmann (1973).

Effects of gibberellic acid and benzyladenine

The effect of gibberellic acid and benzyladenine (N-6-benzylaminopurine, BA) both individually and in combination on the germination response of seeds was examined in five of the bedding plants studied; Primula, Impatiens, Salvia, Verbena and Petunia. A mixture of gibberellins A_4 and A_7 ($GA_{4/7}$) were dissolved in 0.013 M phosphate buffer at pH 6.3 and used at concentrations between 10^{-3} and 10^{-5} M. BA, also dissolved in buffer at pH 6.3, was used at concentrations of 10^{-4} and 10^{-5} M. When combined, $GA_{4/7}$ was 10^{-4} and BA 10^{-5} M. All chemical treatments were replicated three times and placed at a range of temperatures between 15 and 30°C.

As there was no effect of light on the germination response of Salvia, Verbena and Petunia in the previously described experiments, chemical treatment comparisons were made in the light with control seeds on distilled water and on buffer. For Primula and Impatiens where seed germination response was affected by light, the treatments and both water and buffer controls placed in the dark were compared to further

controls in the light maintained at optimum temperatures (Primula 20°C and Impatiens 25°C).

Results and Discussion

Effects of environment

Mean germination time in the light was reduced to a minimum as temperature increased in all species (Figure 1). This reduction was comparatively small in Tagetes species which germinated rapidly at all temperatures. Mean germination time in Primula reached a minimum at 20°C, but in all other species mean germination time declined to 25°C and then showed little change or an increase with increasing temperature. The spread in times to germination showed a very similar pattern with temperature to that of germination time (data not shown).

There was little difference in percentage germination in the light over a wide range of temperatures in all species (Figures 2 and 3), but germination was reduced at 5 and 35°C in most cases. Primula seeds showed a more limited optimum range of temperatures between 15 and 20°C and little germination above 30°C. Impatiens seeds did not germinate at 5°C. In Tagetes patula, there was no effect of light, but in all other species percentage germination was reduced at the extremes of the temperature range tested in the dark (data not shown). There was no effect of light on germination in the following temperature ranges and species; Salvia 10-25°C, Verbena 10-30°C, Petunia 15-30°C and Tagetes erecta 5-30°C. A different pattern of germination response to temperature was shown in the light and in the dark by seeds of Primula and Impatiens (Figure 3). Fewer seeds germinated and there was a more clearly defined optimum temperature in the dark.

Figure 1. Effects of temperature on mean germination time in the light. S.E.1 = standard error for Primula and Impatiens (DF=13), S.E.2 = standard error for other species (DF=34). □ , Primula; ○ , Impatiens; ● , Salvia; △ , Verbena; ■ , Petunia; ◇ , Tagetes patula; ▲ , Tagetes erecta.

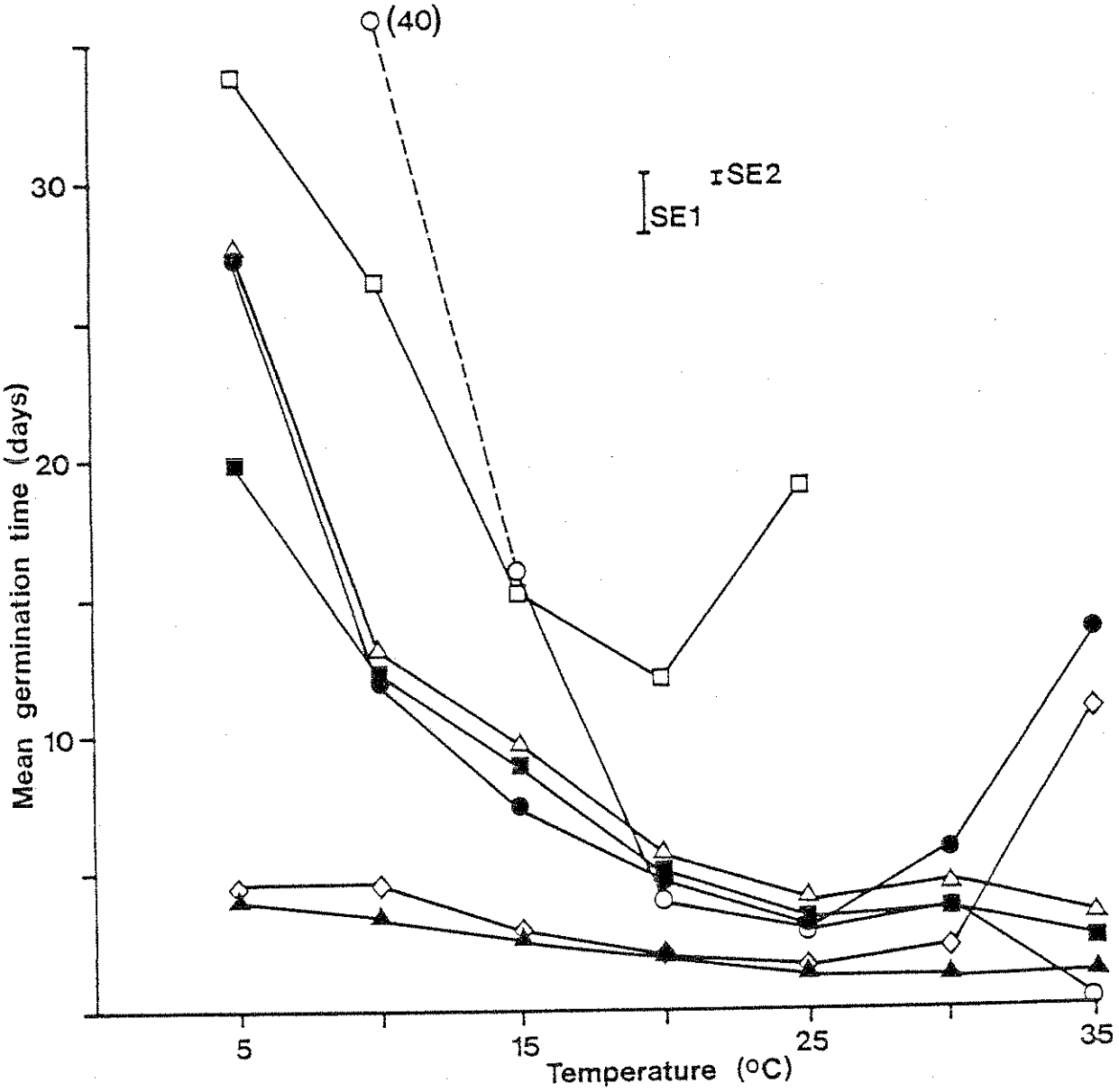


Figure 2. Effects of temperature on percentage germination (angular transformation). S.E.= standard error with 34 DF. Symbols as for Figure 1.

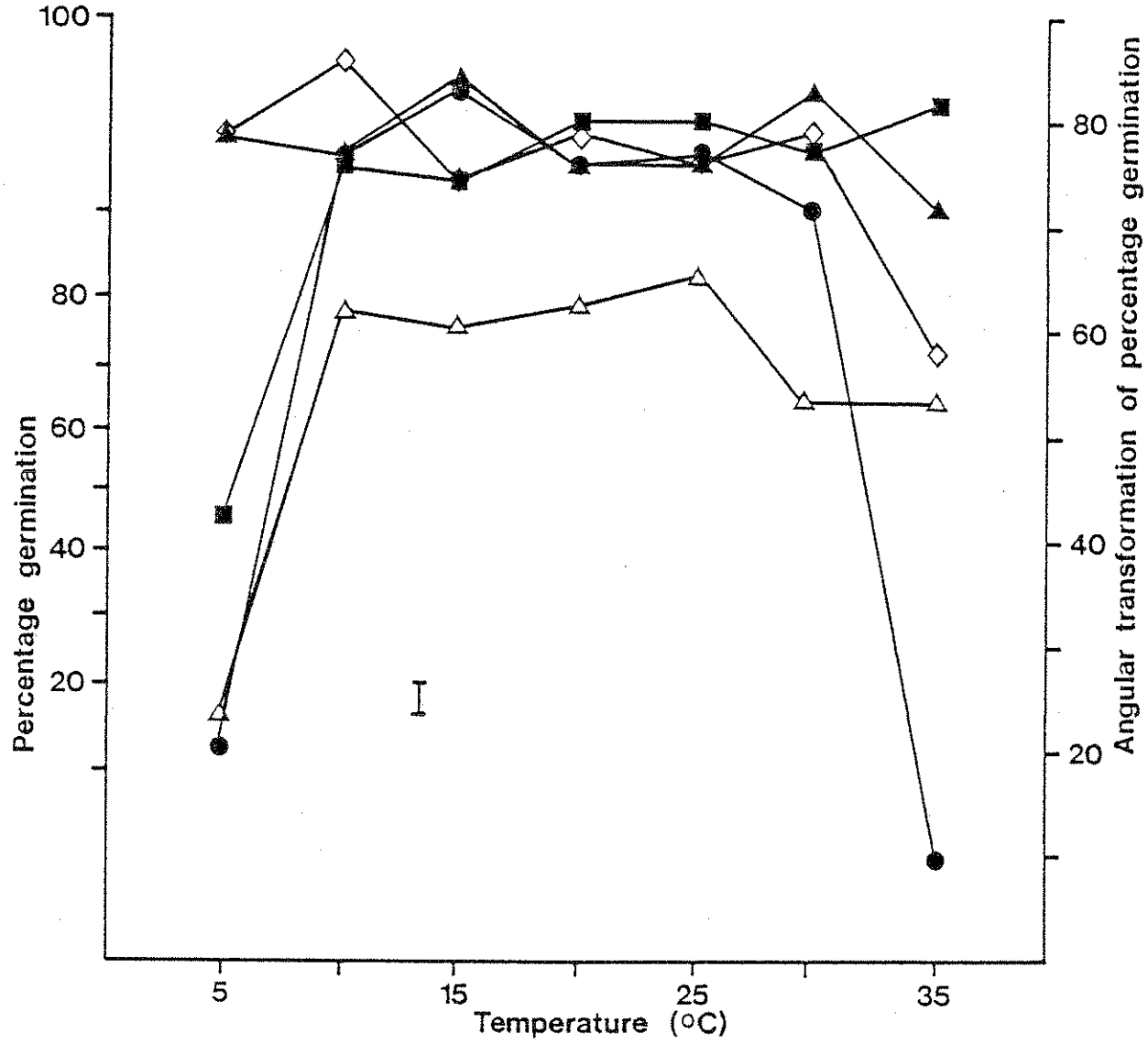
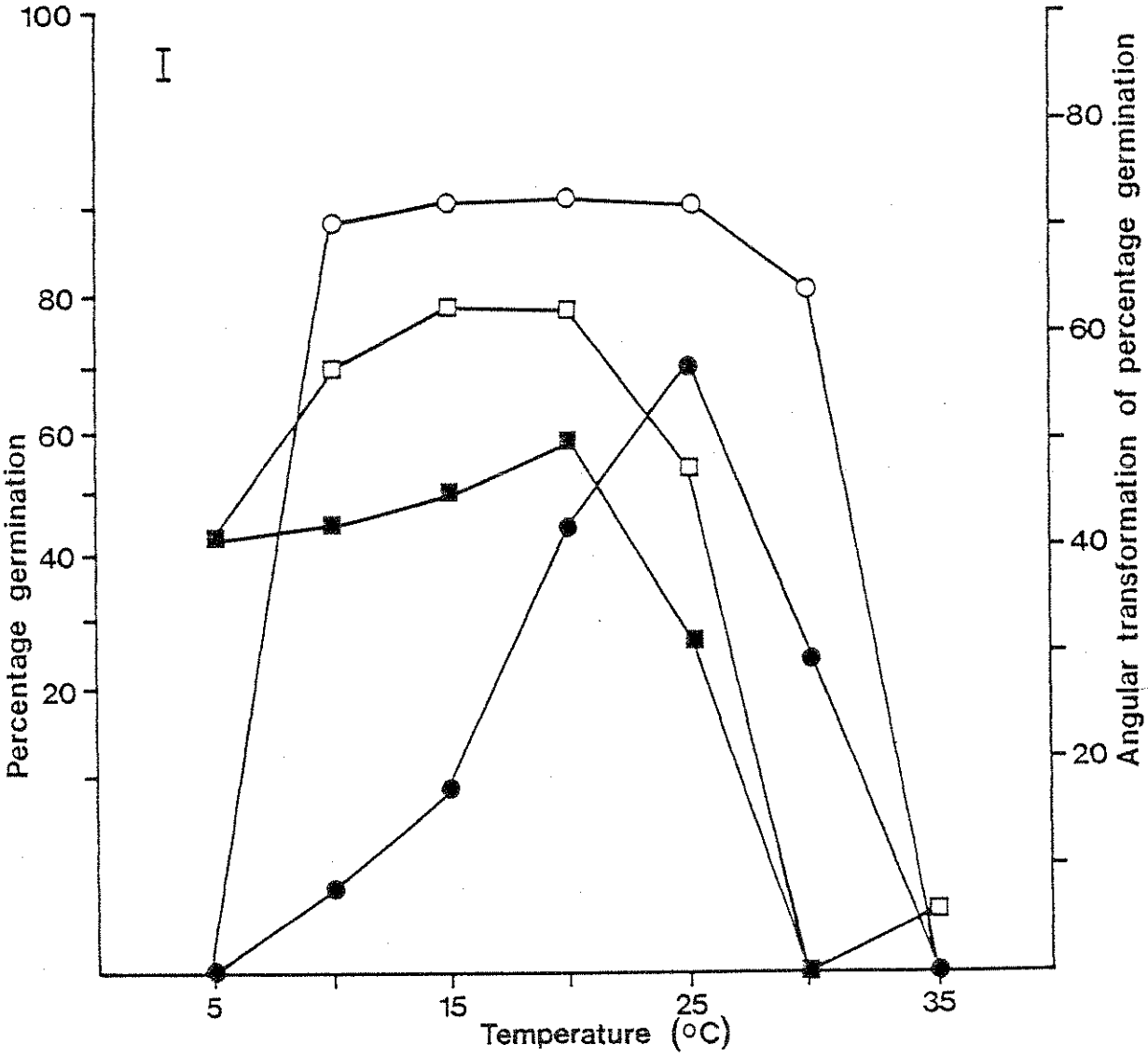


