GERMINATION AND COMPETITION STUDIES ON SELECTED WEED SPECIES IN CEREAL CROPPING SYSTEMS IN THE WESTERN CAPE

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entire or in part submitted it at any University for a degree.

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Abstract

The high cost of herbicides for weed control in crop fields in the Western Cape is a major cause of reducing farmers' net income. As chemical weed control became more difficult and expensive, it became necessary to focus on the technique of reducing weed impact, which does not only involve herbicide usage. Aspects such as tillage method, sowing date of crops, crop rotation, weed ecology and germination requirements, amongst other, may play a role in reducing weed impact. The first experiment was done to determine whether temperature and light had an effect on the germination of six selected weed species, namely *Arctotheca calendula, Avena fatua, Bromus diandrus, Emex australis, Lolium temulentum* and *Raphanus raphanistrum.* Seeds of the aforementioned weeds were collected from Langgewens during 2000 and stored at room temperature before being used in this study. The seeds were germinated in a germination cabinet at three temperature regimes namely 5 °C /15 °C, 10 °C / 15 °C and 10 °C / 20 °C. Most seeds showed a positive germination response at the 10 °C / 15 °C treatment, except for *Emex australis* and *Lolium temulentum*, which was believed to germinate throughout the year under favourable conditions. Among the germinated weed species, *Avena fatua* germinated best with a cumulative value of 90% as compared to *Raphanus raphanistrum*, which germinated least with a cumulative value of 12%. The second experiment was done to evaluate the effect of three growth regulators, namely gibberellic acid, hydroxylamine (auxin), and kinetin (cytokinin) to break dormancy and enable simultaneous germination of the six weed species mentioned above. Weed seeds were germinated in a germination cabinet at 20 °C using the test solutions of the aforementioned growth regulators. The germination was assessed after 3, 7, 10 and 14 days of incubation and the tetrazolium test for the viability of seeds was done for ungerminated seeds. The result obtained showed that no chemical / concentration proved to be successful in stimulating the germination of all species tested. As for example a high concentration of hydroxylamine increased germination of *Emex australis* to nearly 100% and inhibited germination of *Raphanus raphanistrum* to less than 12.5% at all hydroxylamine concentrations. The third experiment was conducted with the aim of determining the competitiveness of the six weed species mentioned above when grown together with wheat in order to decide when weed control will be cost-effective. An additive series experiment was conducted in a glasshouse. The influence of weed species on wheat plant height, tiller

number at different growth stages, vegetative dry mass and grain mass was determined by using different varying weed densities. Weed densities, through reduction in number of tillers, reduced wheat grain yield. By increasing the density of wheat this competitive effect could be reduced. Different weed densities caused a significant difference in wheat plant height, tiller number, dry mass and grain mass. The results showed that species had a significant effect ($p < 0.05$) on wheat plant height during tillering, stem elongation and heading growth stages. Total wheat plant above-ground dry mass was significantly ($p < 0.05$) reduced by an increase in weed density.

Uittreksel

Die hoë koste van onkruiddoders vir onkruidbeheer in graangebiede van die Wes-Kaap is een van die hooffaktore wat graanprodusente se netto inkomste verlaag. Weens moeiliker en duurder chemiese onkruidbeheer en om die impak van onkruide te verlaag, het dit noodsaaklik geword om op die tegnieke te fokus wat nie die gebruik van chemikalieë insluit nie. Faktore wat in rol kan speel sluit bewerkingspraktyke, saaidatum van gewasse, wisselbou, ekologie en ontkiemingsvereistes van onkruide in. Die eerste eksperiment is gedoen om te bepaal of temperatuur en lig 'n effek het op die ontkieming van ses gekose onkruide, naamlik *Arctotheca calendula*, *Avena fatua*, *Bromus diandrus*, *Emex australis*, *Lolium temulentum* en *Raphanus raphanistrum*. Sade van die voorgenoemde onkruide is in 2000 op Langgewens versamel en by kamertemperatuur geberg voordat dit in hierdie studie gebruik is. Die sade is in 'n ontkiemingskabinet geïnkubeer by drie temperatuurreekse naamlik 5 °C / 15 °C, 10 °C / 15 °C en 10 °C / 20 °C. Die meeste sade het 'n positiewe ontkiemingsreaksie getoon na die 10 °C / 15 °C behandeling, met die uitsondering van *Emex australis* en *Lolium temulentum*, wat oënskynlik heeljaar sal ontkiem onder gunstige omstandighede. *Avena fatua* het die hoogste ontkiemingspersentasie oor alle spesies getoon met 'n kumulatiewe waarde van 90% en *Raphanus raphanistrum* die minste met 'n kumulatiewe waarde van 12%. Die tweede eksperiment is gedoen om die invloed van drie groeireguleerders, naamlik gibberelliensuur, hidroksielamien (ouksien) en kinetin (sitokinien), op die opheffing van saadrus te ondersoek en om ook die gelyktydige ontkieming van bogenoemde ses onkruidspesies moontlik te maak. Onkruidsade is in 'n ontkiemingskabinet by 20 °C ontkiem deur gebruik te maak van toetsoplossings

van bogenoemde groei-reguleerders. Die ontkieming van die sade is na inkubasie periodes van 3, 7, 10 en 14 dae geëvalueer en die tetrazoliumtoets vir saadkiemkragtigheid is toegepas vir onontkiemde sade. Die verkreë resultate het getoon dat geen chemiekalie / konsentrasie die ontkieming van alle spesies suksesvol kon stimuleer nie. Hoë konsentrasies hidroksielamien het die ontkieming van *Emex australis* tot byna 100% verhoog en het die ontkieming van *Raphanus raphanistrum* geïnhibeer tot minder as 12.5% by alle hidroksielamien konsentrasies. Die derde eksperiment is uitgevoer met die doel om die kompetisievermoë van dieselfde ses onkruidspesies te bepaal as dit saam met koring groei en om te besluit wanneer onkruidbeheer koste effektief sal wees. 'n Additiewe reeks eksperiment wat uit vier herhalings bestaan het, is in plastiekpotte in 'n glashuis uitgevoer. Die invloed van die onkruidspesies op koring planthoogte, halmgetal by verskillende groeistadiums, droë massa en graanmassa is bepaal deur onkruiddigthede te gebruik. Onkruide het koring opbrengs verlaag deur die vermindering van halmgetal en hierdie kompeterende effek kon verminder word deur 'n toename in die plantestand van koring. Verskillende onkruiddigthede het 'n betekenisvolle invloed op koring planthoogte, halmgetal, droë massa en graanmassa gehad. Die resultate het getoon dat spesies 'n betekenisvolle effek ($p< 0.05$) op koring planthoogte, stem verlenging en aarverskyning gehad het. Die totale bogrondse droë massa van koring is betekenisvol ($p< 0.05$) verminder deur 'n verhoging in onkruiddigtheid.

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List of Abbreviations

A. calendula.....*Arctotheca calendula*

A. fatua.....*Avena fatua*

Anova.....Analysis of variance

B. diandrus.....*Bromus diandrus*

cm.....Centimetre

^{o}C .....Degrees Celcius

Cv.....Coefficient of variation

Df.....Degrees of freedom

DM.....Dry material

E. australis.....*Emex australis*

Flow.....Flowering growth stage

g.....Gram

GLM.....General linear Model

GY.....Grain mass

h.....Hour

ha^{-1}.....Per hectare

Head.....Heading growth stage

Kg.....Kilogram

KOH.....Potassium hydroxide

ℓ$^{-1}$.....Per litre

LSD.....Least significant difference

L. temulentum.....*Lolium temulentum*

m^{2}.....Square metre

m^{-2}.....Per square metre

mg. ℓ$^{-1}$.....Milligram per litre

mℓ.....Millilitre

mℓ.ℓ$^{-1}$.....Millilitre per litre

mm.....Millimetre

N.....Nitrogen

NaOH.....Sodium hydroxide

N NaOH.....Normal solution of Sodium hydroxide

p.....Probability

Ripe.....Ripening growth stage

R. raphanistrum.....*Raphanus raphanistrum*

S.....Species

S x T.....Species by treatment (density)

SAS.....Statistical Analysis Systems

Seed.....Seedling growth stage

Stem.....Stem elongation growth stage

Till.....Tillering growth stage

Trt.....Treatment

't'.....Time

x.....By

v/v.....Volume per volume

%..... Percentage

<.....Smaller than

>.....Bigger than

Contents

Germination and Competition studies on selected weed species in cereal cropping systems in the Western Cape

Chapter 4

Chapter 5

Chapter 6

Chapter 1

Introduction

Persistent weed control problems present a major challenge to the most efficient farm operations because of the increasing labour and other production costs that reduce net income. Weeds hinder complete mechanised production of many crops and in addition to lowering crop quality and yield, weeds cause many other losses, such as poisoning of livestock, inducing off-flavours in milk, and reducing flow of irrigation and drainage waters (Ashton & Crafts, 1973).

Weed infestation has been reported as a major constraint to wheat production the world over (Tanner & Sahile, 1991). Since the development of 2,4-D in the early fifties, chemical weed control gained in popularity. In the decade from 1980 until 1990 chemical weed control in wheat fields of the Western Cape was done by broadleaf herbicides such as 2,4-D, MCPA and bromoxynil, while very few herbicides were used for grass control. Since 1990 the sulfonylurea herbicides became the backbone of chemical control methods for broadleaf weeds in winter cereals in the Western Cape, while graminicides such as diclofop are widely used for the control of grassy weeds. This general use of herbicides to control weed may however create some problems. For the year 2001, the cost of herbicides for weed control in wheat in the Western Cape was in the order of R200 ha^{-1}. As local wheat producers are dependent on the presently generally low international wheat price, this may have a large effect on their net margin.

According to Tanner & Sahile (1991), repeated application of phenoxy herbicides such as 2,4-D and MCPA to wheat fields may result in a shift of the predominant weed species to the more resistant annual grassy weeds and dicotyledonous weeds which are not controlled by the above-mentioned herbicides. Herbicide usage may as a result also shift towards more expensive grass and broad-spectrum broadleaf herbicides. As new crop rotation systems are being proposed and continuously investigated for the Western Cape, it became evident that weed problems are increasing in complexity. Chemical weed control has become not only more difficult,

but may become more expensive, because herbicides with long residual effects would not fit into crop rotation systems.

Inefficient control also contributed to the increased weed problem and probability of herbicide resistance in weed (Rao, 2000). This may be due to inefficient applications, weed species which germinate over the entire growing season and thus escaping chemical weed control or species which altered their metabolism as a result of sub-lethal herbicide concentrations (Rao, 2000).

One possible option to improve weed control in these production systems would be to manipulate the weed seed bank. Buried weed seeds are a perpetual concern to the agriculturist. The seeds may be distributed, principally by tillage implements in arable situations, and form reservoirs within the surface layers of soil. The seeds can eventually germinate and the resulting plants compete with crops for water, nutrients and light (Omami *et al.*, 1999). The depletion of seed reserves can be made successful by understanding the dormancy characteristics and germination behaviour of the seeds (Cheam, 1986). More even germination at the beginning of the growing season would allow more efficient and cost-effective weed control. This can only be achieved with adequate knowledge about the physiology and germination requirements and competitiveness of the dominant weed species.

At present *Arctotheca calendula, Emex australis, Raphanus raphnistrum, Avena fatua, Bromus diandrus,* and *Lolium temulentum* are the most troublesome weed species in wheat in the Western Cape, but little is known with regard to their seed-bank dynamics, germination requirements and competitiveness.

The aims of this study were:

i) To determine the effect of temperature regimes on the germination of the above mentioned six weed seed species:

ii) To evaluate the efficiency of three growth regulators applied at four different application rates to break dormancy and enable simultaneous germination of the mentioned species.

iii) To determine the competitiveness of the mentioned weed species when grown together with wheat to decide when weed control will be cost effective.

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Chapter 2

Literature review

Effect of weeds on crop production due to competition

Weeds and crops have the same requirements for normal growth and development (Anderson, 1983). According to this author, weeds and crops require and compete for an adequate supply of the same nutrients, moisture, light, heat energy (temperature), carbon dioxide, and growing space. In an intermixed community of weed and crop plants, the more aggressive species usually dominate. Weeds compete successfully with crop plants by: (1) being more aggressive in growing habit (2) obtaining and utilising the essentials of growth at the expense of the crop plants and (3) in some cases, secreting chemicals that adversely affect the growth and development of the crop plants (Rao, 2000). Differences in rate of root elongation, accompanied by an increase in potential for nutrient and moisture absorption, may for example contribute to successful competition between one species over another in mixed plant populations. The yield response to weed density, is weed species and environmentally dependent (Murray, 2000). The higher the weed density, the greater the yield losses. In general, weeds are able to withstand adverse environmental conditions better than crops and thus have a competitive advantage under such conditions (Holzner & Numata, 1982).

The time and duration of competition are also very important (Anderson, 1983). Weed competition during the first 6 weeks or so after crop plantings tends to have the greatest adverse effect on crop yields, but only if they are allowed to compete longer than the first 2 to 3 weeks after planting. The relative time of emergence of the weed and the crop also influences the degree of competition and thus crop production. The earlier the weed emerges prior to the crop, the more time it has to establish and compete. Forecasting yield loss due to weed competition is important for determining whether the practice of weed control is necessary or not (Fryer & Matsunaka, 1977), by comparing the cost of control measures against the value of the increase in yield obtained by removing weeds (Fryer & Evans, 1970).

In spite of the fact that wheat competes well with most weeds, due to its extensive root system and close spacing, and that weeds are therefore less of a problem with wheat than with many other crops, they do become a serious problem in certain situations (Quisenberry & Reitz, 1967). Wheat yield losses due to weed competition can primarily be attributed to a decrease in tillering (Murray, 2000). This author found that irrespective of soil fertility or crop seeding rate, wheat tillering gradually declined with an increase in wild oat density. When wild oats exceeded 200 plants/m^2, tillering was reduced more than 50%. Reduced tillering of wheat has also been observed in the presence of green foxtail, blackgrass, ryegrass, russian thistle, wild buckwheat and volunteer canola.

In contrast to tillering, the 1000 kernel weight was found to be generally unaffected. Winter wheat is generally considered to be more competitive than spring wheat, largely due to the fact it has a head start over the weed species, while evidence indicates that semi-dwarf wheat is less competitive than normal-height wheat. Similarly, the long-strawed spring wheat was observed to be a better competitor with wild oats than the short-strawed cultivars (Murray, 2000). It is clear that efficient weed control in most crops is of the utmost importance and therefore an essential part of modern production systems.

General characteristics of weedy plants

Weedy plants are known for their competitiveness due to physiological features (Duke, 1985), various methods of regeneration and seed dispersal, as well as number of seed produced per plant, seed dormancy and seed longevity (Holzner & Numata, 1982).

Omami *et al.* (1999) is of the opinion that buried weed seeds are of a perpetual concern to agriculturist. Large numbers of seed produced annually may be mixed into the soil, mainly by tillage implements in arable situations, and form reservoirs within the surface layers of soil. The seeds can eventually germinate and the resulting plants compete with crops for water, nutrients and light. Information on the life span of weed seeds in soil is important since potential weed problems exist as long as weed seeds remain viable in the soil (Cheam, 1987).