Figure 3. Effects of temperature and light/dark on percentage germination (angular transformation) of Primula and Impatiens. S.E.= standard error with 13 DF. □ ■, Primula; ○ ●, Impatiens. Open symbols in the light, closed symbols in the dark.



The germination responses to environmental conditions reported here are broadly in agreement with those of Cathey (1969). Although germination was a little more rapid at 25°C in some species, in practice all species could be germinated well at 20°C. The effect of water potential on mean germination (Figure 4) and percentage germination (Figure 5) are therefore shown at 20°C. In general mean germination time increased with a decrease in water potential (more negative) in all species except Verbena (Figure 4). With Verbena mean germination time was increased by -0.5 MPa only. The effects of temperature were similar to that shown already and again a similar pattern was shown in the spread in time to germination as that shown for germination time (data not shown). There was no significant effect of water potential on percentage germination of Tagetes species and Petunia at 20°C. With Primula there was a progressive drop in percentage germination with decreasing water potential, with the other species germination was significantly reduced at -0.5 MPa only. At 10°C the pattern of results was similar but at 30°C all species gave significantly lower percentage germination at -0.5 MPa compared to other water potentials. Again no germination occurred at 30°C in Primula seed and the effects of light on all species were as reported for the previous experiments.

The rapid germination of a high percentage of seeds from Tagetes species in all the environments tested would suggest that the establishment problems experienced in practice are associated more with the mechanical difficulties of sowing these elongated seeds than with physiological problems. Tagetes species were therefore not included in further work.

In further experiments not described here the germination responses of several seed lots and cultivars of Salvia, Verbena, Petunia, and the

Figure 4. Effects of water potential on mean germination time at 20°C. S.E.= standard error with 22 DF for Primula and Impatiens, 11 DF for other species. dw, distilled water. Symbols as for Figure 1.

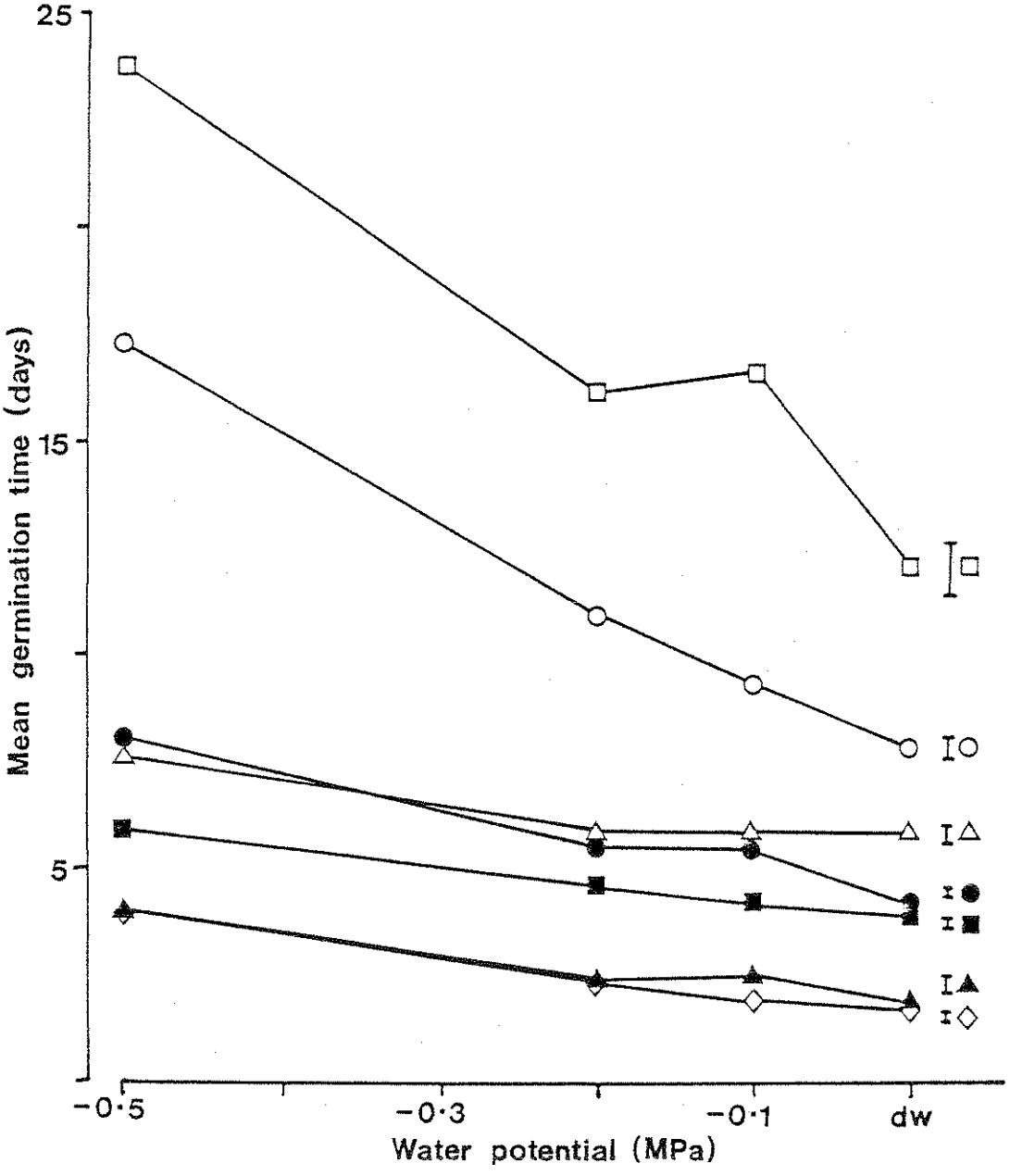
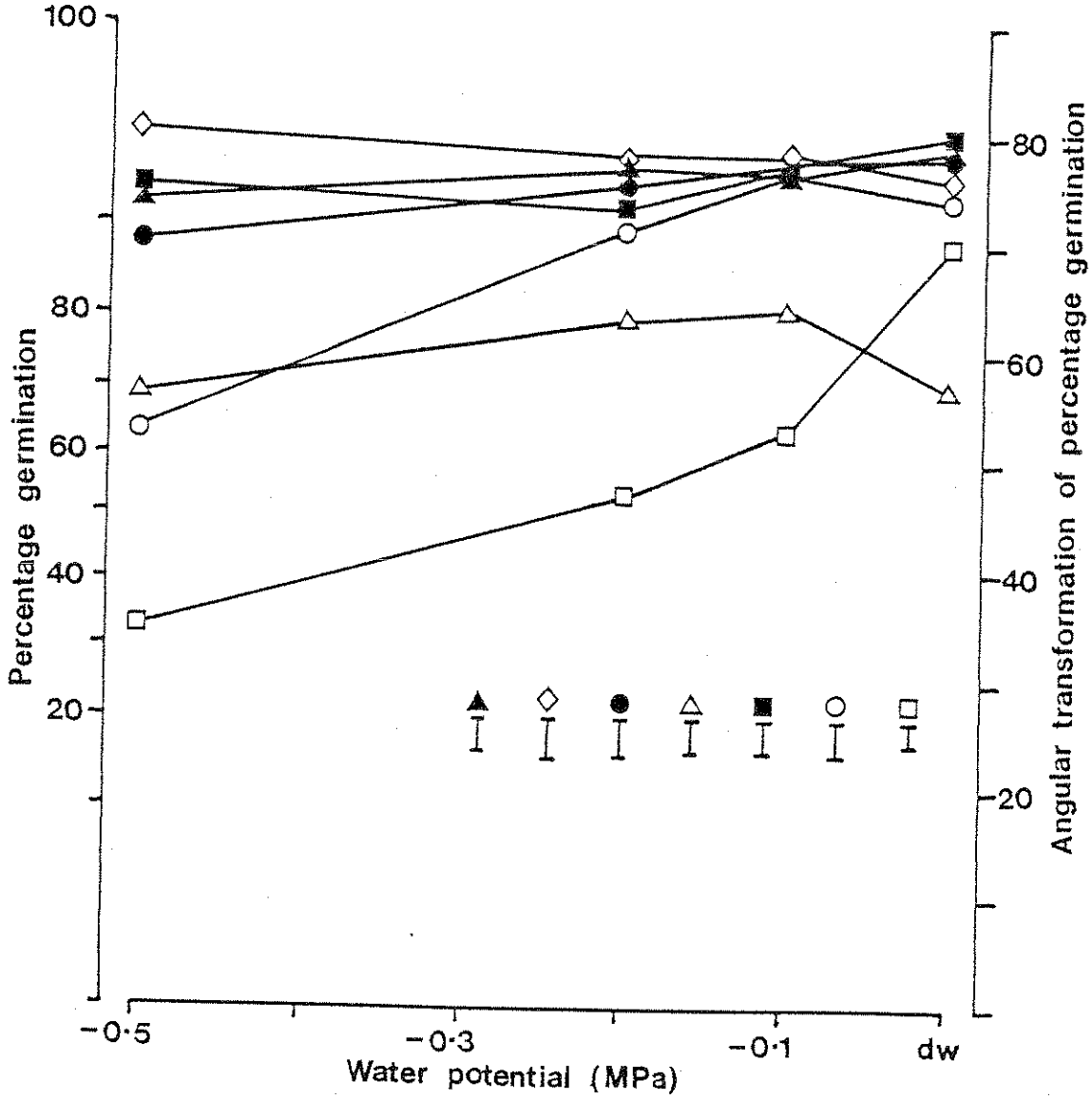


Figure 5. Effects of water potential on percentage germination (angular transformation) at 20°C. S.E.= standard error with 22 DF for Primula and Impatiens, 11 DF for other species. dw, distilled water. Symbols as for Figure 1.