Most weed seed-banks in agroecosystems contain many weed species (Wilson & Furrer, 1986). The percentage of seed in the seed-bank that emerges in a given year varies widely among species and environmental conditions (Hartzler *et al.*, 1999), since the soil acts as a seed storage reservoir and a growth medium for weedy plants. The type or species and numbers of seed in the soil are closely linked to the cropping history of the land. The number of seed in the soil is variable and may range from 4 seeds per kilogram of surface soil in grassland to 280 seeds per kilogram of surface soil in cropland (Wilson & Furrer, 1986).

Several factors may affect the weed-seed population of a soil, namely (1) amount of seed produced; (2) the dissemination of seeds into the area, important mainly for wind- and water- borne seeds; (3) planting weed seeds during the seedling stage of the crop; (4) losses of seeds due to activities of birds, rodents, ants, etc., and (5) the rate of decay of seeds in the soil (Crafts & Robins, 1962, Radosevich & Holt, 1984). Weed seeds remain viable (capable of germination) in soil and in flowing fresh water for varying periods of time, depending on the species involved, depth of burial in the soil and length of time buried in soil or immersed in water. Seed longevity therefore represents major survival mechanisms for certain weed species; it constitutes a continuing source of weeds emerging in croplands, and such longevity is detrimental to the interests of the agriculturist (Anderson, 1983).

According to Leck *et al.* (1989), longevity of seeds occurred as a result of germination of seeds that had been buried but remained viable for a long time. They also found that large seeds (with presumably more food in storage) would be more likely to show extended longevity. Seeds of weed species in cropland have adapted to reach reproductive maturity at the most opportune time in relation to harvest, while in relatively primitive agricultural systems, weed seed is harvested accidentally with crop seed.

Duke (1985) stated that most weed seeds have the ability to germinate at the right time and in the right place after remaining for several years in the soil seed bank. These seeds also can withstand extreme environmental conditions such as frost or hot and dry seasons without losing their viability. Then, when conditions are right, they will germinate and start a new generation. Knowledge of when these species are likely to emerge is thus important in planning effective weed management programs.

Requirements for germination

Light

According to Duke (1985), light has long been known to be a requirement for the germination of the seeds of many weed species. The light requirement of seed was found to be the main reason why the seed of some species only germinate when their seed were left on or near the soil surface. In an agricultural environment, many weed seeds are buried by cultivation and will only germinate when re-exposed to light by subsequent cultivation. The increased emergence of weed seedlings caused by soil disturbances is therefore a well-known phenomenon (Duke, 1985).

Some weed species germinate best in light, others in darkness and others germinate readily in either light or darkness, as for example germination of bluegrass is favored by light, Jimsonweed by darkness while that of wheat by either light or darkness (Klingman & Ashton, 1975). According to Iglesias *et al.* (1993) *Bromus* seeds are not as photosensitive as other seeds of other grass weeds, although light may inhibit germination to some extent.

Gases

The germination process requires oxygen in addition to the favourable temperature and moisture. Aerobic respiration requires more free oxygen than anaerobic respiration. Some seeds start germination under anaerobic conditions and shift to aerobic respiration when the seed coat ruptures. The oxygen amount needed for seed germination differ with different species as for example the best germination for horsenettle was found at 36% oxygen while that of field bindweed at 53% (Klingman & Ashton, 1975).

Moisture

Gulliver & Heydecker (1973) reported that all seeds require sufficient moisture for imbibition and germination and most will germinate even when supplied with a clear excess of water. Excessive amounts of water, on the other hand, reduce the permeability of the coat to oxygen and inhibit germination of beetroot and spinach seeds.

Temperature

Different species have different temperature ranges within which they germinate, whereas at very low temperatures and very high temperatures the germination of all seeds is prevented. The temperature at which different seeds germinate and the range within which they germinate is determined by the source of the seeds, genetic differences within a given species (example variety differences) as well as age of the seeds (Mayer & Poljakoff-Mayber, 1982).

According to Mayer & Poljakoff-Mayber (1982), some seeds in hydrated state can survive temperatures from –12 to –18 °C, while some seeds such as radish and turnips can tolerate high temperatures of up to 90 °C. Klingman & Ashton (1975) stated that Russian pigweed seed could germinate in ice and on frozen soil while wild oats can germinate at temperatures of 1.67 °C. They also stated that alternating temperatures are often better than a constant temperature for seed germination.

Temperature also strongly influences the breaking of both primary and secondary dormancy as primary dormancy can be rapidly broken by high temperature treatment of dry seeds (Duke, 1985). When seeds are shed to the soil, variation in the degree of dormancy among the seeds provides both the potentials for considerable persistence in extreme individuals, and a regular proportion of surviving seeds, which germinate each year. The annual emergence therefore depends on an interaction of the soil environment and the dormancy of seeds buried in the soil (Murdoch & Carmona, 1993).

Dormancy

Dormancy is a failure of seeds to germinate when given moisture, air and a suitable constant temperature for radicle emergence and seedling growth. If these minimum requirements for germination are lacking the seed is quiescent since metabolism will often be reduced (Bewley & Black, 1982).

Dormancy of seed may be divided into primary dormancy and secondary or induced dormancy (Bradbeer, 1988). Primary dormancy may be the result of factors such as i) impermeable seed coats, ii) immaturity of the embryo, iii) chemical inhibition or even a

combination of factors (Wareing, 1969). Secondary dormancy on the other hand may be induced in seed after the initial after-ripening phase as a result of conditions such as a lack of oxygen or temperatures which do not favour germination (Barton, 1965). Dormancy may be influenced by several factors, including parental effects interacting with those of the environment during maturation of seed, as well as edaphic effects on buried seeds (Omami *et al.,* 1999).

In the soil environment, seeds are exposed to fluctuations of light, temperature, moisture and gases as well as being subjected to possible damage by soil fauna. These can interact to varying degrees and often result in cyclical changes in dormancy. Depending on the location of seeds in the soil profile, exposure to these factors differs considerably and may influence dormancy and viability. In general, greater seed longevity is favoured by deep burial (Omami *et al.*, 1999). The first flush of weed seedlings to emerge on cultivated lands usually originates from the germination of those weed seeds in a non-dormant, viable condition lying in the upper layer of soil, generally those in the upper 25mm layer but occasionally as deep as 100mm or more (Anderson, 1983).

The number of weed seedlings that would emerge during a growing season is thus largely determined by the dormancy status of seeds in the seed-bank (Cardina & Sparrow, 1997). Dormancy and irregular germination of weed seeds are therefore responsible for a major part of the difficulty and expense of weed control, because a successful weed seed must be in the right physiological state to germinate in the right place, usually within a limited period (Murdoch & Carmona, 1993). An understanding of temporal patterns in seed dormancy is therefore important to predict both the timing and extent of weed germination and emergence in crops. Knowledge of the growth and development of the plant from seed to maturity may also help to develop an understanding of plant responses during different growth stages to herbicidal action (Muzik, 1970). Seed dormancy mechanisms are a well-established biological means of survival for weeds and it will be very difficult to overcome (Bradbeer, 1988). A better understanding of the mechanisms controlling dormancy and germination, and the development of the technology necessary to use dormancy and germination regulating treatments in agriculture, may however help to manipulate weed life cycles and, thereby, provide new mechanisms for weed control (Goldmark & Walker-Simmons, 1992).

Methods to break dormancy

Many different kinds of chemicals, when applied to dormant seeds might cause them to germinate (Bewley & Black, 1982). Some of these chemicals may have potential value in agriculture to accelerate germination or break the dormancy of seeds. Numerous species of seed respond to these substances, supplied either singly or in combination, although it is difficult to find a seed, which is sensitive to all of the compounds. Mayer & Poljakoff-Mayber (1982) found that various chemical substances could completely or partially substitute the need for light in breaking dormancy.

According to Bradbeer (1988), dormancy may be broken as a result of the exposure of the seed to a single factor at the requisite intensity for an appropriate period of time. Several chemicals have shown potential to stimulate germination of weed species (Corns, 1959; Metzger, 1983; Hurtt & Taylorson, 1986). Potassium nitrate can be used to reduce dormancy especially if followed by 10 to 14 days at 4.4 and 7.2 °C or can virtually overcome it. The application of potassium nitrate stimulated the germination in both darkness and light of *Avena fatua* seeds from a range of soil depths (Hilton, 1984). Cairns & de Villiers (1986) reported that gibberellic acid, nitrates, respiratory inhibitors, herbicides and light stimulated germination of dormant or semi-dormant wild oat seed.

Ethylene promoted the germination of several weed species in soil in growth chamber studies, whereas butylate and several carbamate herbicides had stimulated weed emergence (Hurt & Taylorson, 1986). The chilling method can be used to break dormancy in hazel nuts. The nuts again can be germinated by an exposure to longer stratification periods. Leaching is considered as a contributor to the dormancy-breaking process in hazel seeds when the leachates contain germination inhibitors (Bradbeer, 1988).

The value of determining the reservoir of weed seeds in the soil and the early fate of seedlings during establishment lies in being able to predict potential weed infestations. Using the demographic parameters of seed production and dispersal, seed reserves in the soil, rate of seedling recruitment, and expected mortality, it should be possible to identify the species and determine the expected density of weeds likely to occur on a site (Radosevich & Holt, 1984).

The behaviour of weed seeds has a large influence on the effectiveness of control measures adopted and the long-term achievements of programmes planned to eradicate or control weeds. Knowledge of seed behaviour is crucial to implementing an effective weed control programme. Weeds that have little or no seed dormancy, such as annual grasses, are much easier to eliminate than weeds whose seeds can remain dormant in the soil for many years (Pearce, 1984).

From the literature it became clear that knowledge about the germination requirements, dormancy and competitiveness of the most dominant weed species might help to optimise weed control strategies. In a study done in Nebraska (USA), Burnside *et al.* (1996) showed that although 57% of the seed of the 11 annual grasses and 47 % of that of the 14 annual broadleaf species still germinated after 9 years of seed burial, species differed significantly. Seed longevity also differed between localities.

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Chapter 3

The effect of temperature on the germination of six selected weed species

Abstract

The understanding of environmental variables influencing germination characteristics of weeds is essential for developing weed control programs. A laboratory experiment was conducted to determine whether temperature had an effect on the germination of six weed species. The field-collected seeds were incubated in a germination cabinet at three temperature regimes namely 5 / 15 °C, 10 / 15 °C and 10 / 20 °C, and germination percentage was determined after 3, 7, 10 and 14 days of incubation. Ungerminated seeds were categorized as either viable or dead after performing the tetrazolium test for viability of seeds. Species tested differed in response to the different temperature treatments. Species such as *Arctotheca calendula*, *Avena fatua, Bromus diandrus* and *Raphanus raphanistrum* germinated best when subjected to a temperature regime of 10/15 °C, which correlates with late autumn to early winter temperatures in the western Cape. *Emex australis* and *Lolium temulentum* showed little response to the temperature regimes tested. Among the germinated weed species, *Avena fatua* germinated most with a cumulative value of 90% as compared to *Raphanus raphanistrum* which germinated least with a cumulative value of 12%.

Keywords: *Arctotheca calendula*, *Avena fatua*, *Bromus diandrus*, *Emex australis, Lolium temulentum, Raphanus raphanistrum*, germination, temperature, tetrazolium.

Uittreksel

'n Begrip van omgewingsveranderlikes wat ontkiemingseienskappe beïnvloed is noodsaaklik om onkruidbeheerprogramme te ontwikkel. 'n Laboratorium eksperiment is uitgevoer om te bepaal of temperatuur 'n effek het op die ontkieming van ses onkruidspesies. Saad wat in die veld versamel is, is in 'n ontkiemingskabinet geïnkubeer by drie temperatuurreekse naamlik; 5 °C/15 °C, 10 °C/15 °C and 10 °C/20 °C en ontkiemingspersentasie is na 3, 7, 10 en 14 dae van inkubasie bepaal. Saad wat nie ontkiem het nie is as kiemkragtig of dood gekategoriseer nadat die tetrazoliumtoets vir

saadkiemkragtigheid daarop uitgevoer is. Die ontkiemde saad het verskillende reaksies teenoor verskillende temperatuurreekse getoon. Die optimum temperatuur vir die ontkieming van *Arctotheca calendula*, *Avena fatua*, *Bromus diandrus* en *Raphanus raphanistrum* was 10 °C / 15 °C, wat ooreenstem met laat herfs tot vroeë winter temperature in die Wes-Kaap. *Emex australis* en *Lolium temulentum* het min reaksie teenoor die getoetste temperatuurreekse getoon. Van alle ontkiemde onkruidsade, het *Avena fatua* die hoogste ontkiemspersentasie met 'n kumulatiewe waarde van 90% getoon. Hierteenoor het *Raphanus raphanistrum,* met 'n kumulatiewe waarde van 12%, die minste ontkiem.

Introduction

Germination can be defined as the resumption of embryo growth that is sufficient for the embryo to protrude through coverings surrounding the embryo (Camper, 1986). Germination will not proceed unless conditions are favourable as the major factors controlling germination are water, oxygen, temperature and light (Bidwell, 1979).

Germination is a complex process composed of many biological steps and is highly temperature-dependent (Camper, 1986). According to Bewley & Black (1994), temperature acts to regulate germination in the field in three ways, that is: by determining the capacity and rate of germination, by removing primary or secondary dormancy, and by inducing secondary dormancy. Soil temperature and water content are two important factors that regulate seedling emergence. Water availability is critical for seed imbibition, while temperature is closely related to embryo development before germination (Harris *et al.*, 1998).

The objective of this study was to determine the optimum temperature regimes on the germination of six weed seed species, namely: *Arctotheca calendula, Emex australis, Raphanus raphanistrum, Avena fatua, Bromus diandrus,* and *Lolium temulentum.*

Materials and Methods

Germination test

Seeds of 6 weed species, namely *A. calendula* (cape marigold), *E. australis* (devil's thorn), *R. raphanistrum* (wild radish), *A. fatua* (common wild oat), *B. diandrus* (ripgut brome)

and *L. temulentum* (rye grass) were collected at Langgewens experimental farm during 2000 and stored at room temperature till germination tests started approximately six months later. To determine their viability, 20 healthy looking seeds (not treated or sterilized with anything which may influence dormancy) from each species were spaced evenly on germination towels soaked in distilled water (7 mℓ / petri dish) and placed inside petri dishes to ensure optimum moisture conditions. The petri dishes were sealed with Parafilm to ensure optimum moisture conditions.

The incubation took place in germination cabinets at three night / day temperature treatments, namely 5 °C/15 °C, 10 °C/15 °C and 10 °C/20 °C. Each minimum / maximum temperature setting was maintained for a 12h / 12h period on a daily basis. These temperature treatments were selected to represent three scenarios of daily temperature patterns at the soil surface during winter in the winter rainfall region of the western Cape. All seeds were subjected to a dark period of 12 hours followed by a 12-hour light treatment, which coincided with the night/day temperature settings.

Germination was determined after 3, 7, 10 and 14 days of incubation. Seeds were considered germinated when the radicle was approximately 2mm in length and removed from the germination towels. Ungerminated seeds were categorized as dead or viable after performing the tetrazolium test (Wood *et al.,* 1997). The percentage of seeds that germinated was based on the number of germinated seeds relative to the total number of viable seeds tested. The tetrazolium test results are shown in Table 3.1. All the treatments were replicated three times in a factorial design.

Testing the viability of seeds

Tetrazolium test

Pre-conditioning of the seeds

The seeds from the following 6 weed species, namely *Arctotheca calendula* (cape marigold), *Emex australis* (devil's thorn), *Raphanus raphanistrum* (wild radish), *Avena fatua* (common wild oat), *Bromus diandrus* (ripgut brome), and *Lolium temulentum* (rye grass) that failed to germinate were used. Seeds were moistened to be easily bisected or punctured because the viability test was not performed

immediately after germination test. Seeds were soaked in distilled water for 6 hours at 20 °C in a germination cabinet.

Preparation for staining

The following preparation methods were done to allow rapid staining and evaluation of the embryo. Magnification was used when cutting seeds. The following procedures were done according to different weed species:

Avena fatua – Cutting transversely near embryo.

Arctotheca calendula – Removal of the testa (seed coat) completely.

Bromus diandrus – Cutting of seeds transversally near embryo.

Emex australis – Cutting of seeds longitudinally through the midsection on the distal half.

Lolium temulentum – Incising of seeds transversely near embryo.

Raphanus raphanistrum – Puncturing of seeds near the centre (without damaging the embryo).

Staining

Seeds were soaked in tetrazolium solution (containing 0.5% concentration of tetrazolium) for 6 hours in an incubator at 30 °C. The petri dishes were placed in the dark to avoid the effect of ultra violet light on the solution colour.

Concentration of tetrazolium

The concentration used for the 6 weed species was 0.5%, which is 0.5g of tetrazolium salt dissolved in 100mℓ of buffer solution (pH 7, Potassium di-Hydrogen phosphate di- Sodium Hydrogen phosphate).

Washing

The seeds were washed several times with distilled water after staining. Evaluation was done immediately after washing.

Evaluation

The seeds were prepared for evaluation in order to expose the essential structures and the embryo. To prepare the seeds for evaluation, all the seeds were prepared by cutting longitudinally through the midsection of the axis to expose the embryo, and

separating the seed in halves. Magnification (Binocular microscope) was used when evaluating the seeds and seeds were categorized according to the following 4 groups, namely (i) completely stained and thus viable seeds; (ii) partially stained yet still positive (as agreed with the characteristics for evaluating seeds as stated in the International Rules for Seed Testing – ISTA, 1999), (iii) partially stained but negative (iv) completely unstained and thus dead.

Table 3.1: The viability of seed: test results for six weed species

		Total number of seeds (Mean of 3 replications)				
Weed Species	Temperature	Tested	Viable	Viable/un-germinated	Dead	% Germinated
Arctotheca calendula	5/15 °C	20	18	12	2	33
	10/15 °C	20	17	10	3	41
	10/20 °C	20	17	12	3	29
Avena fatua	5/15 °C	20	19	11	1	42
	10/15 °C	20	17	2	1	88
	10/20 °C	20	20	3	0	85
Bromus diandrus	5/15 °C	20	18	15	2	17
	10/15 °C	20	15	8	5	47
	10/20 °C	20	18	12	2	33
Emex australis	5/15 °C	20	19	7	1	63
	10/15 °C	20	17	5	3	71
	10/20 °C	20	18	5	2	72
Lolium temulentum	5/15 °C	20	16	13	4	19
	10/15 °C	20	16	12	4	25
	10/20 °C	20	18	11	2	39
Raphanus raphanistrum	5/15 °C	20	12	11	8	8
	10/15 °C	20	15	13	5	13
	10/20 °C	20	14	12	6	14

Results

Arctotheca calendula

Table 3.2 shows that none of the *Arctotheca calendula* seed germinated during the first three days (0-3 day period) of incubation at any of the temperature regimes. During the 3-7 day period of incubation, 8% of the seed germinated, followed by 16.4% and 8.2% during the 7-10 and 10-14 day periods of incubation respectively. Most of the *A. calendula* seed therefore germinated between 7 and 10 days of incubation.

The rates of germination at the 3-7 day period of incubation were however significantly affected by incubation temperature (Table 3.2). During the 3-7 day incubation period, significantly more ($p < 0.05$) seed of *A. calendula* germinated at the 10 °C/ 15 °C temperature regime (15.3%) compared to the 10 °C/ 20 °C temperature regime (0%) (Figure 3.1a). During the 0-3 day, 7-10 day and 10-14 day incubation periods, no significant differences in germination rate were however found between the different temperature regimes. Maximum germination rates for *A. calendula,* at different incubation temperatures, were therefore found at different periods of incubation.

Table 3.2 Germination rates (%) for three dicotyledonous weed species at three temperature regimes respectively, over a period of 14 days.

		Periods				**Mean**
Weed species	Temperature	0-3days	3-7days	7-10 days	10-14days	
Arctotheca calendula	5/15 °C	0 ^{c}	9 ^{abc}	14 ^{abc}	8 ^{abc}	8
	10/15 °C	0 ^{c}	15 ^{ab}	14 ^{abc}	10 ^{abc}	10
	10/20 °C	0 ^{c}	0 ^{c}	22 ^{a}	6 ^{bc}	7
Mean		0	8	16	8	
LSD 't' Main effect temperature (P<0.05) = 2.94 LSD 't' Main effect periods (P<0.05) = 8.41 LSD 't' temperature x periods (P<0.05) = 14.57						
Emex australis	5/15 °C	2 ^{c}	44 ^{a}	9 ^{c}	9 ^{c}	16
	10/15 °C	4 ^{c}	37 ^{ab}	12 ^{c}	15 ^{bc}	17
	10/20 °C	0 ^{c}	43 ^{a}	12 ^{c}	19 ^{bc}	19
Mean		2	41	11	14	
LSD 't' Main effect temperature (P<0.05) = 9.82 LSD 't' Main effect periods (P<0.05) = 13.73 LSD 't' temperature x periods (P<0.05) = 23.78						
Raphanus raphanistrum	5/15 °C	0 ^{b}	3 ^{ab}	0 ^{b}	0 ^{b}	1
	10/15 °C	7 ^{a}	0 ^{b}	0 ^{b}	5 ^{ab}	3
	10/20 °C	2 ^{ab}	3 ^{ab}	2 ^{ab}	3 ^{ab}	3
Mean		3	2	1	3	
LSD 't' Main effect temperature (P<0.05) = 5.79 LSD 't' Main effect periods (P<0.05) = 3.95 LSD 't' temperature x periods (P<0.05) = 6.84						

Table 3.3 Germination rates (%) for three monocotyledonous weed species at three temperature regimes respectively, over a period of 14 days.

		Periods				**Mean**
Weed species	Temperature	0-3days	3-7days	7-10 days	10-14days	
Avena fatua	5/15 °C	25 ^{bc}	15 ^{bcd}	2 ^{cd}	2 ^{cd}	11
	10/15 °C	71 ^{a}	12 ^{bcd}	0 ^{d}	8 ^{bcd}	23
	10/20 °C	0 ^{d}	55 ^{a}	27 ^{b}	5 ^{bcd}	22
Mean		32	27	10	5	
LSD 't' Main effect temperature (P<0.05) = 5.37 LSD 't' Main effect periods (P<0.05) = 13.82 LSD 't' temperature x periods (P<0.05) = 23.94						
Bromus diandrus	5/15 °C	0 ^{c}	7 ^{abc}	4 ^{bc}	8 ^{abc}	5
	10/15 °C	0 ^{c}	14 ^{ab}	19 ^{a}	16 ^{ab}	12
	10/20 °C	0 ^{c}	13 ^{ab}	11 ^{abc}	7 ^{abc}	8
Mean		0	11	11	10	
LSD 't' Main effect temperature (P<0.05) = 6.14 LSD 't' Main effect periods (P<0.05) = 6.90 LSD 't' temperature x periods (P<0.05) = 11.94						
Lolium temulentum	5/15 °C	0 ^{c}	20 ^{ab}	0 ^{c}	0 ^{c}	5
	10/15 °C	0 ^{c}	12 ^{abc}	6 ^{bc}	4 ^{c}	6
	10/20 °C	0 ^{c}	25 ^{a}	9 ^{bc}	3 ^{c}	10
Mean		0	19	5	3	
LSD 't' Main effect temperature (P<0.05) = 4.69 LSD 't' Main effect periods (P<0.05) = 8.37 LSD 't' temperature x periods (P<0.05) = 14.49						

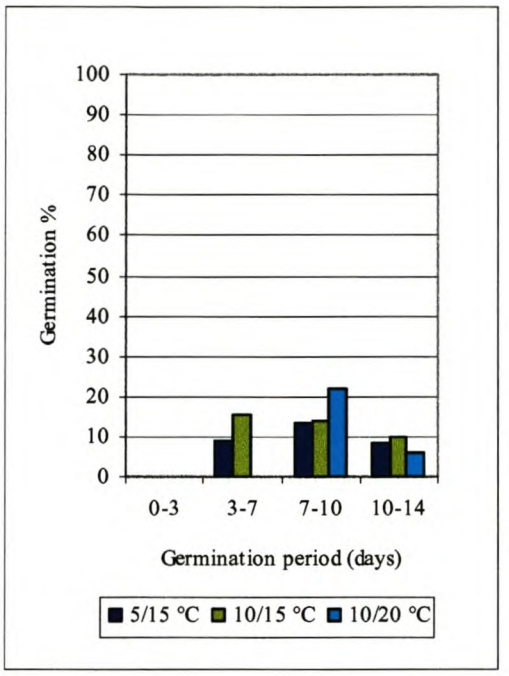

Figure 3.1a Germination of *Arctotheca calendula* at three temperature regimes.

Cumulative germination figures for *A. calendula* (Figure 3.1b) showed that nearly 40% of the seed germinated after 14 days at an incubation temperature regime of 10 °C/15 °C. At temperature regimes of 5 °C/15 °C and 10 °C/20 °C only 30.5% and 28% of the seed germinated within 14 days (Table 3.2). Cumulative germination of below 50% for all temperature regimes tested indicated that *A. calendula* might germinate over a long period, which will require repeated control methods or the use of herbicides with a long field half-life. Chaharsoghi & Jacobs (1998) stated that weed control methods like repeated tillage in combination with herbicides might provide mechanisms for manipulating the *A. calendula* seedbank prior to crop establishment. This could be made possible by the fact that most *A. calendula* seedlings likely to emerge from the surface layer of the soil profile.

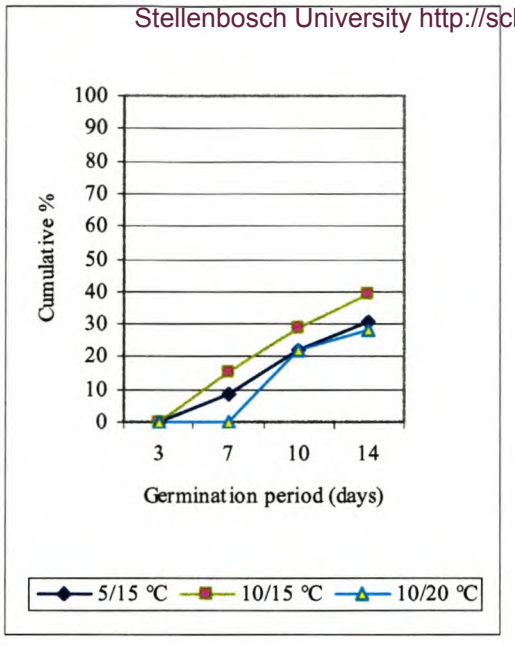

Figure 3.1b Cumulative germination of *Arctotheca calendula* at three temperature regimes.

Avena fatua

Only 31.84% of the *Avena fatua* seed germinated during the first three days (0-3 day period) of incubation (Table 3.3). During the 3-7 day period of incubation, 27% of the seeds germinated, followed by 9.6% and 5.1% during the 7-10 and 10-14 day periods of incubation, respectively. Germination rate of *A. fatua* therefore decreased with incubation time.

The rates of germination at 0-3 day, 3-7 day and 7-10 day of incubation periods were significantly affected by incubation temperature (Figure 3.2a). During the 0-3 day incubation period, significantly more ($p < 0.05$) seed of *A. fatua* germinated at the 10/15 °C temperature regime (70.7%) compared to the 10/20 °C (0%) and 5/15 °C (24.8%) temperature regimes. These statement coincide with that of Peters (1982), who confirmed that the optimum temperature for germination of *A. fatua* was found to be about 15 °C. During the 3-7 and 7-10 day incubation periods, significantly more ($p < 0.05$) seed germinated at the 10/20 °C regime compared to 10/15 °C and 5/15 °C regimes, but no significant differences in germination rate were found during the 10-14 day incubation periods at different temperature regimes. The maximum germination rates for *A. fatua*, at the higher incubation temperature were therefore found after a longer period of incubation compared to the lower temperature regimes.

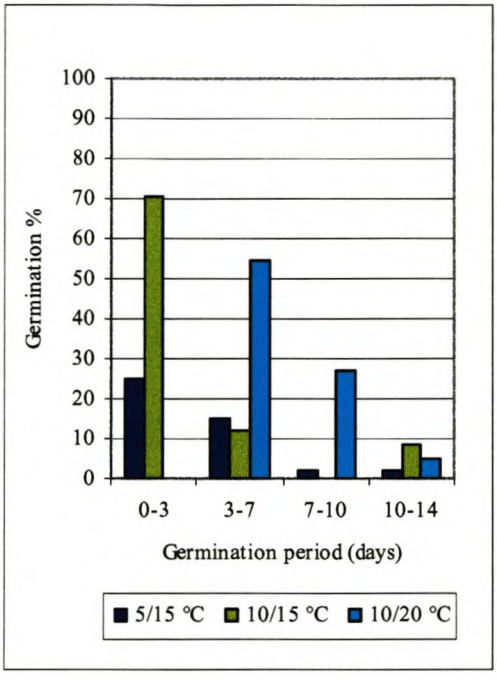

Figure 3.2a Germination rates of *Avena fatua* at three temperature regimes.

Cumulative germination figures of *A. fatua* (Figure 3.2b) showed that about 90% of the seed germinated after 14 days at incubation temperature regimes of 10 °C/15 °C and 10 °C/20 °C, while only 43.5% of the seed germinated at a temperature regime of 5 °C/15 °C (Table 3.3). Cumulative germination of above 50% for two temperature regimes, 10 °C/15 °C and 10 °C/20 °C, indicates that *A. fatua* might germinate over a short period during autumn before the soil temperature become too cold. Delayed planting of winter crops may thus allow farmers to use soil cultivation or non-selective herbicides to control early germinating *A. fatua*. Post-emergence herbicides with a short field half-life would be effective.