Tagetes species were recorded at a range of temperatures between 10 and 30°C. For mean germination time and percentage germination there were no significant temperature x seed lot interactions for Salvia, Verbena and Tagetes species. With Petunia lower viability seed gave a progressive increase in percentage germination with temperature, whereas high viability seed did not (data not shown). These results suggest that general recommendations within these species would be adequate and apply to a wide range of lots in commerce.

Effects of GA

Gibberellins can be used to overcome dormancy in some flower seeds (Alderson, 1987) although their effectiveness can vary according to seed structure and the nature of the block to germination (Atwater and Vivrette, 1987). Gibberellins have been shown to promote germination in a range of Primula species (Thompson, 1970; Miller and Holcomb, 1982) and Impatiens species (Jouret, 1977). The effect of gibberellins can also be enhanced by combination with cytokinins, for example, in celery (Thomas et al, 1975; Biddington, Thomas and Dearman, 1980). In the present experiments imbibing seeds on plant growth regulator solutions had no significant effect on the germination response of Verbena and no beneficial effect on the response of Petunia and Salvia. BA delayed germination of Petunia and Salvia seeds and reduced the percentage germination from 92 to 82% and 90 to 25% respectively in the highest concentration tested (10^{-4} M). However, $GA_{4/7}$ improved the germination of Primula and Impatiens in the dark (Table 1) although it had no effect on the germination response to temperature in either species. $GA_{4/7}$ completely overcame the light requirement for germination in Primula so that percentage germination was not significantly different from that of the control which was kept in the light. Impatiens percentage

TABLE I

The effect of plant growth regulators on percentage germination (angular transformation) of Primula and Impatiens seeds in the dark

Germination solution	Light(+)/Dark(-)	Primula			Impatiens		
		15°C	20°C	25°C	15°C	20°C	25°C
Water	+		62.5				75.1
Water	-	44.2	43.5	28.4	2.7	25.3	48.1
Buffer	-	36.8	36.1	23.6	12.4	23.4	39.5
$GA_{4/7}(10^{-4}M)$	-	56.0	61.2	46.9	16.4	56.4	60.3
$GA_{4/7}(10^{-4}M)+BA(3x10^{-5}M)$	-	54.0	51.2	29.7	30.5	59.6	66.2
SE (DF 26)			1.40			2.40	

germination in the dark was further improved when $GA_{4/7}$ was combined with BA, but was still significantly less than in the control kept in the light. The seed response of Impatiens to GA was in agreement with that shown by Simmonds (1980). These results indicate the potential benefit to be obtained from developing seed soak treatments with plant growth regulators in these two species.

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REPORT 2: The combined effects of osmotic priming with plant growth regulator and fungicide soaks on the seed quality of five bedding plant species

Summary

The effects of fungicide and plant growth regulator (PGR) soaks and osmotic priming, both alone and in combination, on the germination of five bedding plant species are reported. The species were Primula acaulis, Impatiens wallerana, Salvia splendens, Verbena X hybrida and Petunia X hybrida. Germination results are reported from seeds air dried after treatment.

In general priming treatments reduced mean germination time of all species. PGRs applied in a 48h soak at 5°C increased percentage germination of Verbena seeds in the light and Primula and Impatiens seeds in the dark. These same PGRs enhanced the benefits of osmotic priming to these species when added to priming solutions. In each of these cases the most effective of the range of treatments that were tested is identified. With the exception of Salvia seeds which could not be dried following treatment without damage, significant benefits were shown with all species for practical seed treatments that have commercial potential.

Introduction

For the efficient and profitable production of direct sown bedding plants in cellular trays it is essential to have seeds of high quality, however, for many bedding plant species such seeds are difficult to obtain reliably in adequate quantities. A survey of UK growers was used

to identify six species that had major establishment problems in practice. When the germination responses of seeds to environmental conditions were investigated (Report 1), it was shown that in several of these species germination performance, even under optimum conditions, was inadequate for direct seeding into cellular trays. Clearly improvement of seed quality in commerce will result from improved seed production techniques, from treatment of seeds or a mixture of both approaches. Many seed treatments have been tested and developed to improve seed performance of a wide range of species (Heydecker and Coolbear, 1976) and the effects of some of these treatments on flower seed germination have been reviewed recently by Alderson (1987). However, few studies have been made with seeds of bedding plant species. The purpose of this present study was to investigate the potential for seed technology techniques now becomming widely used on vegetable seeds (Gray, 1989) to improve seed quality in bedding plant species known to have establishment problems (Report 1).

Materials and Methods

General experimental details

Five bedding plant species were studied; Primula acaulis cv. Improved Biedermeier Strain, Impatiens wallerana cv. Dwarf Baby Mixed, Salvia splendens cv. Blaze of Fire, Verbena X hybrida cv. Olympia Mixed and Petunia X hybrida cv. Red Star. In all experiments before drying of the seed after treatment or testing, both treated and untreated seeds were washed under running tap water for 0.5 mins and then rinsed 3 times in distilled water. When seeds were dried they were placed in a flow of air at 15°C and 45 ± 5% rh for 48 h and this was found to be sufficient to allow the seeds to reach an equilibrium moisture content. Comparisons

between treated and control seeds were made in germination tests carried out in 80 x 120 x 20 mm transparent polystyrene boxes containing fifty seeds on two layers of moistened absorbent paper (Whatman grade 181). Germination (visible radicle present) was recorded daily initially, then at longer time intervals on three replicates per treatment. In treatments where germination response in the dark was measured seeds were placed into germination boxes under green light and then wrapped in aluminium foil to exclude light. When germination in the light (c. 100-170 μmol m^{-2} s^{-1}) was complete a single germination count was made on seeds kept in the dark. When germination counts were complete seedlings were evaluated according to International Seed Testing Association (ISTA) rules (Anon, 1985). Percentage data were angularly transformed and spreads in time to germination (Orchard, 1977) were log transformed before all measured parameters were subjected to analyses of variance.

Preliminary experiments

Different water to absorbent paper ratios were used for germination tests to develop optimum seed test conditions. The optimum quantity of distilled water for germination of Verbena was 7.5 ml per box. All other species performed best with 10 ml per box which was sufficient to fully wet the paper. These quantities of water were then used under test conditions. For priming studies using the same boxes and paper 15ml of polyethylene glycol (PEG) was most effective.

In order to develop a simple prophylactic treatment against seed born fungal proliferation in test conditions, seeds of all species were imbibed for 3 and 6h in two concentrations of Iprodione (0.1 and 0.3% a.i. as Rovral, 50% a.i. wettable powder). Treated seeds gave visibly cleaner seedlings. Treatments that had no phytotoxic effect were then

adopted as standard pre-treatments in all experiments unless otherwise stated. These pre-treatments were 3h imbibition in 0.1% a.i. Iprodione for Verbena and Impatiens and 0.3% for the other species, all seeds not treated with Iprodione were soaked in water for the same period. Seeds were subsequently dried before entering priming treatments, but were not dried before entering PGR soak treatments.

Osmotic priming

Seeds of all five species were primed on solutions of 232, 273 and 342 g PEG '6000' Kg^{-1} water giving nominal osmotic potentials of -0.75,-1.00 and -1.50 MPa respectively (Michel & Kaufmann, 1973). All treatments were placed at 15°C for three durations (7, 10 and 14 days). Following treatment seeds were placed in germination tests at 20°C after drying to equilibrium, partial drying for 8h and without drying. Treatments were compared to a double replicated untreated control.

Plant growth regulator soaks

In a series of experiments, seeds of Primula, Impatiens and Verbena were soaked in plant growth regulator (PGR) solutions for 48h at 5°C before drying and were then compared with controls in germination tests. The controls included untreated seeds and seeds soaked in water and in buffer. Comparisons were made at 20°C for Impatiens and at 15°C for Primula and Verbena. Germination of Primula and Impatiens PGR soaked seeds in the dark was compared to that from the controls in the light and in the dark. Germination comparisons of PGR soaked Verbena seeds with control seeds were made in the light only. Verbena seeds were not iprodione pre-treated.

PGR solutions were a mixture of gibberellins A_4 and A_7 ($GA_{4/7}$),

benzyladenine (N-6-Benzyl-aminopurine, BA) and daminozide (N-dimethylaminosuccinamic acid) individually and as $GA_{4/7}$+BA and $GA_{4/7}$+ daminozide combinations. All PGRs were dissolved in 0.013 M phosphate buffer at pH 6.3. $GA_{4/7}$ was used at concentrations of 10^{-3}-10^{-5} M, BA at 10^{-4}-10^{-6} M and daminozide at 10^{-2}-10^{-4} M.

Early seedling growth from treated and untreated seeds was compared using a slope test technique described by Gray and Steckel (1983).

Combined treatments

Primula seeds were primed for 10 days at 15°C on a PEG solution at a nominal osmotic potential of -1.50 MPa, Impatiens for 14 days at -0.75 MPa and Verbena for 14 days at -1.50 MPa. Seeds were also primed under the same conditions following PGR soaks in the most effective concentrations of $GA_{4/7}$ alone and combined with BA and with daminozide which were identified in previous experiments. Seeds were dried following the PGR soak prior to priming. In a further set of treatments seeds were primed on PEG solutions containing the same concentrations of PGRs used for soaking seed. All treatments were compared with untreated controls after drying.

Germination test comparisons were made in both the light and dark with Primula and Impatiens at 15°C and 20°C respectively. Verbena seed treatments were compared in the light only at 15°C.