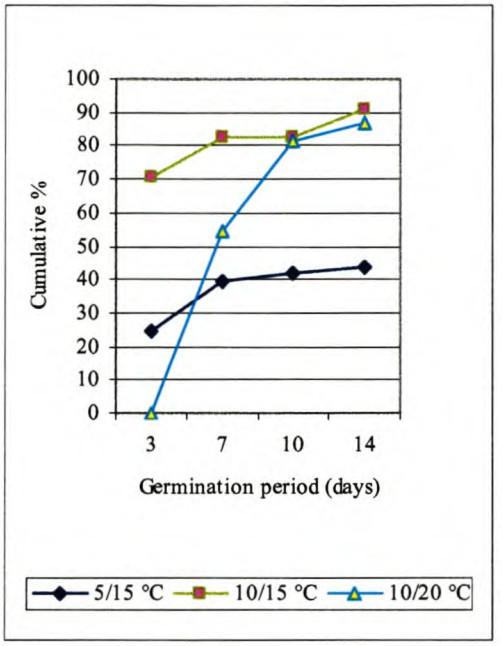

Figure 3.2b Cumulative germination of *Avena fatua* at three temperature regimes.

Bromus diandrus

Table 3.3 shows that none of the *Bromus diandrus* seed germinated during the first three days (0-3 day period) of incubation at any of the temperature regimes tested. During the 3-7 day period of incubation, 11.5% of the seed germinated, followed by 11.3% and 10.4% during the 7-10 and 10-14 day periods of incubation, respectively. *Bromus diandrus* seed therefore germinated quite evenly between 3 and 14 days of incubation. Maximum germination of *B. diandrus* was obtained at 10 °C/15 °C temperature regimes and this information agrees with that of Gill & Blacklow (1985) as they obtained 85% germination at temperatures lower than 20 °C. Iglesias *et. al.* (1993) stated that high temperatures and hydric stress inhibit germination of *Bromus* species.

The rate of germination at the 7-10 day incubation period was however significantly affected by incubation temperature (Figure 3.3a). During this period, significantly more ($p < 0.05$) seed germinated at the 10 °C/15 °C temperature regime (18.9%) compared to the 5 °C/15 °C regime (3.6%). During the 0-3 day, 3-7 day and 10-14 day incubation periods, no significant differences in germination rate were found between the different temperature regimes. Although significant differences were only found at the 7-10 day incubation period, different incubation temperatures tested showed a tendency for higher germination rates at 10 °C/15 °C.

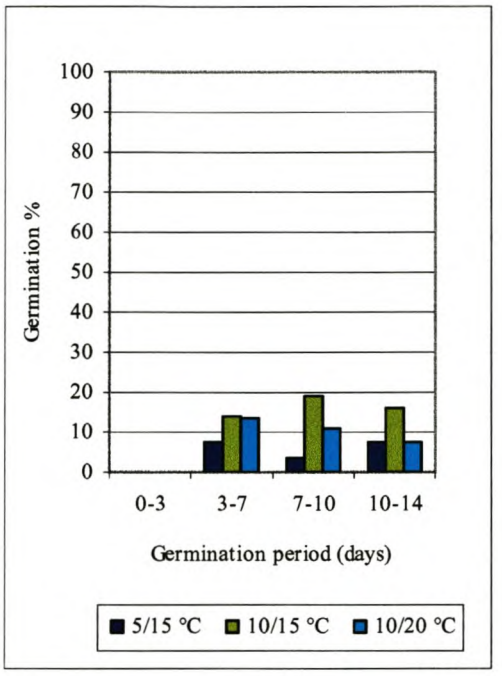

Figure 3.3a Germination rates of *Bromus diandrus* at three temperature regimes.

According to the cumulative germination data for *B. diandrus* (Figure 3.3b), nearly 50% of the seed germinated after 14 days at an incubation temperature regime of 10 °C/15 °C compared to 31.9% and 18.6% at temperature regimes of 10 °C/20 °C and 5 °C/15 °C respectively (Table 3.3). The cumulative germination of below 50% for all temperature regimes tested, indicate that *B. diandrus* might germinate over a long period, which will require repeated control methods or the use of herbicides with a long field half-life. Poor germination at the 5 °C/15 °C incubation temperature however, indicated that peak germination would probably occur during autumn or early winter. This tendency may favour the use of non-selective herbicides or soil cultivation at planting of the winter crops.

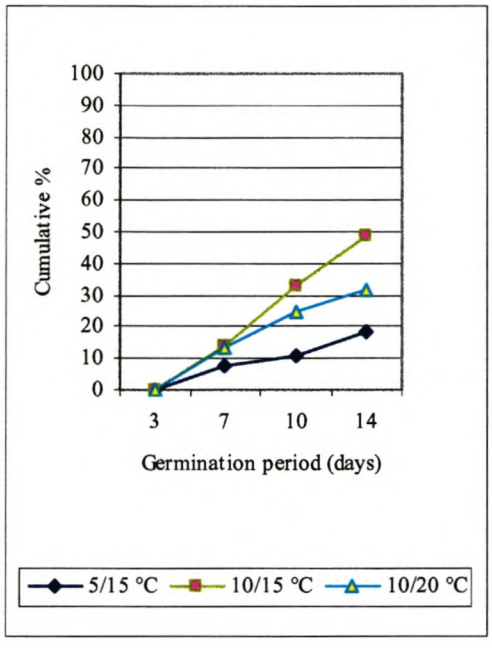

Figure 3.3b Cumulative germination of *Bromus diandrus* at three temperature regimes.

Emex australis

Very few (1.86%) *Emex australis* seed germinated during the first three days (0-3 day period) of incubation (Table 3.2). During the 3-7 day period of incubation 41.1% of seed germinated, followed by 11.2% and 14.2% during the 7-10 and 10-14 day periods of incubation. Most of the *E. australis* seed therefore germinated between 3 and 7 days of incubation.

No significant differences in germination rates were found among all incubation periods and between different temperature regimes (Figure 3.4a). It can therefore be said that germination of *E. australis* seed were not affected by different incubation temperatures tested in this study.

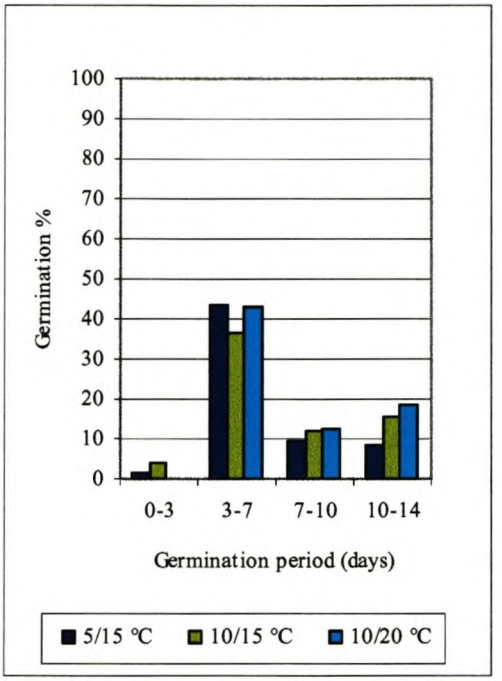

Figure 3.4a Germination rates of *Emex australis* at three temperature regimes.

The results showed that nearly 75% of the *E. australis* seed germinated after 14 days at an incubation temperature regime of 10/20 °C compared to 63% and 67.7% at temperature regimes of 5/15 °C and 10/15 °C respectively (Figure 3.4b). Cumulative germination of above 60% for all temperature regimes tested indicate that *E. australis* will germinate almost any time of the year provided that soil moisture content is sufficient. If so, most of the seed will germinate after the first autumn rains or even after an unexpected rain during summer in the Western Cape. For this reason several control methods such as tillage or non-selective herbicide sprayings before planting should kill most of the *E. australis* seedlings.

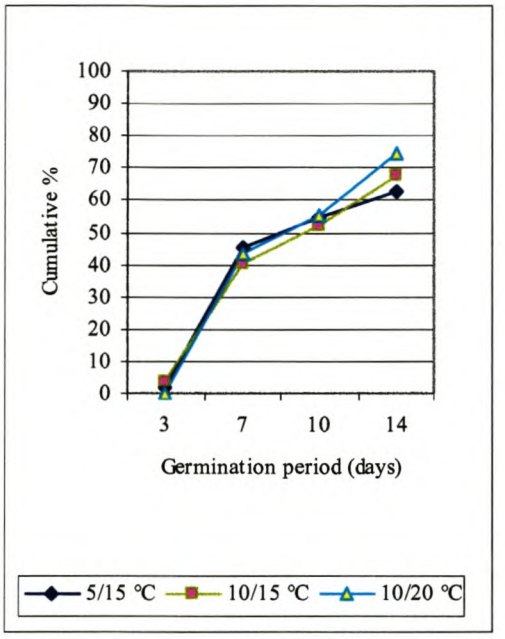

Figure 3.4b Cumulative germination of *Emex australis* at three temperature regimes.

Lolium temulentum

None of the *Lolium temulentum* seed germinated during the first three days (0-3 day period) of incubation at any of the temperature regimes tested (Table 3.3). During the 3-7 day period of incubation 19.1% of seed germinated, followed by 5.1% and 2.7% during the 7-10 and 10-14 day periods of incubation, respectively. Most of the *L. temulentum* seed therefore germinated between 3 and 7 days of incubation.

Although the 10/20 °C temperature regime showed the highest germination rate during the 7-10 day incubation period differences were not significant and germination rates were below 10%. Very little seed germinated during the 10-14 day incubation period were not significantly ($p < 0.05$) affected by incubation temperature at all incubation periods (Figure 3.5a).

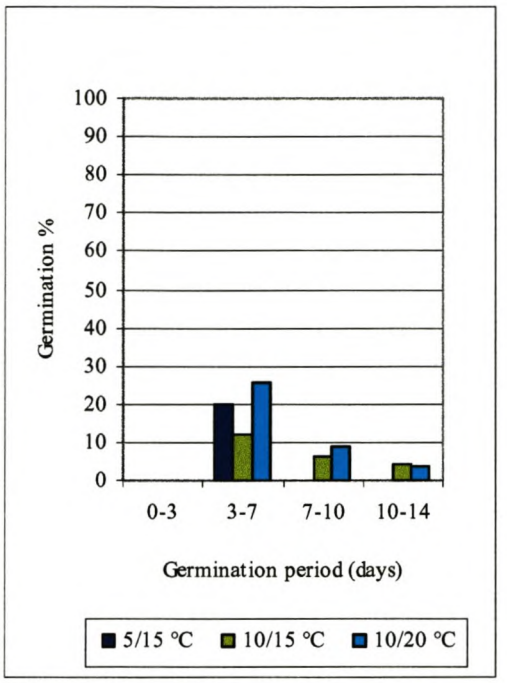

Figure 3.5a Germination rates of *Lolium temulentum* at three temperature regimes

Cumulative germination figures for *L. temulentum* (Figure 3.5b) showed that nearly 40% of the seed germinated after 14 days at an incubation temperature regime of 10 °C/20 °C. At temperature regimes of 5 °C/15 °C and 10 °C/15 °C only 19.7% and 22.7% of the seed germinated within 14 days, respectively. Cumulative germination of below 40% for all temperature regimes tested indicated that *L. temulentum* will germinate over a long period if not limited by other factors such as moisture or light intensity. Under such conditions repeated control methods or herbicides with a long field half–life will be required.

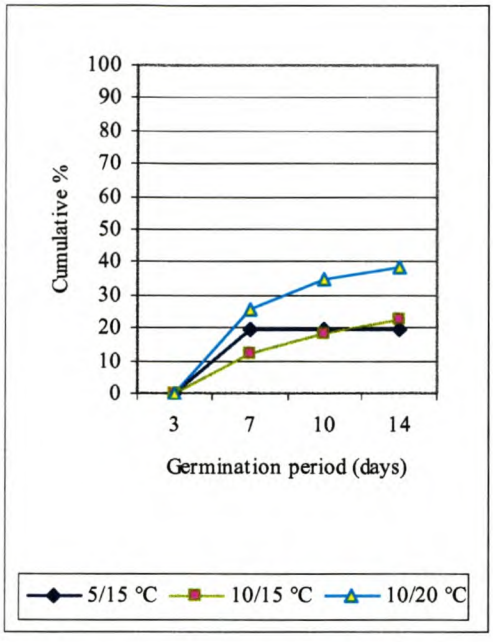

Figure 3.5b Cumulative germination of *Lolium temulentum* at three temperature regimes.

Raphanus raphanistrum

Only 3.1% of the *Raphanus raphanistrum* seed germinated during the first three days (0-3 day period) of incubation, while 2.1%, 0.7% and 2.6% germinated during the 3-7 day, 7-10 day and 10-14 day periods of incubation respectively (Table 3.2). It is therefore obvious that the *R. raphanistrum* seed used were either in a dormant stage due to factors such as the presence of chemical inhibitors or an impenetrable seed-coat or germination were limited by some other factor such as a specific light stimulus (Duke, 1985).

Due to the above-mentioned very poor germination, significant differences were found only between 0-3 day incubation period (Figure 3.6a). During this period, significantly more seed of *R. raphanistrum* - germinated at the 10/15 °C regime (7.1%) compared to the 5/15 °C regime (0%). During the 3-7 day, 7-10 day and 10-14 day incubation periods, no significant difference were found at different incubation temperature tested. The germination rate was below 8% across all incubation periods and different temperatures tested.

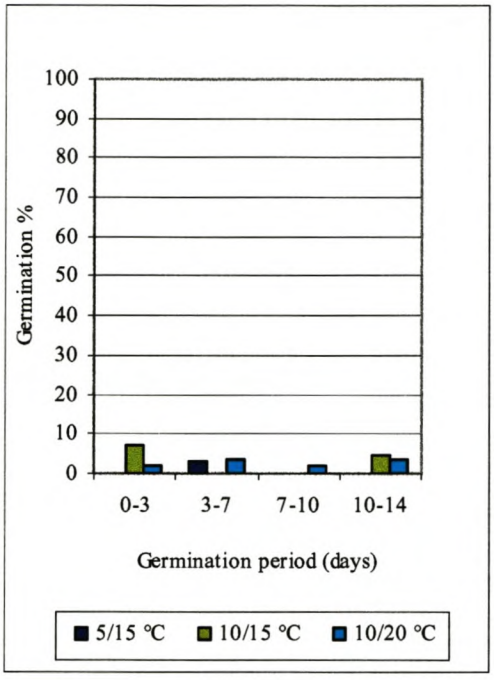

Figure 3.6a Germination rates of *Raphanus raphanistrum* at three temperature regimes.

Although cumulative germination values for *R. raphanistrum* showed that nearly 12% of the seeds germinated after 14 days at an incubation temperature regime of 10 °C/15 °C, compared to 11% and 3% at temperature regimes of 10/20 °C and 5/10 °C, respectively (Figure 3.6b), differences were of no practical value. Germination of *R. raphanistrum* will thus be controlled by its state of dormancy and not by differences in temperature. Results however indicated that once dormancy has been broken, germination would occur within 3 days at 10 °C/15 °C.

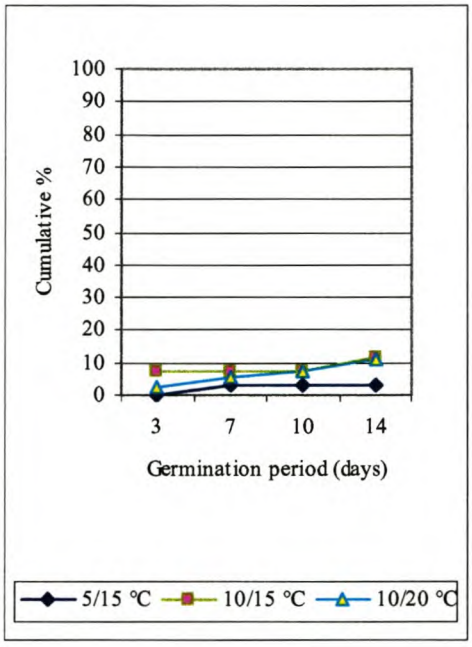

Figure 3.6b Cumulative germination of *Raphanus raphanistrum* at three temperature regimes.

Discussion

Results showed large differences between species, which may have a significant effect on the efficiency of different herbicides and methods used in winter crops to control these weed species.

Cumulative germination during the 14-day incubation study varied between less than 12% for *R. raphanistrum* at all temperature regimes tested to nearly 90% for *A. fatua* at the 10 °C/15 °C treatment. Because all seed used in this experiment were collected during 2000, these large differences suggested that the species tested differ with regard to either the length of their period of primary dormancy or specific germination requirements such as a light stimulus (Duke, 1985). Jones (1976) also showed that *A. fatua* experience little dormancy, while Andersen (1968) found that *R. raphanistrum* is likely to experiences a lengthy period of primary dormancy. It is however also known that the germination of large-seeded species such as *R. raphanistrum* is enhanced when exposed to dark conditions, while all seed were exposed to an alternating dark and light period of 12-hours in this study. Cumulative germination of less than 50% after a 14-day period of incubation, as found for *A. calendula, B. diandrus, L. temulentum* and *R. raphanistrum* in this study, indicated that best control

of these species will most probably be obtained with herbicides with a long field half-life. Iglesias *et al.*, (1993), suggested that the achievement of rapid and effective reduction of *Bromus* spp. on farms could be attained by a cropping system that facilitates uniform and rapid germination of that weeds.

Species tested also differed in response to the different temperature treatments. Most species tested germinated best when subjected to a temperature regime of 10 °C/15 °C, which correlates with late autumn to early winter temperatures in the Western Cape. This information agrees with that of Jones (1976), who reported that *A. fatua* tends to emerge more often in autumn than in spring. The finding on the optimum temperature for *A. calendula* corresponds with that of Dunbabin & Cocks (1999), who obtained maximum germination of *A. calendula* at 15 °C. These species *(A. calendula, A. fatua, B. diandrus* and *R. raphanistrum)* will therefore germinate at planting or after planting of wheat in the Western Cape region. Pre-planting treatments such as soil tillage will therefore not be very efficient to control these weeds. *E. australis*, and to a lesser extent *L. temulentum*, showed little response to the temperature regimes tested, which indicated that these species may germinate all year round if other germination requirements such as soil moisture content (Bidwell, 1979) are met. Andersen (1968) also found that *L. temulentum* is not affected by temperatures between 2-35 °C. Chersa *et al.* (1994) obtained 95% germination of Italian ryegrass seeds incubated at red light as compared to 65% in the darkness and far red light and this shows that light is a contributing factor in the germination of *Lolium* species.

The rate of germination also differed between weed species tested. In the case of *A. fatua,* the highest germination rate was found during the first three days of incubation, while most seed of *E. australis* and *L. temulentum* germinated during the 3-7day period of incubation. *B. diandrus* on the other hand germinated quite evenly during the incubation period. Due to the very rapid germination of *A. fatua* this weed may emerge earlier than the planted wheat, which may give a competitive advantage to the weeds.

Many studies dealing with the effect of temperature on germination of weed seeds have been conducted, but literature on the effect of temperature on germination of *E.*

australis and *R. raphanistrum* is scarce. A detailed knowledge regarding the environmental conditions required for weed seed germination and establishment in soil is an important prerequisite for the development of integrated and biological weed control strategies.

Conclusions

In conclusion it can be said that results from this study showed that different control methods might be needed for different weed species. Because fields are most often infested with several weed species, knowledge with regard to germination requirements obtained in this study will certainly help to improve weed control in field crops of the Western Cape.

In conclusion, the results indicated that species such as *A. calendula, A. fatua*, *B. diandrus* and *R. raphanistrum* will germinate well at a temperature regime of 10 / 15 °C, and this temperature regime is also suitable for growing winter wheat in the Western Cape. Therefore, earlier planting of wheat in the region will help to overcome problems caused by those weeds. Species such as *E. australis* and *L. temulentum* will germinate all year round if germination requirements are met and control methods such as non-selective herbicides, herbicides with long field half-life or tillage before planting will be essential.

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Chapter 4

Breaking of seed dormancy in six weed species using gibberellic acid, auxin and cytokinin as growth regulators

Abstract

A laboratory experiment was conducted to evaluate the effect of three growth regulators, to break dormancy and enable simultaneous germination of *Arctotheca calendula, Emex australis, Raphanus raphnistrum, Avena fatua, Bromus diandrus,* and *Lolium temulentum.* Weed seeds gathered from Langgewens experimental farm were germinated in a germination cabinet at 20 °C using test solutions of the following growth regulators: gibberellic acid, hydroxylamine (auxin) and kinetin (cytokinin). The germination of seeds was assessed after 3, 7, 10 and 14 days of incubation and the tetrazolium test for viability of seeds was done for ungerminated seeds. The results showed that no chemical / concentration proved to be successful in stimulating the germination of all species tested. For example, a high concentration of hydroxylamine increased germination of *E. australis* to nearly 100% and inhibited germination of *R. raphanistrum* to less than 12.5% at all hydroxylamine concentrations. Therefore, it had been concluded that application of different chemical concentrations can stimulate the germination of some dormant weed seeds in the field and this will help in reducing weed seed populations in the seed-bank.

Keywords: dormancy, germination, gibberellic acid, hydroxylamine (auxin), kinetin (cytokinin), tetrazolium.

Uittreksel

'n Laboratorium eksperiment is uitgevoer om die invloed van drie groeireguleerders op die opheffing van saadrus te ondersoek en om ook die gelyktydige ontkieming van *Arctotheca calendula, Emex australis, Raphanus raphnistrum, Avena fatua, Bromus diandrus,* en *Lolium temulentum.* moontlik te maak. Onkruidsade wat op Langgewens versamel is, is in 'n ontkiemingskabinet by 20 °C ontkiem met toetsoplossings van die volgende groeireguleerders: gibberelliensuur, hidroksielamien (ouksien) en kinetin (sitokinien). Die ontkieming van die sade is na inkubasie periodes van 3, 7, 10 en 14 dae geëvalueer en die tetrazoliumtoets vir saadkiemkragtigheid is uitgevoer vir onontkiemde

sade. Die resultate het getoon dat geen chemikalie / konsentrasie suksesvol was om die ontkieming van alle getoetste spesies te stimuleer nie. 'n Hoë konsentrasie hydroksielamien het byvoorbeeld die ontkieming van *E. australis* tot byna 100% verhoog en die ontkieming van *R. raphanistrum* geïnhibeer tot minder as 12.5% by alle hydroksielamien konsentrasies. Daar word dus tot die gevolgtrekking gekom dat die toediening van verskillende chemiese konsentrasies, die ontkieming van dormante onkruidsade in die veld kan stimuleer en dit sal meehelp om die onkruidsaadpopulasie in die saadbank te verminder.

Introduction

Dormancy is a property of many weed seeds that enables them to survive conditions hazardous to plant growth and to germinate at some later time or in some other place. Seeds may persist in the soil for many years because of dormancy and germinate when conditions are favourable for seedling survival through to maturity (Duke, 1985). Grant & Duke (1985) defined dormancy as the failure of a seed to germinate under conditions normally favourable for growth of the seedling.

A seed is considered dormant if it does not germinate when conditions are normally favorable for growth of seedlings of that species. Seeds that are dormant at the time of seed release from the parent plant are in primary dormancy. The seeds that were non-dormant originally but unable to germinate because of unfavorable conditions, may acquire secondary dormancy (Camper, 1986).

Bewley & Black (1982) stated that the ability of growth regulators, when applied to seeds, to release seeds from dormancy and promote germination is particularly interesting as it gives a clue to possible dormancy mechanisms. A better understanding of the mechanisms controlling dormancy and germination may also help to manipulate weed life cycles and, thereby, provide new mechanisms for weed control (Goldmark & Walker-Simmons, 1992).

Several chemicals, when applied to dormant seeds might cause them to germinate and although the seed of numerous species respond to one or more of these chemicals, large

differences are found between species (Corns, 1959; Bewley & Black, 1982; Metzger, 1983; Hurtt & Taylorson, 1986).

Hilton (1984), for example found that potassium nitrate can be used to reduce dormancy of *A. fatua* especially if followed by 10 to 14 days at 4.4 to 7.2 °C while Cairns & de Villiers (1986) reported that gibberellic acid, nitrates, respiratory inhibitors, herbicides and light stimulated germination of dormant or semi-dormant wild oat seed. Little is however known with regard to the response of other troublesome weed species in the Western Cape to these chemicals.

The objective of this study was to evaluate the effect of three growth regulators to break dormancy and enable simultaneous germination of *A. calendula, E. australis, R. raphnistrum, A. fatua, B. diandrus,* and *L. temulentum.*

Materials and Methods

Seed of *Arctotheca calendula, Emex australis, Raphanus raphanistrum, Avena fatua, Bromus diandrus and Lolium temulentum* which were gathered during the year 2000 at Langgewens Experiment Farm in the Swartland wheat producing area of South Africa and stored at room temperature (15-25 °C), were used for this germination study.

To determine the germination response of the above-mentioned weed species to three plant growth stimulators, 20 seeds of each species were placed on Whatman's filter paper in 9.5-cm diameter petri dishes and wetted with 7 mℓ of the test solution [gibberellic acid, hydroxylamine (auxin) and kinetin (cytokinin)]. After this the petri dishes were sealed with parafilm and placed in an incubator at 20 °C at a 12-hour day/night cycle.

The following test solutions were used:

Gibberellic acid

Gibberellic acid (purity > 90%) was tested at concentrations of 0 (control), 1 mg. ℓ^{-1}, 10 mℓ. ℓ^{-1} and 100 mg. ℓ^{-1}. The test solution also contained 2% (v/v) acetone and

0.1% (v/v) oxysorbic (Tween) which helped with the dispersal of the test compounds (Metzger, 1983). Test solutions were adjusted to pH 4.8 using 6N KOH.

Hydroxylamine (auxin)

Hydroxylamine concentrations of 0 (control), 3, 10 and 30 mg. ℓ^{-1} were used. Each concentration were adjusted to pH 7.3 using NaOH and made up to 1ℓ with distilled water as described by Esashi *et al.* (1979).

Kinetin (cytokinin)

Kinetin concentrations of 0 (control), 0.2, 0.3, 0.5 mg. ℓ^{-1} were used. Each concentration was dissolved in 10 mℓ of slightly heated 0.5N NaOH before diluting with distilled water and made up to 1ℓ with distilled water (Igbinnosa & Okonkwo, 1992).

The germination was assessed by emergence of the radicle and determined after 3, 7, 10 and 14 days. The ungerminated seeds were categorized as either viable or dead after performing the tetrazolium test. The germination percentage was based on the total number of seeds germinated as opposed to the total number of viable seeds tested. All treatments were replicated 2 times in a factorial design. The tetrazolium test results are shown in Table 4.1 and 4.2 (as a mean of 2 replications).

Statistical Analysis

Data from the laboratory experiment were subjected to analysis of variance to assess the effect of different chemical concentrations on the germination of six weed species. The data were analysed using SAS (Statistical Analysis Systems).

Table 4.1: The viability test result of *Arctotheca calendula*, *Avena fatua* and *Bromus diandrus* seeds.

			Total number of seeds (Mean)				
Weed Species	Chemicals	Concentrations	Tested	Viable	Viable/un-germinated	Dead	% Germinated
Arctotheca calendula	Gibberellic acid	0 mg. ℓ^{-1}	20	16	10	4	38
		1 mg. ℓ^{-1}	20	18	18	2	0
		10 mg. ℓ^{-1}	20	19	15	1	21
		100 mg. ℓ^{-1}	20	18	17	2	6
	Hydroxylamine	0 mg. ℓ^{-1}	20	19	13	1	32
		3 mg. ℓ^{-1}	20	20	18	0	10
		10 mg. ℓ^{-1}	20	18	11	2	39
		30 mg. ℓ^{-1}	20	20	15	0	25
	Kinetin	0 mg. ℓ^{-1}	20	18	15	2	17
		0.2 mg. ℓ^{-1}	20	20	15	0	25
		0.3 mg. ℓ^{-1}	20	18	12	2	33
		0.5 mg. ℓ^{-1}	20	20	16	0	20
Avena fatua	Gibberellic acid	0 mg. ℓ^{-1}	20	20	7	0	65
		1 mg. ℓ^{-1}	20	18	4	2	78
		10 mg. ℓ^{-1}	20	19	4	1	79
		100 mg. ℓ^{-1}	20	19	0	1	100
	Hydroxylamine	0 mg. ℓ^{-1}	20	20	1	0	95
		3 mg. ℓ^{-1}	20	19	2	1	89
		10 mg. ℓ^{-1}	20	19	3	1	84
		30 mg. ℓ^{-1}	20	19	5	1	74
	Kinetin	0 mg. ℓ^{-1}	20	19	2	1	89
		0.2 mg. ℓ^{-1}	20	19	2	1	89
		0.3 mg. ℓ^{-1}	20	19	3	1	84
		0.5 mg. ℓ^{-1}	20	19	1	1	95
Bromus diandrus	Gibberellic acid	0 mg. ℓ^{-1}	20	19	13	1	32
		1 mg. ℓ^{-1}	20	19	14	1	26
		10 mg. ℓ^{-1}	20	18	16	2	11
		100 mg. ℓ^{-1}	20	17	16	3	6
	Hydroxylamine	0 mg. ℓ^{-1}	20	20	18	0	10
		3 mg. ℓ^{-1}	20	19	16	1	16
		10 mg. ℓ^{-1}	20	18	11	2	39
		30 mg. ℓ^{-1}	20	19	15	1	21
	Kinetin	0 mg. ℓ^{-1}	20	19	15	1	21
		0.2 mg. ℓ^{-1}	20	18	16	2	11
		0.3 mg. ℓ^{-1}	20	18	15	2	17
		0.5 mg. ℓ^{-1}	20	20	14	0	30

Table 4.2: The viability test results for *Emex australis*, *Lolium temulentum* and *Raphanus raphanistrum* seeds.