Results and Discussion

The purpose of the experiments presented was to determine what improvements in seed quality might be achieved by seed treatments. As

seed drying is a necessary pre-requisite for storage and handling under commercial conditions the data selected for presentation were from treatments that gave the best response from seeds air dried after treatment. These treatments could therefore form the basis of practically useful techniques.

Osmotic priming

Priming without subsequent drying reduced mean germination time compared to that from unprimed seeds of all species except Primula (table 1). Germination began earlier from primed Primula seeds, but as a result of a greater spread in time to germination mean germination time was delayed compared to untreated seeds. There was relatively little effect of priming on the spread in time to germination of other species. Priming increased percentage germination of Salvia seeds, but reduced percentage germination of Primula seeds. The general effects of priming on Impatiens seeds is in agreement with those published elsewhere (Simmonds, 1980; Frett and Pill, 1989), but optimum treatments cannot be compared as different ranges of treatments were used in each study.

The effect of drying seeds following priming was small except with Salvia where germination was reduced and delayed compared to that from undried primed seeds. In this species even the partial drying treatment damaged seeds. Drying damage was also reported following low temperature imbibition treatments to Salvia seeds (Carpenter, 1989). Here drying damage also occurred in Salvia seeds primed for shorter durations and in seeds primed in a further experiment using solutions with more negative osmotic potentials (-2.0 MPa) to prime seeds. This suggests that damage is not the result of 'over priming'. The results of Carpenter (1989) show a progressive reduction in percentage germination as solutions with increasingly negative osmotic potentials were used for priming Salvia

TABLE I

The effect of osmotic priming at 15°C on the germination of 5 bedding plant species. Primula (-1.5 MPa,10 days), Impatiens (-0.75 MPa,14 days), Salvia (-1.5 MPa,14 days), Verbena (-1.5 MPa,14 days), Petunia (-1.0 MPa, 14 days). S.E.1, for control means, S.E.2,for other treatment means (59 DF). Angular transformations of percentages are in parentheses.

Species	Treatment	Mean germination time (days)	Spread in time to germination (ln variance days)	Percentage germination
Primula	Control	12.2	2.14	82 (65)
	Primed	17.6	2.69	69 (56)
	Primed & dried	17.5	2.60	66 (54)
	S.E.1,2	1.14,1.60	0.085,0.121	(1.9,2.7)
Impatiens	Control	7.9	0.72	92 (74)
	Primed	5.0	0.62	89 (71)
	Primed & dried	5.9	0.37	89 (71)
	S.E.1,2	0.13,0.19	0.063,0.089	(1.7,2.4)
Salvia	Control	8.9	1.55	66 (54)
	Primed	4.0	1.19	76 (61)
	Primed & dried	8.5	1.73	64 (53)
	S.E.1,2	0.39,0.55	0.083,0.118	(1.8,2.6)
Verbena	Control	7.7	1.14	69 (56)
	Primed	4.0	0.92	68 (56)
	Primed & dried	3.8	0.97	67 (55)
	S.E.1,2	0.24,0.34	0.098,0.139	(1.8,2.5)
Petunia	Control	5.6	0.04	94 (76)
	Primed	2.0	0.15	94 (76)
	Primed & dried	2.3	0.28	94 (76)
	S.E.1,2	0.07,0.10	0.099,0.140	(1.2,1.7)

seeds. In these experiments no such trend was shown.

Plant growth regulator soaks

In report 1 it was shown that germinating Primula and Impatiens seeds on $GA_{4/7}$ or $GA_{4/7}$+BA solutions, respectively, promoted germination in the absence of light. Such experimental observations in celery have been used to develop commercially effective seed soak treatments (Thomas and Whitlock, 1980). This soak treatment technique was tested here with Primula, Impatiens and Verbena seeds. High $GA_{4/7}$ concentrations may be required for an effective soak treatment which could result in residual etiolation effects. In an attempt to reduce the concentration of $GA_{4/7}$ required it was used in combination with daminozide and with BA which have promoted $GA_{4/7}$ effects on germination in other species (Thomas et al, 1975; Biddington, Thomas and Dearman, 1980). The results of seed soak treatments with Primula and Impatiens are summarised in Table 2. Germination in the dark was increased by soaking seeds in solutions containing $GA_{4/7}$ both with and without the addition of BA and of daminozide. The most effective treatment with both species involved the highest concentrations of $GA_{4/7}$ and daminozide. However, early seedling growth measurements on Impatiens show significant etiolation and reduced root growth when $GA_{4/7}$ was used at 10^{-3} M (table 2). Seedling growth from seeds soaked in $GA_{4/7}$ at 10^{-4} M was not significantly different from the control, but a small though significant increase in shoot length occurred with the further addition of BA or daminozide. There was little effect of BA and daminozide on Impatiens root growth, with Primula however, BA at 10^{-5} M significantly increased the number of abnormal roots in seedling evaluations. PGR seed soaks can therefore be effective, but the concentration used is critical if adverse effects are to be avoided.

TABLE 2

The effect of PGR soak treatments on percentage germination (angular transformation in parentheses) of Primula and Impatiens seeds in the dark and subsequent growth of Impatiens seedlings on slope tests in the light

Treatment	Impatiens					Primula
	Percentage germination	Shoot length		Root length		Percentage germination
		mm	CV(%)	mm	CV(%)	
Control	99(85)	4.5	29	51.7	46	64(53)
Control in dark	79(64)					41(40)
$GA_{4/7}$ 10^{-4}M	89(71)	4.7	33	51.7	39	55(48)
$GA_{4/7}$ 10^{-3}M	90(72)	7.5	42	41.5	56	53(47)
$GA_{4/7}$ 10^{-4}M + BA 10^{-6}M	93(77)	5.0	33	48.1	47	48(44)
$GA_{4/7}$ 10^{-3}M + BA 10^{-5}M	92(74)	7.0	44	31.4	71	50(45)
$GA_{4/7}$ 10^{-4}M + D 10^{-4}M	90(72)	5.0	37	49.0	48	51(46)
$GA_{4/7}$ 10^{-3}M + D 10^{-3}M	95(79)	8.4	33	47.6	41	57(49)
S.E.(DF=46)	(3.2)	0.17	2.1	2.03	2.9	(2.5)

PGR soaks also increased percentage germination of Verbena seeds (Figure 1) in contrast to earlier reported results with the same cultivar germinated on PGR solutions (Report 1). Soaking seeds in $GA_{4/7}$ at 10^{-3}M significantly reduced the mean germination time and spread in time to germination compared to that in the other treatments (data not shown). The addition of BA or daminozide to $GA_{4/7}$ at 10^{-4}M did not significantly reduce these same germination characteristics.

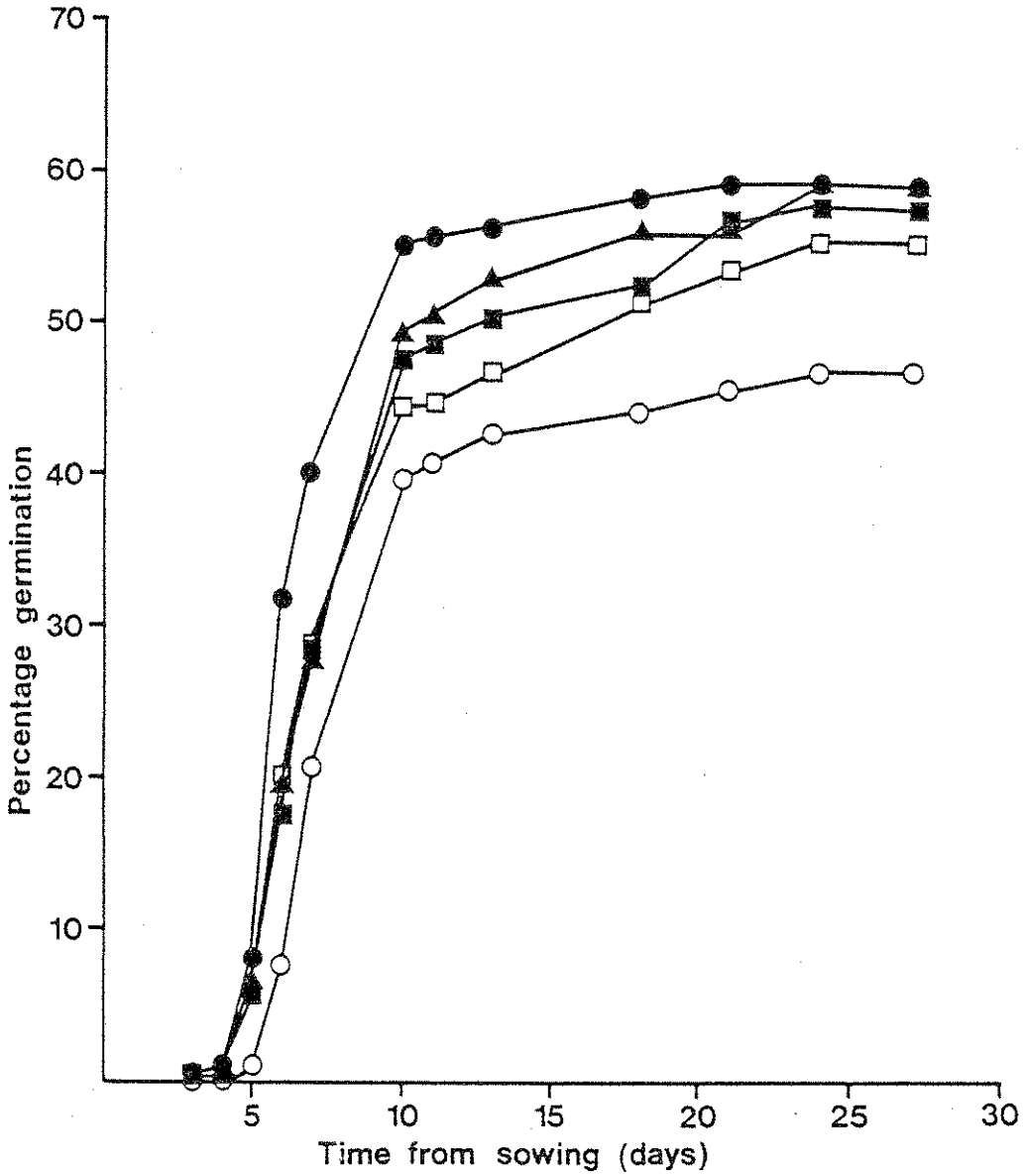
The percentage germination of Verbena seeds can be variable even under the same test conditions and this is largely due to substrate moisture levels (Heit, 1963). Preliminary experiments showed the need for reduced substrate moisture levels in seed tests with Verbena compared to other species. These results are in agreement with those of Heit (1963) and of Ely (1979). It is suggested that the higher substrate moisture levels used in the previous study (Report 1) masked the beneficial effects of PGRs that were demonstrated here. In related experiments not reported here a clear relationship was shown between Verbena seed colour and germination performance. Seed quality progressively improved from green through light brown to dark brown seeds. Green seeds presumably were less mature at harvest. The potential therefore exists to further increase Verbena seed quality by colour sorting.

Combined treatments

There are few reports in the literature on the response of seeds to combinations of treatments. Here several combinations of treatments were tested including: a combined fungicide and PGR soak followed by priming; a fungicide soak followed by priming in solutions containing PGRs; and a fungicide soak followed by priming without PGRs. A fungicide soak was used here as a more accurate method of application than dusting with a

Figure 1. Germination response of Verbena seeds to PGR soak treatments.