			Total number of seeds (Mean)				
Weed Species	Chemicals	Concentrations	Tested	Viable	Viable/un-germinated	Dead	% Germinated
Emex australis	Gibberellic Acid	0 mg. ℓ^{-1}	20	19	6	1	68
		1 mg. ℓ^{-1}	20	19	4	1	79
		10 mg. ℓ^{-1}	20	18	5	2	72
		100 mg. ℓ^{-1}	20	18	8	2	56
	Hydroxylamine	0 mg. ℓ^{-1}	20	19	4	1	79
		3 mg. ℓ^{-1}	20	18	9	2	50
		10 mg. ℓ^{-1}	20	20	2	0	90
		30 mg. ℓ^{-1}	20	19	0	1	100
	Kinetin	0 mg. ℓ^{-1}	20	20	6	0	70
		0.2 mg. ℓ^{-1}	20	20	1	0	95
		0.3 mg. ℓ^{-1}	20	20	0	0	100
		0.5 mg. ℓ^{-1}	20	20	4	0	80
Lolium temulentum	Gibberellic acid	0 mg. ℓ^{-1}	20	20	9	0	55
		1 mg. ℓ^{-1}	20	19	9	1	53
		10 mg. ℓ^{-1}	20	19	11	1	42
		100 mg. ℓ^{-1}	20	19	19	1	0
	Hydroxylamine	0 mg. ℓ^{-1}	20	19	5	1	74
		3 mg. ℓ^{-1}	20	20	8	0	60
		10 mg. ℓ^{-1}	20	17	6	3	65
		30 mg. ℓ^{-1}	20	18	2	2	89
	Kinetin	0 mg. ℓ^{-1}	20	19	5	1	74
		0.2 mg. ℓ^{-1}	20	18	3	2	83
		0.3 mg. ℓ^{-1}	20	18	5	2	72
		0.5 mg. ℓ^{-1}	20	19	6	1	68
Raphanus raphanistrum	Gibberellic acid	0 mg. ℓ^{-1}	20	16	15	4	6
		1 mg. ℓ^{-1}	20	18	18	2	0
		10 mg. ℓ^{-1}	20	17	13	3	24
		100 mg. ℓ^{-1}	20	19	1	1	95
	Hydroxylamine	0 mg. ℓ^{-1}	20	19	18	1	5
		3 mg. ℓ^{-1}	20	18	18	2	0
		10 mg. ℓ^{-1}	20	19	17	1	11
		30 mg. ℓ^{-1}	20	19	17	1	11
	Kinetin	0 mg. ℓ^{-1}	20	19	18	1	5
		0.2 mg. ℓ^{-1}	20	19	19	1	0
		0.3 mg. ℓ^{-1}	20	18	17	2	6
		0.5 mg. ℓ^{-1}	20	18	17	2	6

Results

Arctotheca calendula

The germination rates of *A. calendula* were significantly affected by both the period of incubation and concentration of the chemicals used, but not by chemicals as a main factor (Table 4.3). None of the *Arctotheca calendula* seed germinated during the first three days (0-3 day period) of incubation at any of the chemical treatments tested, while 5.4%, 8.8% and 6.7% germinated during the 3-7 day, 7-10 day and 10-14 day periods of incubation

respectively. These results are in agreement with those found at different temperature regimes (Chapter 3).

Table 4.3 Germination response (%) of *Arctotheca calendula* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
Arctotheca calendula	Gibberellic acid	0 mg. ℓ^{-1}	0 ^{e}	22.5 ^{a}	5 ^{cde}	5 ^{cde}	8.13 ^{a}
		1 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	0 ^{e}	0 ^{e}	0.63 ^{c}
		10 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	2.5 ^{de}	12.5 ^{abcde}	4.38 ^{ab}
		100 mg. ℓ^{-1}	0 ^{e}	0 ^{e}	5 ^{cde}	2.5 ^{de}	1.88 ^{bc}
Mean	3.75						
	Hydroxylamine	0 mg. ℓ^{-1}	0 ^{e}	7.5 ^{bcde}	20 ^{ab}	2.5 ^{de}	7.5 ^{a}
		3 mg. ℓ^{-1}	0 ^{e}	0 ^{e}	0 ^{e}	7.5 ^{bcde}	1.88 ^{bc}
		10 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	20 ^{ab}	10 ^{abcde}	8.13 ^{a}
		30 mg. ℓ^{-1}	0 ^{e}	0 ^{e}	7.5 ^{bcde}	17.5 ^{abc}	6.25 ^{ab}
Mean	5.94						
	Kinetin	0 mg. ℓ^{-1}	0 ^{e}	7.5 ^{bcde}	5 ^{cde}	7.5 ^{bcde}	5.0 ^{abc}
		0.2 mg. ℓ^{-1}	0 ^{e}	12.5 ^{abcde}	10 ^{abcde}	2.5 ^{de}	6.25 ^{ab}
		0.3 mg. ℓ^{-1}	0 ^{e}	5 ^{cde}	15 ^{abcd}	7.5 ^{bcde}	6.88 ^{ab}
		0.5 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	15 ^{abcd}	5 ^{cde}	5.63 ^{abc}
Mean	5.94						
Mean			0 ^{b}	5.42 ^{a}	8.75 ^{a}	6.67 ^{a}	

LSD 't' Main effect chemical (P<0.05) = 2.67 N.S.
LSD 't' Main effect concentration (P<0.05) = 3.08 *
LSD 't' Main effect periods (P<0.05) = 3.65 *
LSD 't' chemical x concentration (P<0.05) = 5.33 *
LSD 't' chemical x periods (P<0.05) = 6.32 N.S.
LSD 't' concentration x periods (P<0.05) = 7.30 N.S.
LSD 't' chemical x concentration x periods (P<0.05) = 12.65 *
* P < 0.05 = Significant, N.S. = Not Significant.

Results also showed a significant ($p < 0.05$) chemical x concentration x period interaction (Table 4.3), which indicates that the response of *A. calendula* to the different concentrations of chemicals used, differ with time. This is due to significant differences found for different gibberellic acid concentrations during the 3-7 day period and hydroxylamine concentrations during the 7-10 and 10-14 day periods of incubation (Table

4.3). From Figure 4.1 it is, however, clear that the results were very inconsistent and did not show any clear trend. Two replicates in the above-mentioned significant interactions are thus most likely due to experimental error.

(a) (b) (c)

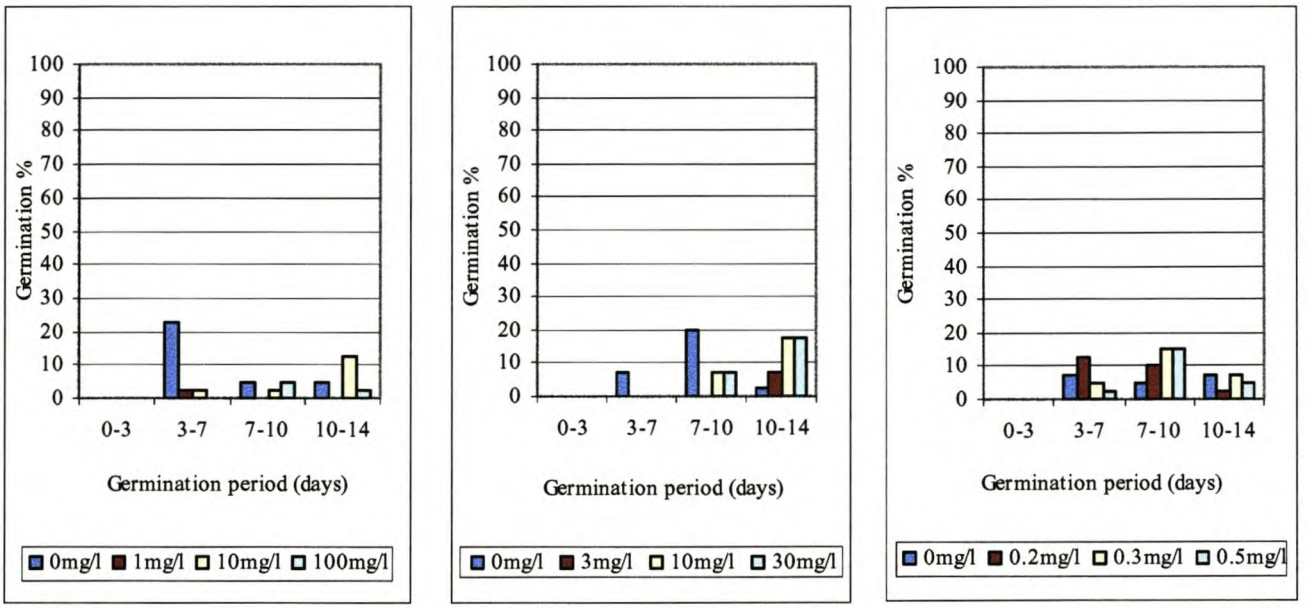

Figure 4.1 Germination of *A. calendula* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Cumulative germination figures of (Figure 4.2) also showed that the germination of *A. calendula* seed was not improved by any of the chemicals used. Cumulative germination of below 40% after 14 days of incubation, as also found in the experiment with different temperature regimes, indicated that *A. calendula* needed either very specific conditions for germination or that germination is prevented by an impermeable seed-coat or immature embryo (Gardner *et al.*, 1985).

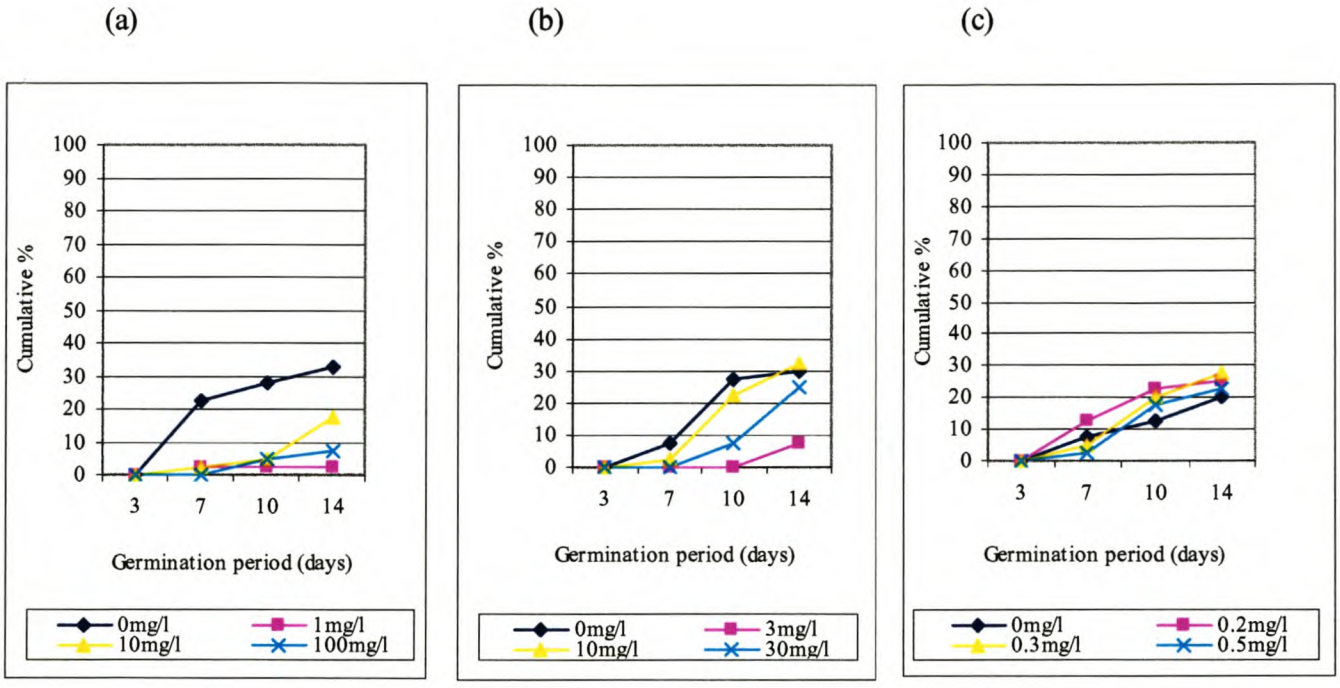

Figure 4.2 Cumulative germination of *A. calendula* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Avena fatua

Germination rate of *A. fatua* was affected by different concentrations of chemicals as well as different incubation periods as main factors, but not by different chemicals used in this study (Table 4.4). On average, 62.3% of the *A. fatua* seed germinated during the 0-3 day period of incubation. These results indicated that *A. fatua* seeds were not dormant during the germination period. During the 3-7 day period of incubation, 9% of seeds germinated, followed by 6% and 5.8% during 7-10 and 10-14 day periods of incubation respectively. The germination of *A. fatua* decreased with an increase in the incubation time and these results confirmed the germination results of *A. fatua* found at different temperature regimes (Chapter 3).

Table 4.4 Germination response (%) of *Avena fatua* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
A. fatua	Gibberellic acid	0 mg. ℓ^{-1}	62.5 ^{abcd}	0 ^{h}	2.5 ^{h}	0 ^{h}	16.25 ^{c}
		1 mg. ℓ^{-1}	60 ^{bcde}	5 ^{gh}	0 ^{h}	7.5 ^{gh}	18.13 ^{bc}
		10 mg. ℓ^{-1}	62.5 ^{abcd}	5 ^{gh}	2.5 ^{h}	7.5 ^{gh}	19.4 ^{abc}
		100 mg. ℓ^{-1}	0 ^{h}	32.5 ^{efg}	42.5 ^{def}	22.5 ^{fgh}	24.38 ^{a}
Mean	19.53						
	Hydroxylamine	0 mg. ℓ^{-1}	82.5 ^{abc}	7.5 ^{gh}	0 ^{h}	0 ^{h}	22.5 ^{ab}
		3 mg. ℓ^{-1}	50 ^{def}	12.5 ^{gh}	5 ^{gh}	12.5 ^{gh}	20.0 ^{abc}
		10 mg. ℓ^{-1}	65 ^{abcd}	2.5 ^{h}	5 ^{gh}	7.5 ^{gh}	20.0 ^{abc}
		30 mg. ℓ^{-1}	90 ^{a}	0 ^{h}	0 ^{h}	2.5 ^{h}	23.13 ^{ab}
Mean	21.41						
	Kinetin	0 mg. ℓ^{-1}	85 ^{ab}	5 ^{gh}	2.5 ^{h}	2.5 ^{h}	23.75 ^{a}
		0.2 mg. ℓ^{-1}	67.5 ^{abcd}	12.5 ^{gh}	7.5 ^{gh}	2.5 ^{h}	22.50 ^{ab}
		0.3 mg. ℓ^{-1}	67.5 ^{abcd}	12.5 ^{gh}	5 ^{gh}	0 ^{h}	21.3 ^{abc}
		0.5 mg. ℓ^{-1}	55 ^{cde}	12.5 ^{gh}	0 ^{h}	5 ^{gh}	18.13 ^{bc}
Mean	21.41						
Mean			62.29 ^{a}	8.96 ^{b}	6.04 ^{b}	5.83 ^{b}	

LSD 't' Main effect chemical (P<0.05) = 2.79 N.S

LSD 't' Main effect concentration (P<0.05) = 3.22 *

LSD 't' Main effect periods (P<0.05) = 7.97 *

LSD 't' chemical x concentration (P<0.05) =5.57 *

LSD 't' chemical x periods (P<0.05) = 13.80 *

LSD 't' concentration x periods (P<0.05) = 15.94 *

LSD 't' chemical x concentration x periods (P<0.05) = 27.61 *

* P < 0.05 = Significant, N.S. = Not Significant

The significant interaction between chemicals used, concentration and incubation period (Table 4.4), however, indicates that the response of *A. fatua* to increasing concentrations of different chemicals used, differed with time. Where gibberellic acid was applied, no significant differences were at any stage found between the control (0 mg. ℓ^{-1}), 1 and 10 mg. ℓ^{-1} concentrations. Application rates of 100 mg. ℓ^{-1} however reduced germination during the 0-3 day incubation period and stimulated germination during all other incubation periods. Although different concentrations of both hydroxylamine and kinetin showed a significant response during the 0-3 day incubation period, results were not

repeated during other periods of incubation and showed no clear trend (Figure 4.3). In the case of both these chemicals, results were dominated by the high germination values found for all concentrations (control included) during the 0-3 day period of incubation (Figure 4.3).

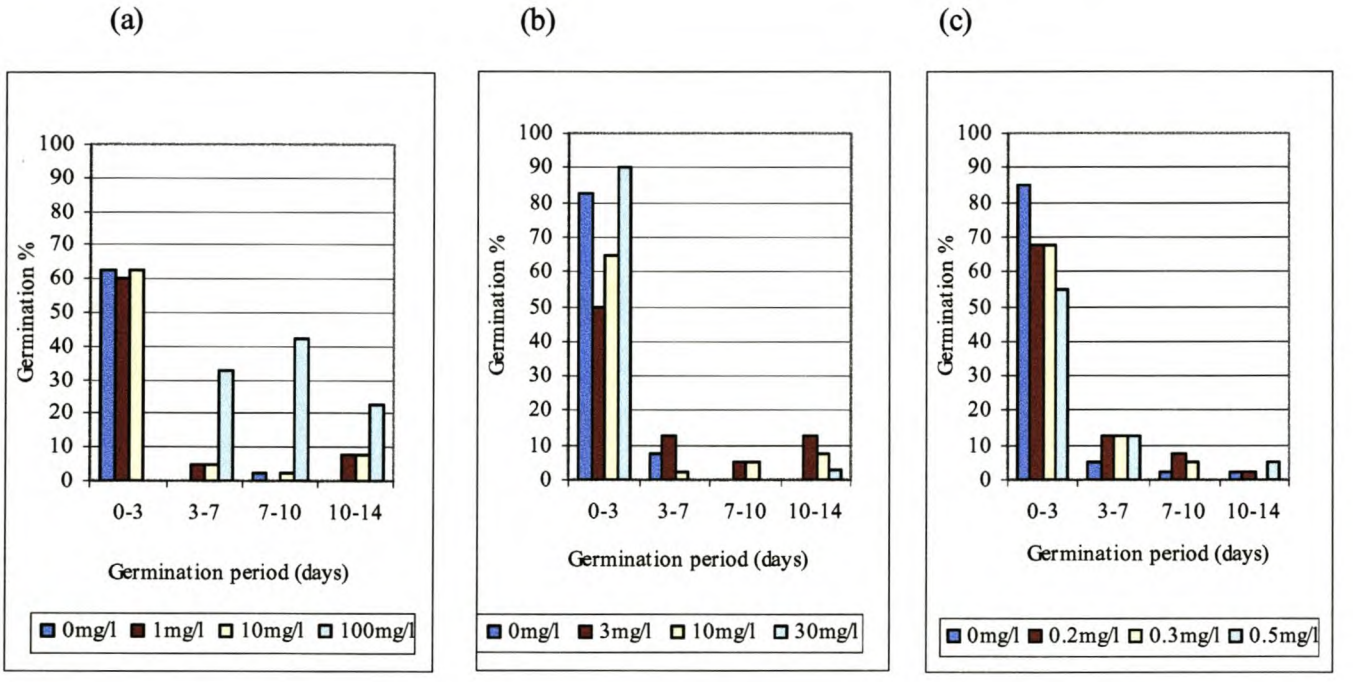

Figure 4.3 Germination of *A. fatua* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Cumulative germination values of *A. fatua* (Figure 4.4) confirms the initial inhibition followed by a pronounced stimulation in germination of non-dormant *A. fatua* seed due to application of high gibberellic acid concentrations. From Figure 4.4 it is also clear that although not significant for individual periods of incubation, cumulative values showed that high concentrations of kinetin inhibited the germination of *A. fatua*.

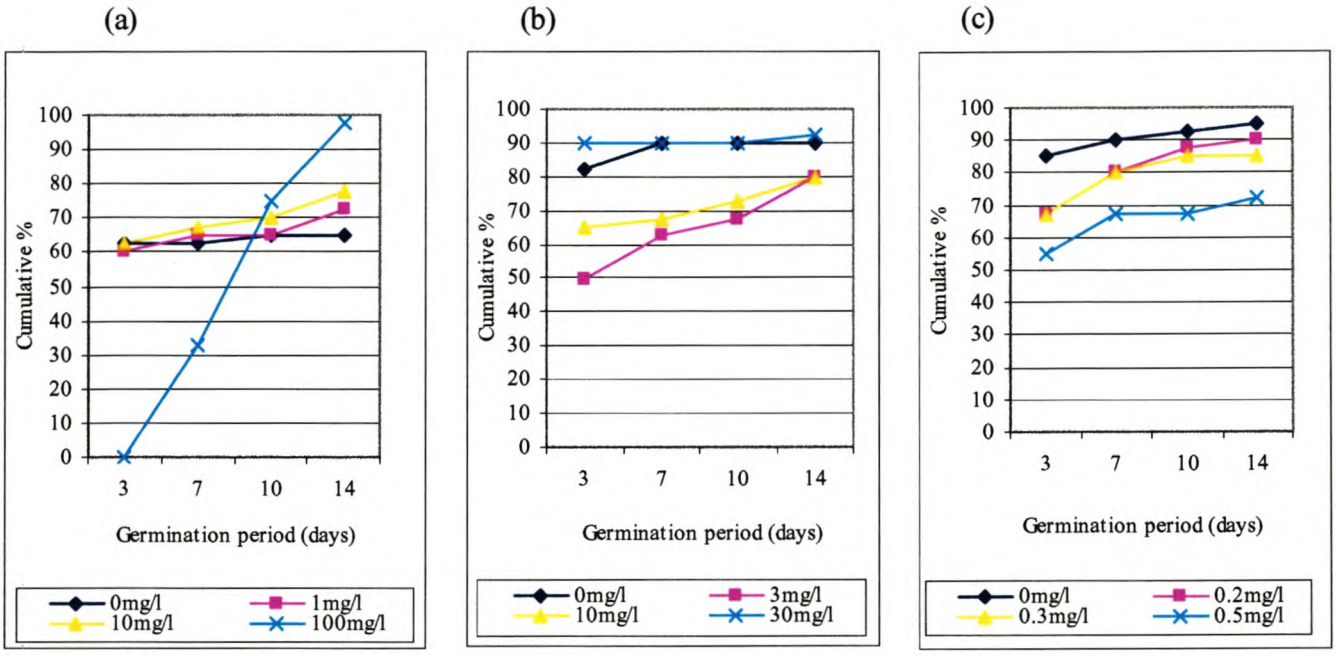

Figure 4.4 Cumulative germination of *A. fatua* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Bromus diandrus

Germination rates of *Bromus diandrus* (Table 4.5) showed a significant effect due to incubation period and chemical concentration as main factors, but were not affected by chemicals used. Only 1.5% of *B. diandrus* seeds germinated during the 0-3 day period of incubation followed by 5.2%, 6.3% and 7.9% during the 3-7, 7-10 and 10-14 day periods of incubation respectively. These low germination rates indicate that *B. diandrus* seeds were dormant during the germination period.

Table 4.5 Germination response (%) of *Bromus diandrus* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
Bromus diandrus	Gibberellic acid	0 mg. ℓ^{-1}	5 ^{cde}	5 ^{cde}	12.5 ^{abcd}	5 ^{cde}	6.88 ^{abc}
		1 mg. ℓ^{-1}	10 ^{abcde}	15 ^{abc}	0 ^{e}	2.5 ^{de}	6.88 ^{abc}
		10 mg. ℓ^{-1}	0 ^{e}	7.5 ^{bcde}	0 ^{e}	5 ^{cde}	3.13 ^{cd}
		100 mg. ℓ^{-1}	0 ^{e}	0 ^{e}	0 ^{e}	2.5 ^{de}	0.63 ^{d}
Mean	4.38						
	Hydroxylamine	0 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	5 ^{cde}	5 ^{cde}	3.13 ^{cd}
		3 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	10 ^{abcde}	7.5 ^{bcde}	5.00 ^{bc}
		10 mg. ℓ^{-1}	0 ^{e}	7.5 ^{bcde}	20 ^{a}	10 ^{abcde}	9.38 ^{a}
		30 mg. ℓ^{-1}	2.5 ^{de}	10 ^{abcde}	5 ^{cde}	5 ^{cde}	5.63 ^{ab}
Mean	5.78						
	Kinetin	0 mg. ℓ^{-1}	0 ^{e}	5 ^{cde}	2.5 ^{de}	17.5 ^{ab}	6.25 ^{abc}
		0.2 mg. ℓ^{-1}	0 ^{e}	0 ^{e}	2.5 ^{de}	10 ^{abcde}	3.13 ^{cd}
		0.3 mg. ℓ^{-1}	0 ^{e}	5 ^{cde}	0 ^{e}	12.5 ^{abcd}	4.38 ^{bcd}
		0.5 mg. ℓ^{-1}	0 ^{e}	2.5 ^{de}	17.5 ^{ab}	12.5 ^{abcd}	8.13 ^{ab}
Mean	5.47						
Mean			1.46 ^{d}	5.21 ^{abc}	6.25 ^{ab}	7.92 ^{a}	

LSD 't' Main effect chemical (P<0.05) = 1.98 N.S.
LSD 't' Main effect concentration (P<0.05) = 2.29 *
LSD 't' Main effect periods (P<0.05) = 2.98 *
LSD 't' chemical x concentration (P<0.05) = 3.96 *
LSD 't' chemical x periods (P<0.05) = 5.16 *
LSD 't' concentration x periods (P<0.05) = 5.96 N.S.
LSD 't' chemical x concentration x periods (P<0.05) = 10.32 *
* P < 0.05 = Significant, N.S. = Not Significant

Table 4.5 showed a significant ($p < 0.05$) chemical x concentration x period interaction. This was due to significant differences shown with increasing concentrations of gibberellic acid at the 3-7 and 7-10 day incubation periods, while different concentrations of hydroxylamine and kinetin resulted in significant differences at the 7-10 day incubation period only. Although the application of 1 mg.ℓ^{-1} of gibberellic acid initially stimulated germination, mean values did not differ significantly ($p < 0.05$) from that of the control where no gibberellic acid was applied. High values of gibberellic acid (10 and 100 mg.ℓ^{-1}) on the other hand, clearly suppressed the germination of *B. diandrus* (Figure 4.5).

Although only significant at the 7-10 day incubation period, Figure 4.3 showed that an application of 10 mg.ℓ^{-1} hydroxylamine also stimulated the germination of *B. diandrus* during the 3-7 and 10-14 day incubation period. Kinetin on the other hand had no clear effect.

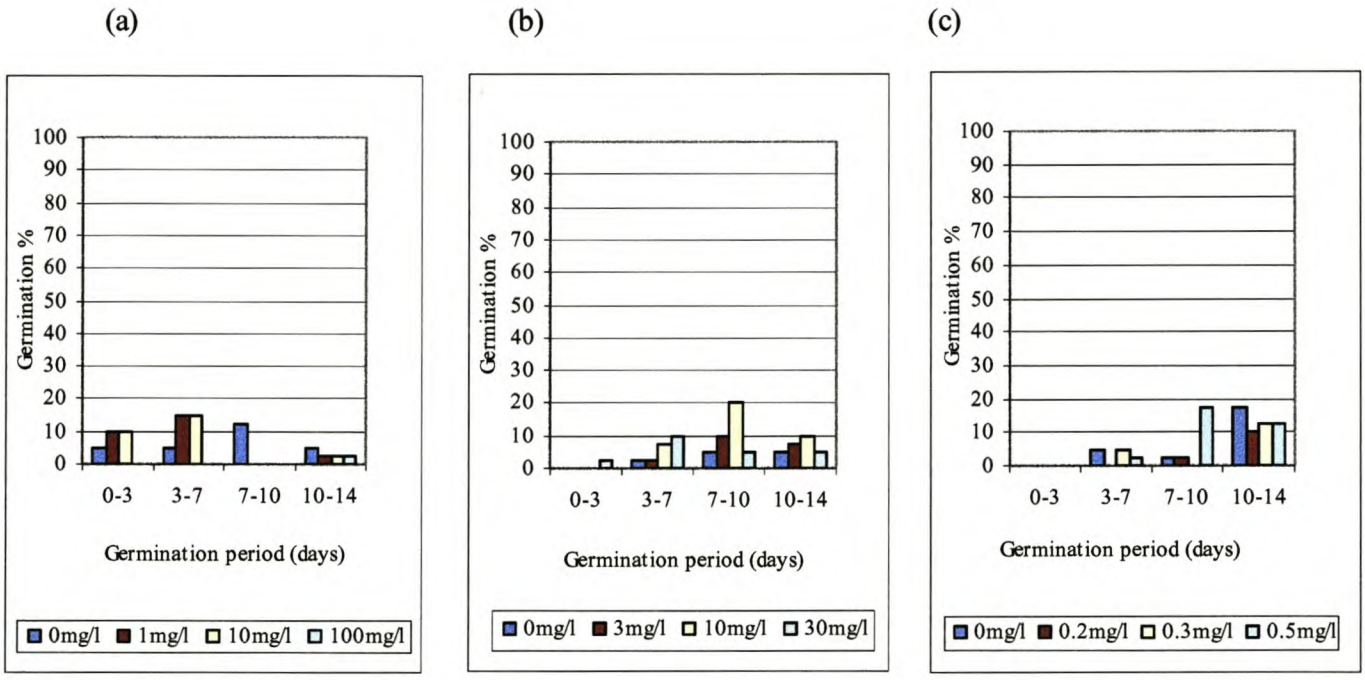

Figure 4.5 Germination of *B. diandrus* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Cumulative values for the germination of *B. diandrus* (Figure 4.6) confirm the above-mentioned trends, namely a suppression of germination by high concentrations of gibberellic acid and a stimulation of germination by hydroxylamine. Cumulative germination values of below 40% for all treatments tested however, indicated that these treatments were not very effective and can therefore not be considered as possible methods to break the dormancy and increase the germination of *B. diandrus* in wheat fields.