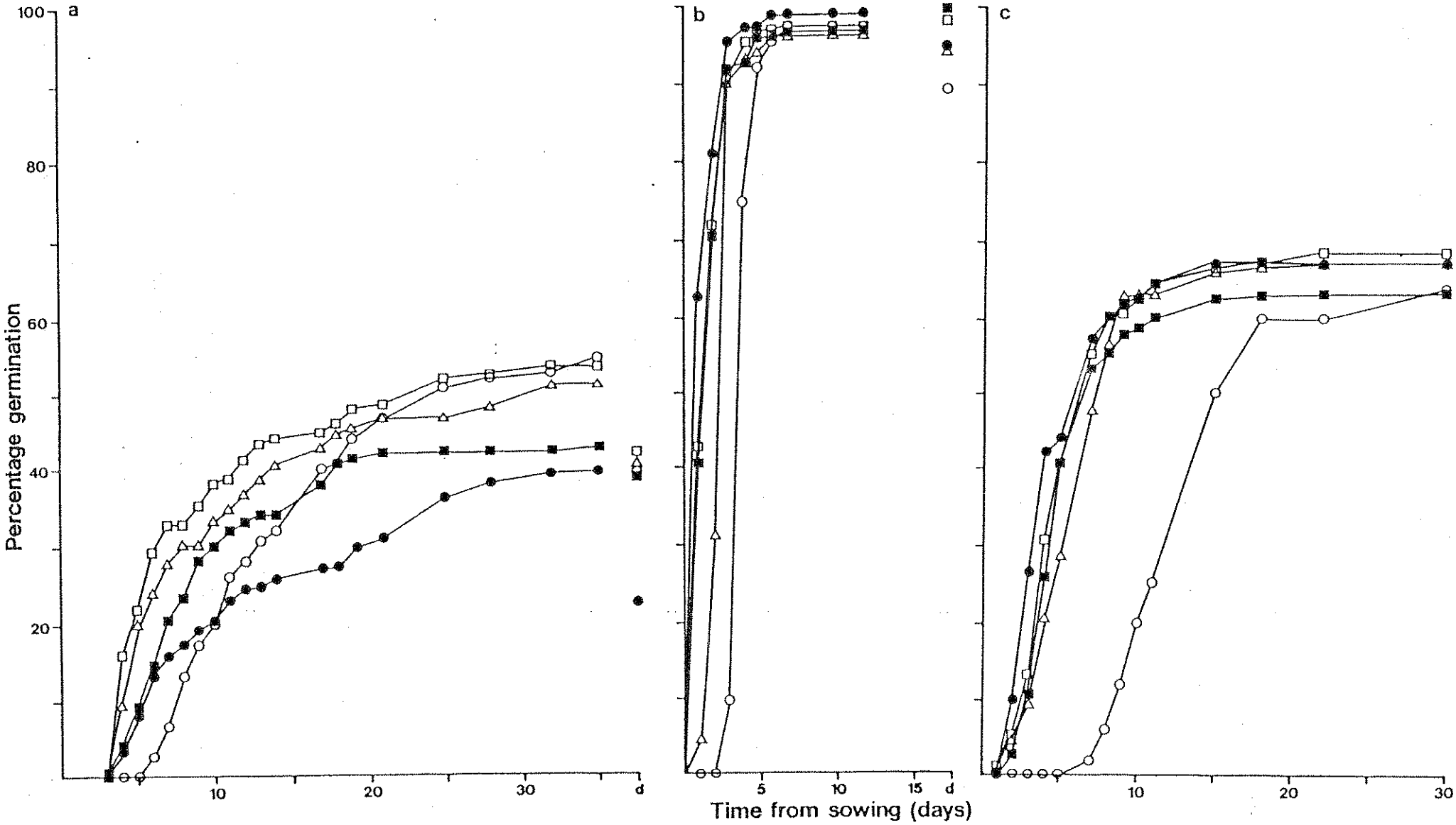
○, Control; ●, $GA_{4/7}$ 10^{-3}M; □, $GA_{4/7}$ 10^{-4}M; ■, $GA_{4/7}$ 10^{-4}M + BA 10^{-8}M; ▲, $GA_{4/7}$ 10^{-4} + daminozide 10^{-3}M



powder, especially on an experimental scale. Fungicides applied by soaking are also less likely to interact with subsequent treatments. In general, there was no significant difference in germination response between the two methods of combining priming and PGR treatments in any species. Results are therefore presented from treatments that had PGRs added to the priming solutions (Figure 2). Seeds from all priming treatments germinated earlier than untreated seeds. For the untreated seeds and most effective priming treatment, mean germination time for Primula was 13.8 and 8.7 days (SE 0.18, DF 18), respectively, corresponding figures for Impatiens were 3.7 and 1.5 days (SE 0.08, DF 18), and for Verbena 12.7 and 4.5 days (SE 0.46, DF 38). With Primula, priming reduced percentage germination as it did in earlier experiments, however when $GA_{4/7}$ was added to the priming solution percentage germination was not significantly different to that from untreated seed. The reason for this reduction in germination percentage following priming is not understood and requires further investigation. Percentage germination of Impatiens and Verbena seeds in all priming treatments was not significantly different from that in the untreated control. In the dark percentage germination of both Primula and Impatiens was increased by priming seeds in solutions containing PGRs. The most effective treatments were priming with $GA_{4/7}$ and $GA_{4/7}$ with BA for Primula and Impatiens respectively. These were also the most effective PGR treatments for these species when not combined with priming (Report 1). The addition of BA or daminozide to $GA_{4/7}$ in the priming solution had no additional benefit with Primula or Verbena seeds.

Seed treatments have been shown to have beneficial effects on all the species studied in the relatively unstressfull conditions of the seed test. However, with Salvia the potential value of practical seed

Figure 2. Germination response of a, Primula, b, Impatiens and c, Verbena seeds to priming in solutions containing PGRs. ○ , Control; ●, Primed; □ , Primed with $GA_{4/7}$ 10^{-4}M; ■ , Primed with $GA_{4/7}$ 10^{-4}M + BA 10^{-6}M (Primula and Impatiens) or $GA_{4/7}$ 10^{-4}M + BA 10^{-5}M (Verbena); △, Primed with $GA_{4/7}$ 10^{-3}M + daminozide 10^{-3}M (Primula and Impatiens) or $GA_{4/7}$ 10^{-4}M + D 10^{-3}M (Verbena). d, germination percentage in the dark.


a
b
c
100
80
60
40
20
Percentage germination
10
20
30
d
5
10
15
d
Time from sowing (days)
10
20
30

treatments is limited by seed damage during subsequent drying. More work is required to develop and optimise the treatments outlined in these experiments. In report 3 the potential to 'scale up' these techniques and their effects on seedling production in cellular trays from seeds of the same species was investigated.

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REPORT 3: Development of bulk priming/plant growth regulator seed treatments and their effect on the seedling establishment of four bedding plant species

Summary

A range of combinations of osmotic priming / plant growth regulator (PGR) / fungicide treatment protocols in aerated solutions were developed for four bedding plant species. The species were; Primula acaulis, Impatiens wallerana, Verbena X hybrida and Petunia X hybrida. Combination priming treatments reduced mean germination time of all species and increased percentage germination of Primula and Impatiens seeds in the dark compared with that from untreated controls. In cellular trays, priming reduced seedling emergence time in all species. These benefits were enhanced by the addition of PGRs to the priming solution. PGRs were more effective when added to the priming solution than when applied as a pre-soak. In general, oxygen enrichment of the priming solution reduced seed performance unless PGRs were also present in the solution. The most effective treatment combinations were: Primula, oxygen enriched priming with gibberellic acid ($GA_{4/7}$, 10^{-5}M); Impatiens, priming with $GA_{4/7}$ (10^{-4}M) and benzyladenine (BA, 10^{-6}M); Verbena, priming with $GA_{4/7}$ (10^{-4}M); and Petunia priming alone. Seeds of all species were pre-soaked in Iprodione solutions. Osmotic potentials of priming solutions and treatment durations are also specified.

Seedling emergence was also recorded in a range of compost temperature and moisture contents. Under near optimal conditions there are worthwhile gains from using seed treatments to increase stands, reduce seedling emergence time and the spread in times to emergence depending on species. However, the results suggest there is only limited potential for bedding plant seed treatments to eliminate the

effects of non-optimal environmental conditions likely to be experienced in seedling production practice.

Introduction

Poor seed quality in many bedding plant species results in prolonged seedling emergence and inadequate plant stands. This causes problems during seedling production in commercial practice. Some of the causes of this poor seed quality are thought to be physiological in origin. For example, dormancy, a wide range of maturity at harvest and a limited temperature range over which seeds can germinate rapidly. To address this problem the germination response of bedding plant seeds to environmental conditions and to a range of seed treatments has been investigated (Reports 1 and 2). Fungicide treatments, osmotic priming to reduce germination times, and plant growth regulator (PGR) treatments to relieve dormancy were combined into treatment protocols carried out in germination boxes (Report 2). In the study reported here, these treatment protocols were adapted to systems capable of commercial scale seed treatment (Nienow and Brocklehurst, 1987) and used to determine what part seed technology can play in overcoming the problems of bedding plant seedling establishment. In order to do this the performance of treated seeds was assessed in a range of conditions that could be experienced during seedling production in good commercial practice.

Materials and Methods

In a series of experiments, the effects of combinations of priming/plant growth regulator/fungicide seed treatments were compared.

The most effective seed treatments selected from those compared in report 2 were applied to four bedding plant species: Primula acaulis cv. Improved Biedermeier Strain; Impatiens wallerana cv.Dwarf Baby Mixed; Verbena X hybrida cv. Olympia Mixed; Petunia X hybrida cv. Red Star.

Seed treatments and germination

All seeds received a 3h pre-soak in Iprodione (Rovral, 50% a.i. wettable powder). All treated seeds were primed at 15°C in 0.25l of polyethylene glycol (PEG) aerated at 0.5l min^{-1}. Treatments to Primula, Impatiens and Verbena seeds included: priming alone; priming following a 48h soak at 5°C in a plant growth regulator (PGR) solution; and priming in a solution containing the same concentration of PGR used in soak treatments. Details of these treatments are given in table 1. During priming in each of these combination treatments, solutions were aerated with the ambient gas mixture or a mixture containing 75% oxygen and 25% nitrogen. This gave six treatments that were compared with untreated controls. No PGR treatments were carried out on Petunia seeds and so only two treatments were compared with controls. Seeds were collected from each treatment after 7, 10 and 14 days of priming and were then washed under running tap water for 0.5 mins and rinsed three times in distilled water. Untreated seeds following the Iprodione soak and all treated seeds were dried in a flow of air at 15°C and 45 ± 5% rh for 48h, to an equilibrium moisture content. After drying, seeds were dusted with Iprodione (5g a.i. kg $seed^{-1}$) and seeds from all treatment and duration combinations (Petunia, 7, other species, 19) were germinated under the test conditions shown in table 1. For each treatment there were three replicates of 50 seeds. The remaining seeds were sealed in laminated aluminium foil packets and stored at 5°C for subsequent seedling emergence experiments.

TABLE I

Treatment details and germination test. GA, Gibberellic acid, BA, Benzyladenine

	Primula	Impatiens	Verbena	Petunia
Priming in PEG (g kg water^{-1})	342	232	342	342
Nominal osmotic potential of PEG (MPa)	-1.50	-0.75	-1.50	-1.50
Plant growth regulator treatment	$GA_{4/7}(10^{-5}M)$	$GA_{4/7}(10^{-4}M)$ +$BA(10^{-6}M)$	$GA_{4/7}(10^{-4}M)$	-
Iprodione in pre-soak (percentage a.i.)	0.3	0.1	0.1	0.3
Germination test	15°C in light and dark	20°C in light and dark	15°C in light	15°C in light

Germination tests were carried out on two layers of absorbent paper (Whatman grade 181) moistened with distilled water in replicate transparent polystyrene boxes (80 x 120 x 20 mm). For germination in the dark, seeds were placed into germination boxes under green light and then wrapped in aluminium foil to exclude light. Germination counts were made on these seeds when germination in the light (c. 100-170 μmol m^{-2} s^{-1}) was complete.

Seedling emergence in cellular trays

From the germination test an optimum priming duration was selected for each of the six treatments. Seeds from each treatment and an untreated control were sown onto compost in eight replicate cellular trays (432, $4cm^{-3}$ cells, Plantpack Ltd.,UK) and covered with moist medium grade vermiculite. There was a two cell wide guard row around each of the trays which were arranged in a randomised block design under fluorescent lights (100 μmol m^{-2} s^{-1} at compost level) at 20°C. The compost was a 75:25 mixture of finely milled and sieved (7mm) sphagnum peat and non-calcareous grit (1-2mm) respectively with a p.H. of 5.8. Seedling emergence was recorded from 48 seeds of each treatment and the control. Under the same conditions of temperature and light early seedling growth from six replicates of 40 Impatiens and Verbena seeds of each treatment and the untreated control was also measured in a slope test (Gray and Steckel, 1983).

The effects of compost temperature and moisture content

The two most effective treatments were selected for Primula, Impatiens and Verbena from the results of seedling emergence in cellular trays. Seedling emergence from freshly prepared and dried seeds of these treatments was compared with that from untreated control seeds at a range of compost moisture contents and temperatures. There were four

compost moisture contents (24 ,36, 53 and 100% on a dry weight basis) held at three temperatures (15, 20 and 25°C). Twenty five seeds of the two seed treatments and the control were sown in sealed transparent polystyrene boxes (75 x 135 x 60mm). There were six replicate boxes at each of the 12 moisture content/temperature combinations. Seeds were sown onto 300cm^{-3} of compost (as described above) given a uniform pressure of 5.5g cm^{-2} and then covered by a further 75cm^{-3} of compost before application of the same pressure. Moisture release curves were constructed in pressure membrane apparatus for compost having the same bulk density (0.59g cm^{-3}). The moisture contents used corresponded to water potentials of <-0.005, -0.01, -0.1 and -0.5 MPa. At 0 MPa compost moisture content was 117%.

Statistical analyses

Germination (visible radicle present) and emergence counts were made daily initially and then at longer time intervals. Percentage data were angularly transformed and spreads in time to germination and seedling emergence (Orchard, 1977) were log transformed before all measured parameters were subjected to analyses of variance.

Results and Discussion

A number of seed treatment protocols were investigated in a previous study to develop methods of improving seed germination of bedding plant species (Report 2). These treatments were carried out on a small scale in germination boxes. The treatment of seeds here on a larger scale in aerated solutions provides the opportunity for further enhancing seed performance by enriching the air supply with oxygen during priming (Bujalski, Nienow and Gray, 1989). Oxygen-enriched atmospheres can help

to relieve dormancy (Corbineau, Rudnicki and Come, 1988) and may be of particular benefit during treatment of seeds such as Verbena which are thought to suffer oxygen deficiency in an excess of water (Ely, 1979). Oxygen enrichment was therefore included here in treatment protocols. In these protocols, Iprodione was applied as a pre-soak treatment because preliminary experiments had shown a phytotoxic effect of Iprodione added to the priming solutions in all species except Petunia. Pre-soaking seeds in Iprodione and then dusting the seeds after priming treatments had no phytotoxic effect.

Seed germination

Priming treatments reduced mean germination time of all species and increased percentage germination of Primula and Impatiens seeds in the dark (table 2) compared with unprimed controls. With Primula, germination in the dark was greatest when $GA_{4/7}$ was added to the priming solution. In all cases the addition of PGRs to the priming solution was more effective than pre-soaking seeds in PGRs. For brevity PGR pre-soaking treatments are therefore not included in the results presented. In general, increasing priming duration improved germination of Primula seeds, whereas, Impatiens seed germination performance declined progressively as treatment duration increased beyond seven days. The positive benefit of priming Primula seeds in aerated solutions in the absense of PGRs shown here contrasts with the adverse effects of priming on absorbent paper shown in report 2. The reasons for this are not known.

Oxygen enrichment of the priming solution did not further enhance germination of Primula, Impatiens or Petunia and contrary to expectation adversely affected germination of Verbena seeds. Treatment durations selected for seedling emergence experiments were: Primula priming

TABLE 2

The effect of priming treatments and treatment duration on mean germination time and percentage germination of Primula and Impatiens seeds. Angular transformations of percentages are in parentheses

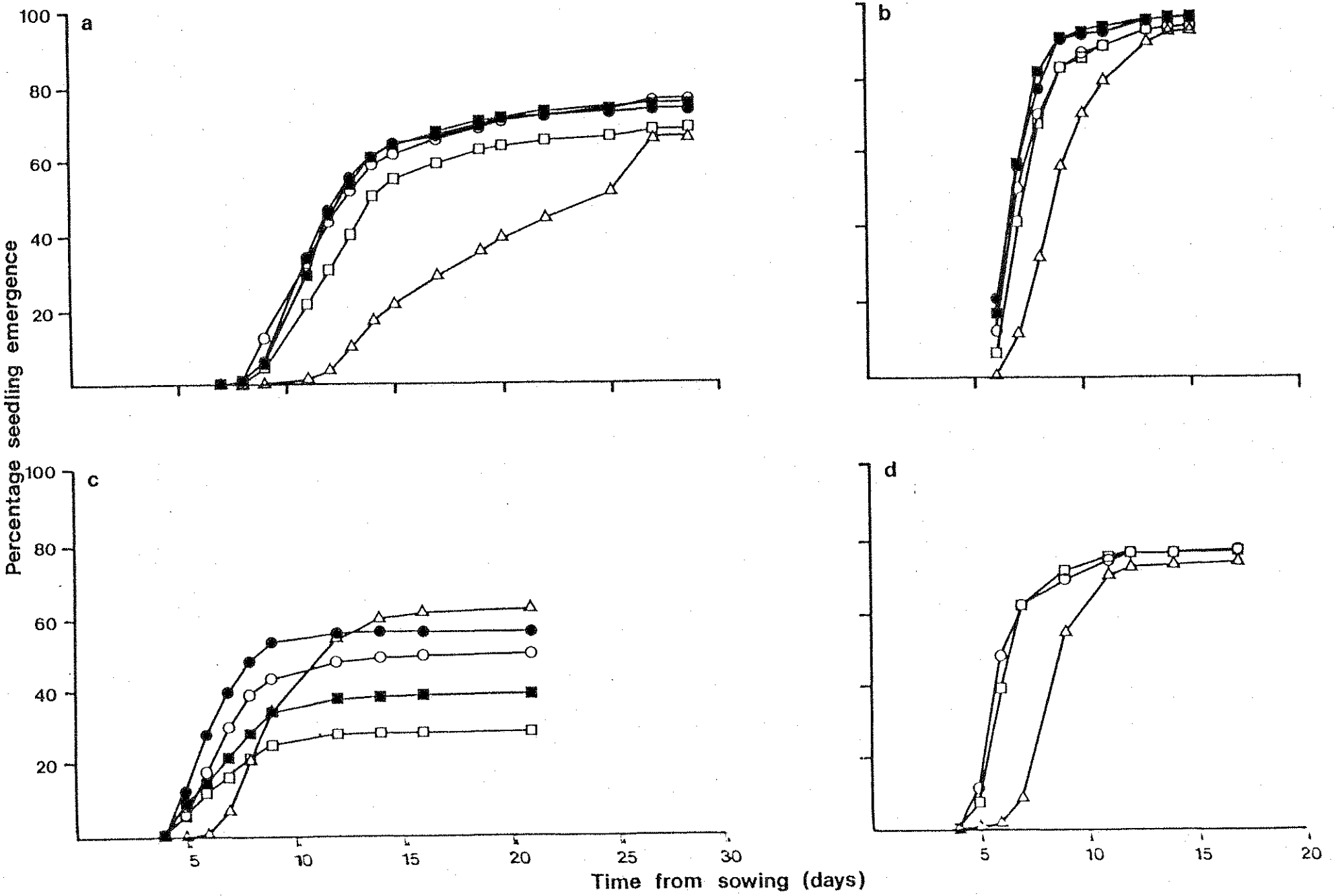
	Mean germination time (days)				Percentage germination in the light				Percentage germination in the dark			
Days of treatment...	0	7	10	14	0	7	10	14	0	7	10	14
Primula												
Untreated	11.8				71(57)				37(38)			
Primed		8.8	7.7	7.3		81(64)	75(60)	79(64)		66(55)	72(58)	79(63)
Primed with PGR		7.1	7.0	5.9		85(67)	81(64)	81(64)		85(67)	83(66)	77(62)
Primed with oxygen enrichment		10.3	9.1	8.4		81(64)	75(60)	81(64)		71(58)	74(60)	73(59)
Primed with PGR and oxygen enrichment		8.2	6.7	6.1		89(70)	83(66)	74(60)		82(65)	88(70)	88(70)
SE			0.50						(2.4)			
Impatiens												
Untreated	3.7				96(81)				79(63)			
Primed		2.7	3.0	3.9		97(80)	97(82)	96(79)		96(81)	95(78)	91(73)
Primed with PGR		2.4	2.6	2.9		99(86)	96(79)	92(74)		93(75)	95(77)	88(71)
Primed with oxygen enrichment		2.9	2.8	3.1		94(76)	94(76)	93(75)		91(73)	88(70)	91(72)
Primed with PGR and oxygen enrichment		2.7	2.5	2.7		99(86)	95(78)	91(72)		94(77)	96(79)	93(75)
SE			0.12						(2.5)			

treatments with oxygen enrichment 10 days and without 14 days; all Impatiens treatments 7 days; all Verbena treatments 10 days; and Petunia priming with oxygen enrichment 10 days and without 7 days. Further treatment for these species was either of no additional benefit or harmful. Slope test results suggest that there is no residual etiolation effect from PGRs at the concentrations used in these treatments in agreement with earlier results from smaller-scale seed treatments (Report 2).

Seedling emergence in cellular trays

Experiments have shown improved bedding plant seed germination in composts that have low nitrogen levels, a pH between 5.5 and 5.9 and a suitable mixture of sieved peat and grit (Farthing and Ellis, 1991). A uniform compost conforming to these specifications was mixed for these experiments. Under the conditions of adequate moisture and temperature which should be provided in commerce, priming significantly reduced the mean seedling emergence time of all species in compost-filled cellular trays (figure 1). PGRs added to the priming solution further enhanced the performance of Verbena and Impatiens seeds. For the untreated seeds and those from the most effective priming treatment, mean seedling emergence times for Primula were 19 and 12 days (SE=0.4, DF=39) respectively. Corresponding figures for Impatiens were 9 and 7 days (SE=0.1, DF=49), for Verbena, 9 and 6 days (SE=0.2, DF=35), and for Petunia, 8 and 6 days (SE=0.1, DF=21). These reductions in emergence time represent increased turnover and reduced heating costs during seedling production in commercial practice. Percentage seedling emergence of Primula was increased by priming but was not significantly different to that in the untreated controls in Impatiens and Petunia. Priming without PGRs significantly reduced final percentage seedling

Figure 1. Seedling emergence of a, Primula, b, Impatiens, c, Verbena and d, Petunia seeds in cellular trays. △ ,untreated control; ○ , primed; □ , primed in oxygen enriched air; ● , primed with PGR; ■ , primed with PGR in oxygen enriched air.

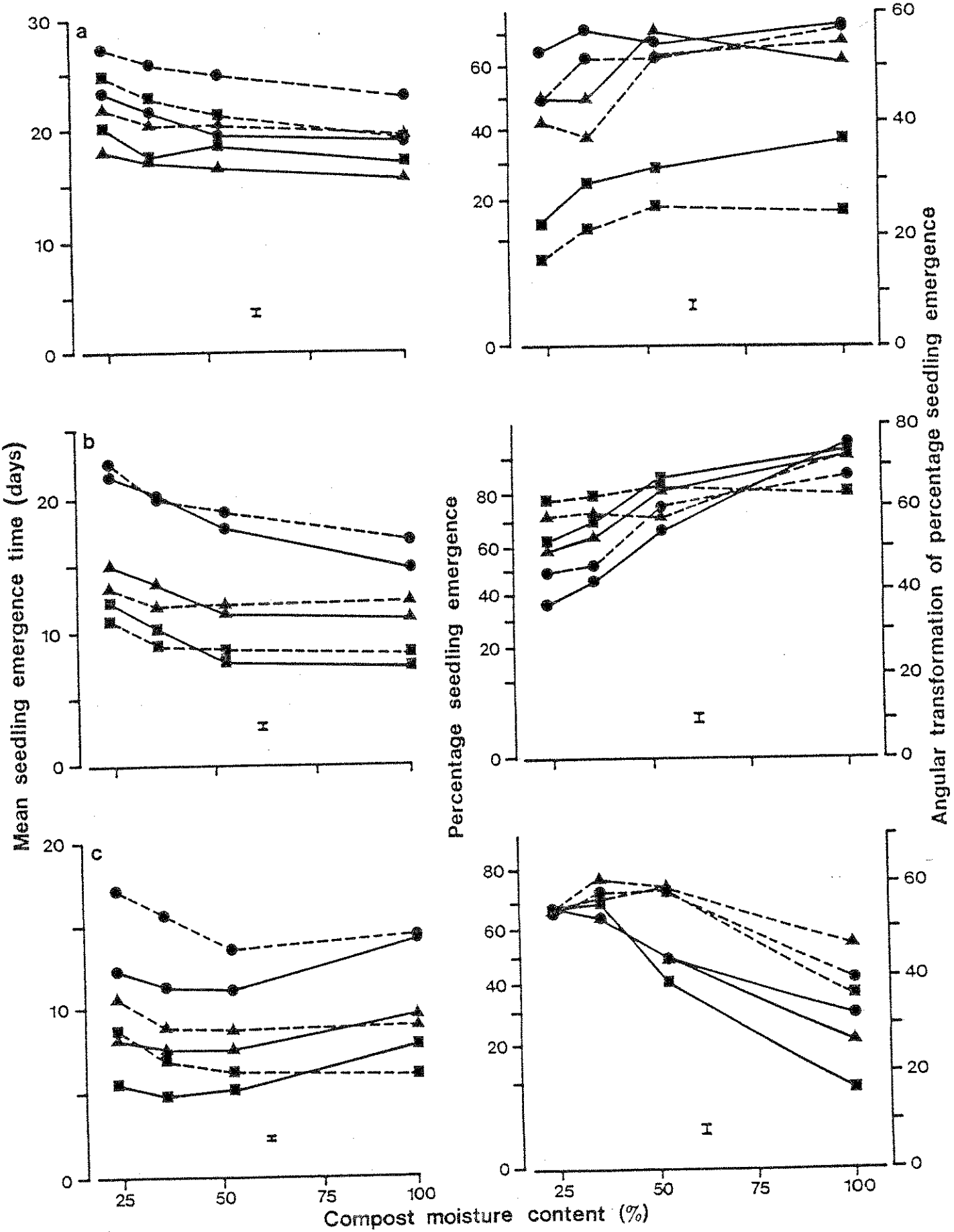

a
b
c
d
100
80
60
40
20
Percentage seedling emergence
5
10
15
20
25
30
Time from sowing (days)

emergence in Verbena. The spread in time to seedling emergence was significantly reduced by the most effective priming treatments in Primula and Verbena. Oxygen enrichment, when not combined with PGRs in the priming solution, reduced and delayed seedling emergence in all species except Petunia where there was no positive benefit (data not shown).

The effects of compost temperature and moisture content

It is generally thought that physiological seed treatments can widen the range of environments in which optimum germination and emergence can occur. If true, this could be a major benefit of seed treatments to bedding plant production in practice. This hypothesis was therefore tested here by exposing primed and unprimed seeds to a range of compost temperatures and water potentials. The range was limited to conditions that could be experienced in seedling production practice. Different relationships were found with each species (Figure 2). There were no significant interactions between seed treatment and environmental treatments with Primula and, in general, seed priming reduced mean emergence time and increased percentage emergence. In Impatiens and Verbena experiments there were, however, significant seed treatment x compost water potential interactions. Primed seeds showing greater sensitivity to compost moisture than the untreated control seeds. Under the most favourable conditions with Impatiens, priming reduced mean emergence time and increased percentage emergence compared with that from the untreated control. Under conditions of lower temperature and drier compost the seedling emergence from primed Impatiens seeds was reduced and delayed compared with that from the untreated control, this situation was reversed with Verbena. Primed Verbena seeds had much greater reductions in percentage emergence with

Figure 2. Percentage seedling emergence (angular transformation) and mean seedling emergence time from a, Primula, b, Impatiens and c, Verbena seeds in a range of temperatures and compost moisture contents. ● , 15°C; ▲ ,20°C; ■ ,25°C; - - - -, untreated control; ———— , primed. Priming treatments are for Primula; PEG with PGR and O_2 enrichment, Impatiens and Verbena; PEG with PGR. Vertical bars are standard errors (Primula and Verbena, 235 DF, Impatiens, 115 DF).


a
b
c
Mean seedling emergence time (days)
Percentage seedling emergence
Angular transformation of percentage seedling emergence
Compost moisture content (%)
25
50
75
100

increasing compost moisture content than untreated control seeds. This result explains the disappointing performance of primed Verbena seeds reported here in cellular trays that were kept moist throughout seedling emergence. The sensitivity of Verbena seeds to high compost moistures is also in agreement with results in germination tests (Ely, 1979 and Report 2).

Under near-optimal conditions there are worthwhile gains from using seed treatments to increase stands, reduce seedling emergence time and the spread in times to emergence depending on the species. However the results reported here suggest that there is only limited potential for bedding plant seed treatments to eliminate the effects of non-optimal environmental conditions likely to be experienced in seedling production practise.

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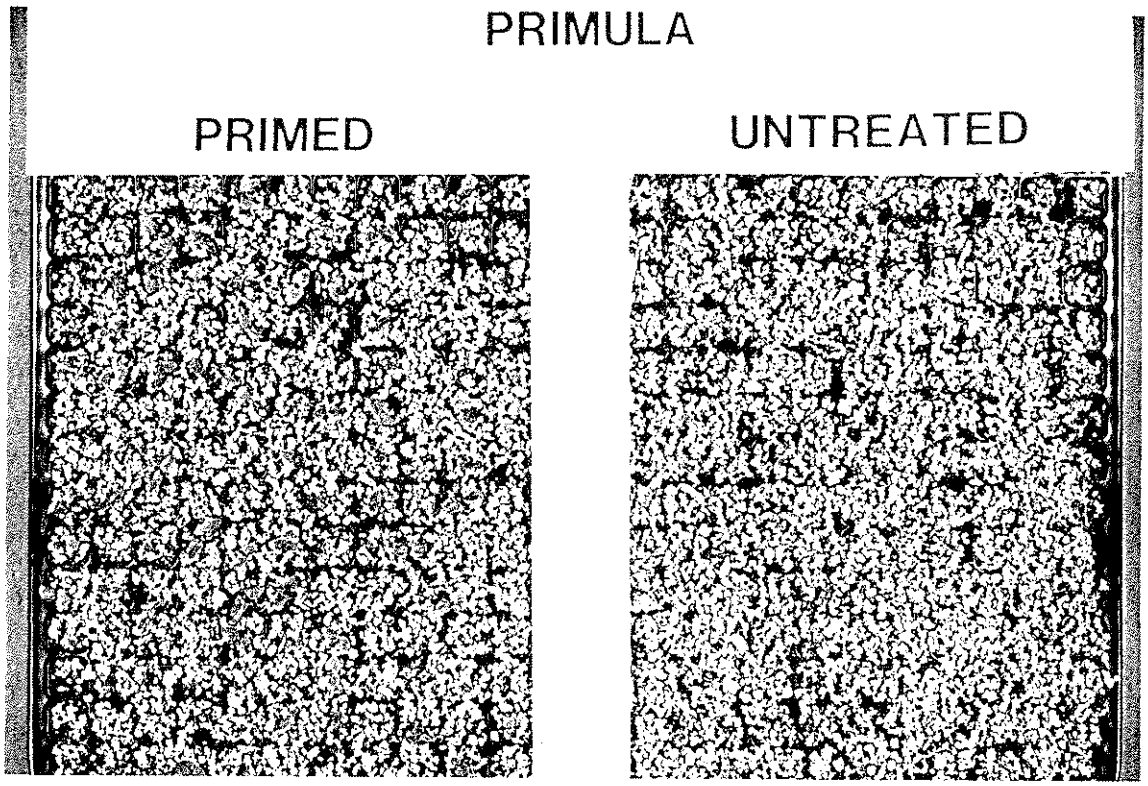
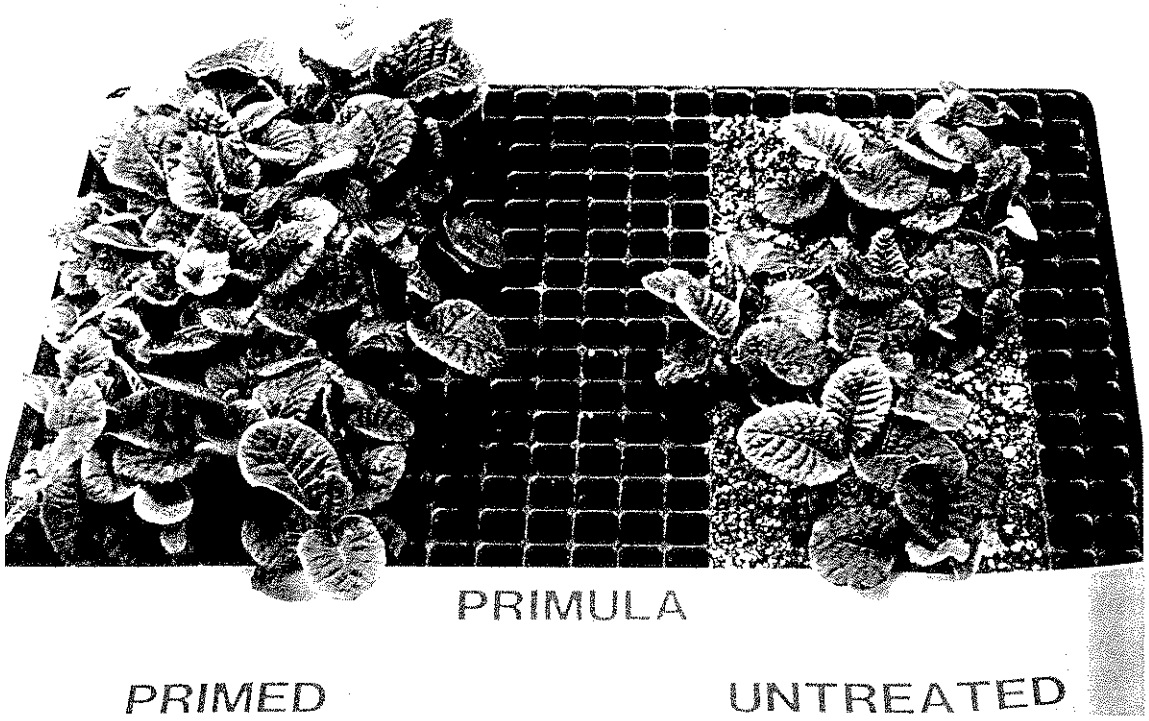
Plates 1-6: Seed priming results in earlier emergence of a greater number of seedlings.

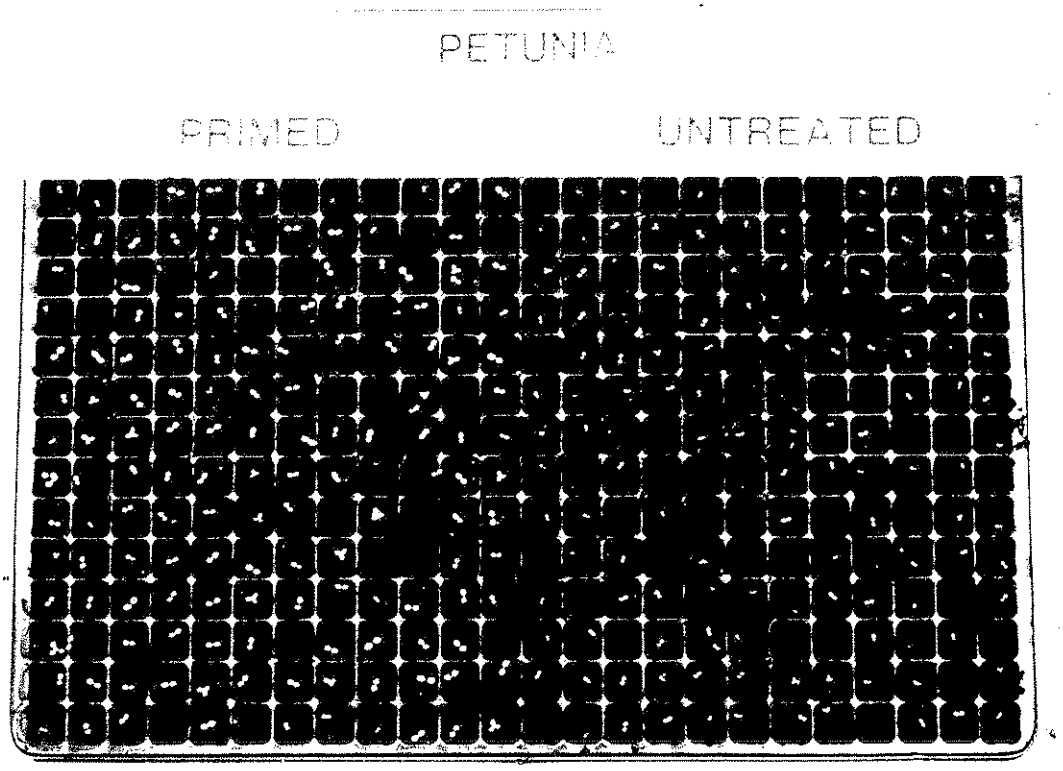
1. Earlier emergence



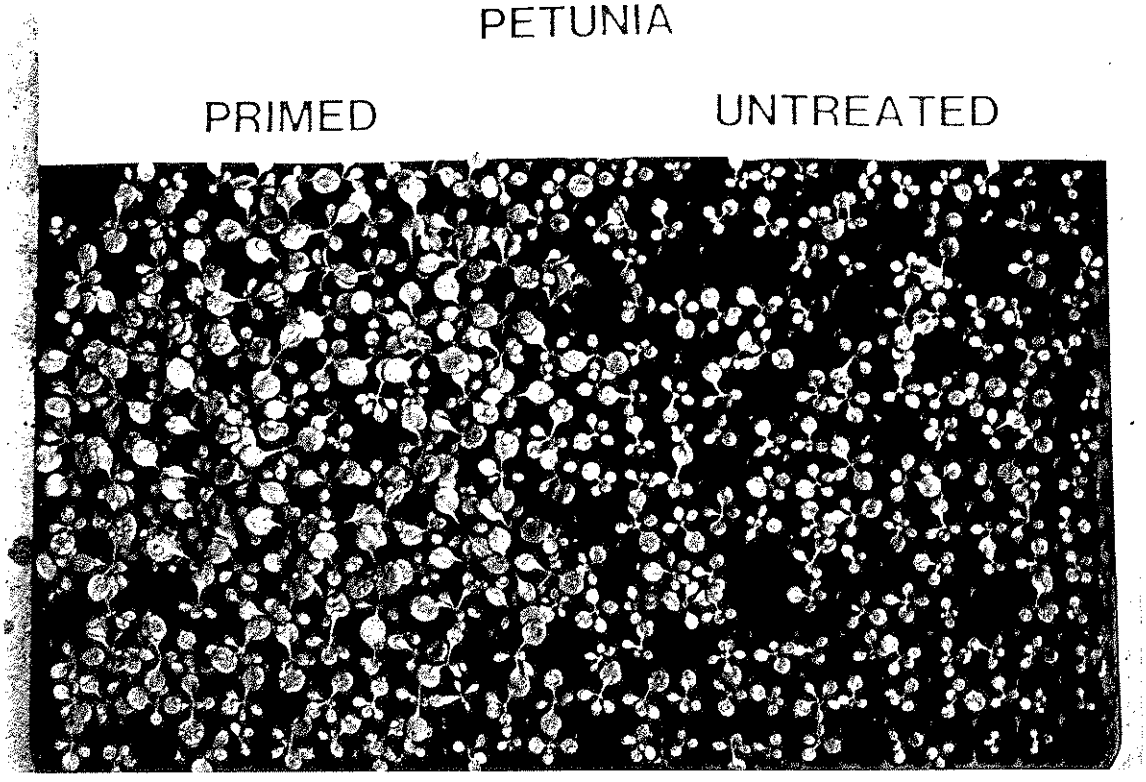
2. More seedlings emerge



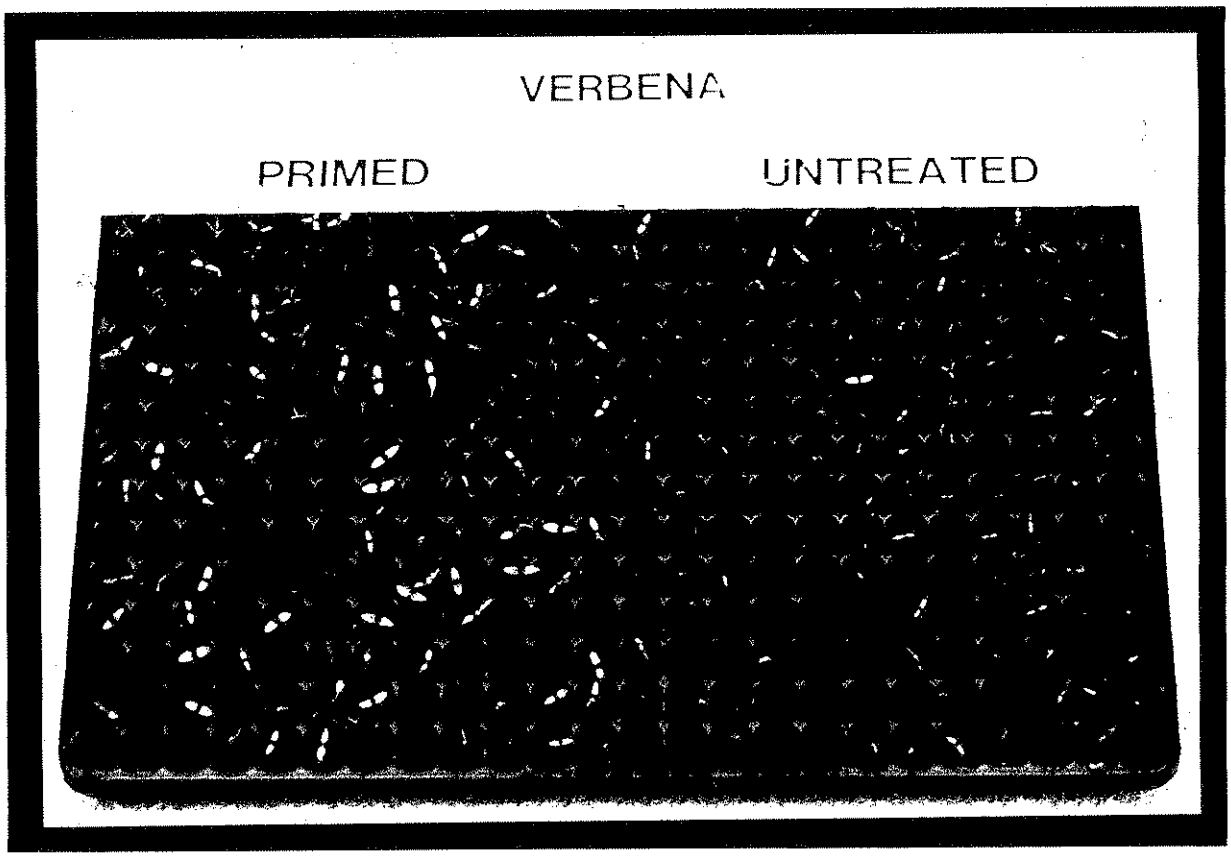
3. Earlier emergence



4. Size differences due to earlier emergence persist



5. Earlier emergence



6. Size differences due to earlier emergence persist