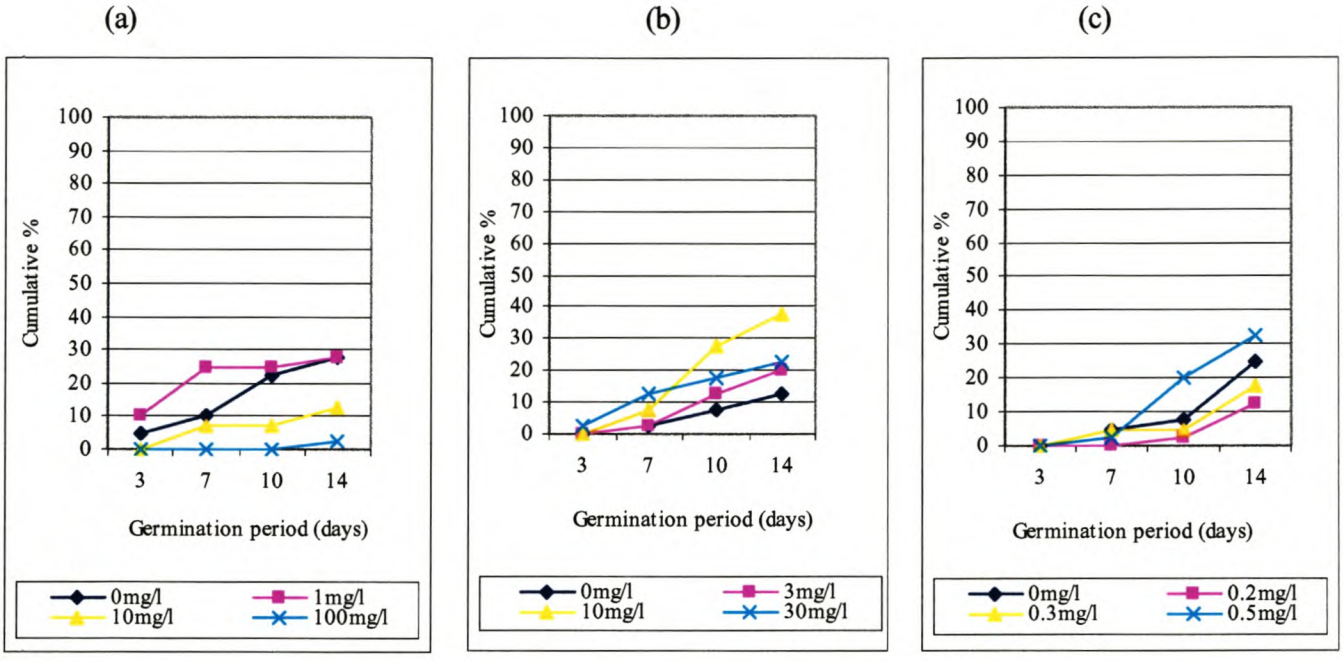

Figure 4.6 Cumulative germination of *B. diandrus* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Emex australis

Germination rates of *E. australis* were significantly ($p < 0.05$) affected by period of incubation, chemicals used and chemical concentrations used as main factors, as well as chemical x concentration and chemical x concentration x period interactions (Table 4.6). Mean values of 23.5% and 43.1% germination during the 0-3 and 3-7 day incubation periods, clearly indicated that seeds of *E. australis* used in this experiment were not dormant.

Table 4.6 Germination response (%) of *Emex australis* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
Emex australis	Gibberellic acid	0 mg. ℓ^{-1}	22.5 ^{defgh}	37.5 ^{bcde}	5 ^{gh}	2.5 ^{h}	16.8 ^{abc}
		1 mg. ℓ^{-1}	12.5 ^{fgh}	60 ^{ab}	5 ^{gh}	0 ^{h}	19.38 ^{a}
		10 mg. ℓ^{-1}	12.5 ^{fgh}	37.5 ^{bcde}	10 ^{fgh}	15 ^{efgh}	18.7 ^{abc}
		100 mg. ℓ^{-1}	2.5 ^{h}	22.5 ^{defgh}	10 ^{fgh}	15 ^{efgh}	12.50 ^{bc}
Mean	16.88 ^{b}						
	Hydroxylamine	0 mg. ℓ^{-1}	15 ^{efgh}	57.5 ^{ab}	2.5 ^{h}	2.5 ^{h}	19.4 ^{abc}
		3 mg. ℓ^{-1}	7.5 ^{gh}	12.5 ^{fgh}	17.5 ^{efgh}	10 ^{fgh}	11.88 ^{c}
		10 mg. ℓ^{-1}	17.5 ^{efgh}	67.5 ^{a}	2.5 ^{h}	5 ^{gh}	23.13 ^{a}
		30 mg. ℓ^{-1}	50 ^{abc}	45 ^{abcd}	0 ^{h}	2.5 ^{h}	24.38 ^{a}
Mean	19.69 ^{a}						
	Kinetin	0 mg. ℓ^{-1}	17.5 ^{efgh}	50 ^{abc}	5 ^{gh}	0 ^{h}	18.1 ^{abc}
		0.2 mg. ℓ^{-1}	27.5 ^{cdefg}	62.5 ^{a}	7.5 ^{gh}	0 ^{h}	24.3 ^{ab}
		0.3 mg. ℓ^{-1}	60 ^{ab}	32.5 ^{cdef}	7.5 ^{gh}	0 ^{h}	25.0 ^{a}
		0.5 mg. ℓ^{-1}	37.5 ^{bcde}	32.5 ^{cdef}	0 ^{h}	10 ^{fgh}	20.0 ^{abc}
Mean	21.88 ^{a}						
Mean			23.54 ^{b}	43.12 ^{a}	6.04 ^{c}	5.83 ^{c}	

LSD 't' Main effect chemical ($P<0.05$) = 4.65 *

LSD 't' Main effect concentration ($P<0.05$) = 5.37 *

LSD 't' Main effect periods ($P<0.05$) = 7.11 *

LSD 't' chemical x concentration ($P<0.05$) = 9.31 *.

LSD 't' chemical x periods ($P<0.05$) = 12.32 *

LSD 't' concentration x periods ($P<0.05$) = 14.22 N.S.

LSD 't' chemical x concentration x periods ($P<0.05$) = 24.64 *

* $P < 0.05$ = Significant, N.S. = Not Significant

Although mean chemical x concentration values showed significant differences ($p < 0.05$) between concentrations for all chemicals tested, mean germination was not significantly increased by any of the chemicals used. During individual periods of incubation, germination of *E. australis* was significantly increased due to the application of 1 mg. ℓ^{-1} of gibberellic acid at 3-7 days, 30 mg. ℓ^{-1} hydroxylamine at 0-3 days and 0.3 mg. ℓ^{-1} kinetin at 0-3 days (Figure 4.7).

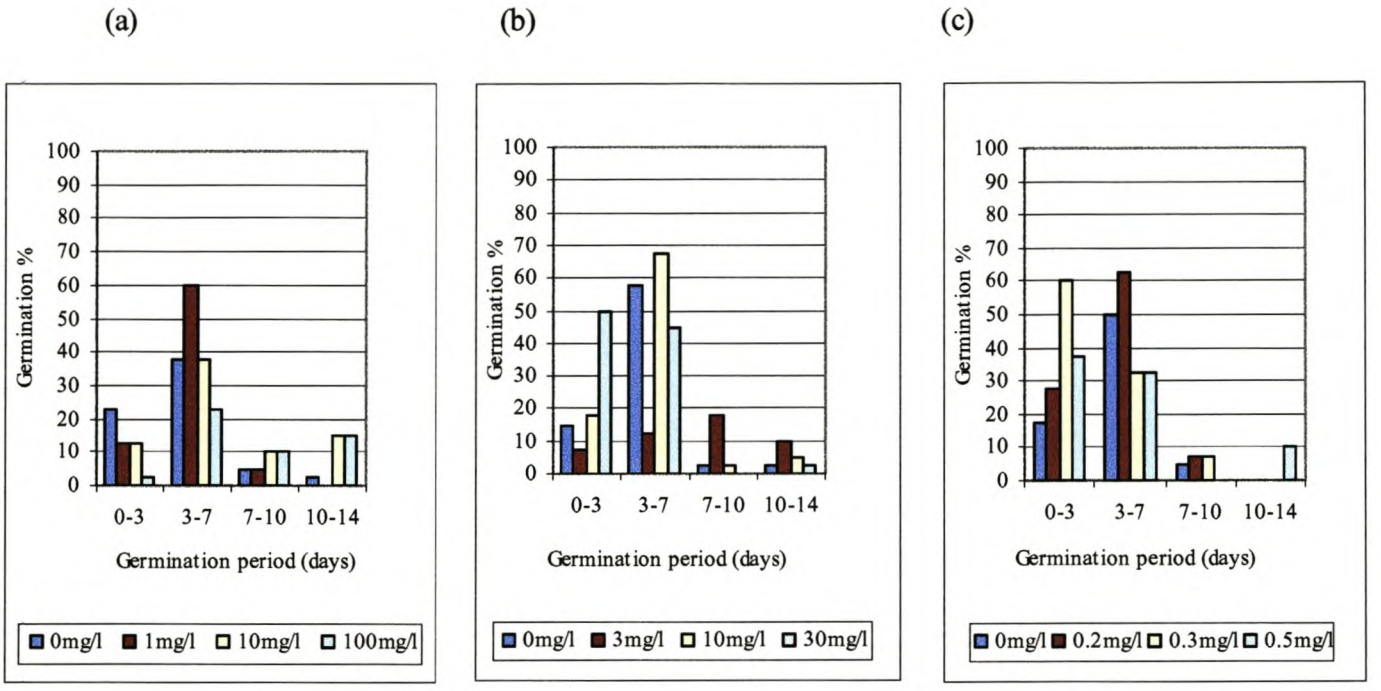

Figure 4.7 Germination of *E. australis* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

This resulted in slightly higher cumulative germination values for *E. australis* if treated with low concentrations (1 and 10 mg. ℓ^{-1}) gibberellic acid or medium concentrations of hydroxylamine (3 and 10 mg. ℓ^{-1}) and kinetin (0.2 and 0.3 mg. ℓ^{-1}) (Figure 4.8). These treatments with hydroxylamine and kinetin resulted in cumulative values of more than 90% germination of *E. australis* after 14 days of incubation.

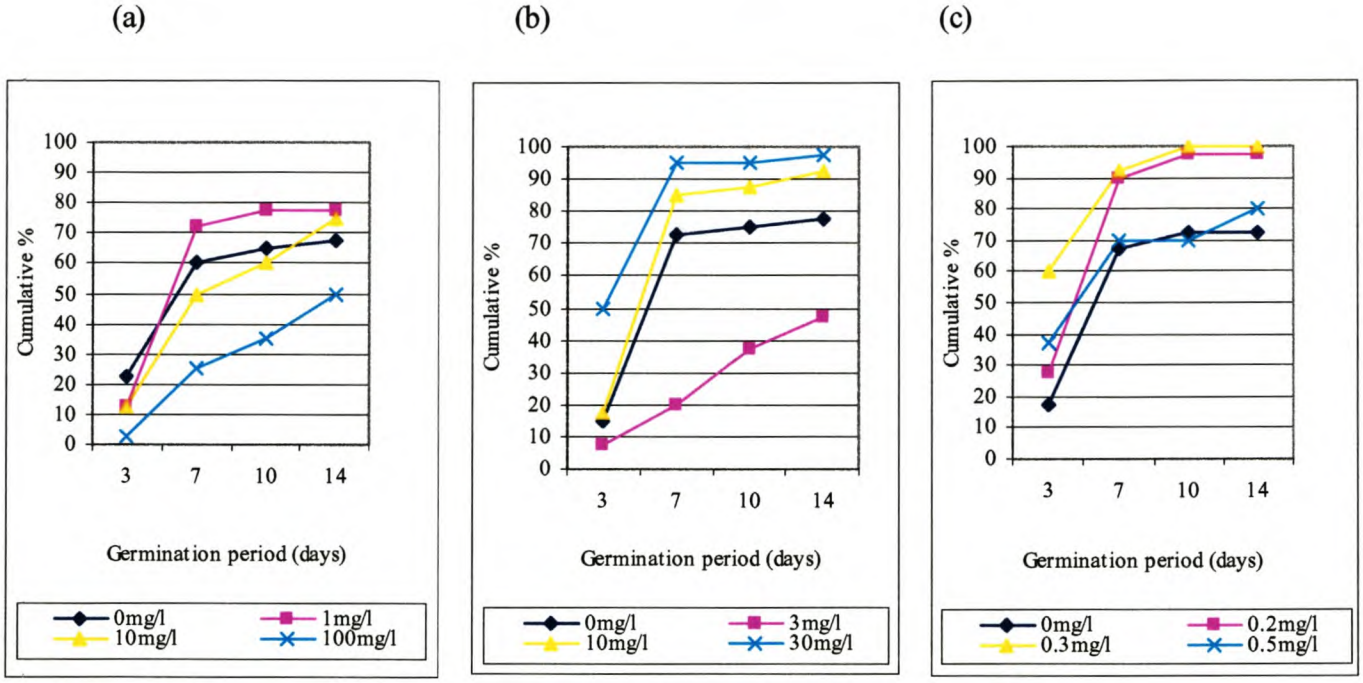

Figure 4.8 Cumulative germination of *E. australis* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Lolium temulentum

Germination rate of *L. temulentum* seeds was significantly (Table 4.7) ($p < 0.05$) affected by all three main factors (chemicals, concentration and period of incubation). Significant interactions were also found between these factors. High germination rates were found for the control treatments (no chemicals) during the 0-3 of gibberellic acid and hydroxylamine and 3-7 day incubation periods of all treatments, clearly showing that most of the *L. temulentum* seeds used in this study were not dormant and germinated very rapidly. In spite of this, all chemicals used still had a significant effect on the germination of *L. temulentum* during this incubation period.

Table 4.7 Germination response (%) of *Lolium temulentum* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
Lolium temulentum	Gibberellic acid	0 mg. ℓ^{-1}	27.5 ^{defg}	27.5 ^{defg}	0 ^{k}	0 ^{k}	13.75 ^{d}
		1 mg. ℓ^{-1}	22.5 ^{efgh}	20 ^{fghi}	7.5 ^{hijk}	0 ^{k}	12.50 ^{de}
		10 mg. ℓ^{-1}	12.5 ^{ghijk}	22.5 ^{efgh}	2.5 ^{jk}	0 ^{k}	9.38 ^{e}
		100 mg. ℓ^{-1}	0 ^{k}	0 ^{k}	0 ^{k}	0 ^{k}	0 ^{f}
Mean	8.91 ^{b}						
	Hydroxylamine	0 mg. ℓ^{-1}	37.5 ^{cde}	22.5 ^{efgh}	7.5 ^{hijk}	2.5 ^{jk}	17.5 ^{bc}
		3 mg. ℓ^{-1}	20 ^{fghi}	37.5 ^{cde}	2.5 ^{jk}	2.5 ^{jk}	15.63 ^{cd}
		10 mg. ℓ^{-1}	17.5 ^{fghij}	42.5 ^{bcd}	0 ^{k}	0 ^{k}	15.0 ^{cd}
		30 mg. ℓ^{-1}	22.5 ^{efgh}	57.5 ^{ab}	2.5 ^{jk}	0 ^{k}	20.63 ^{b}
Mean	17.19 ^{a}						
	Kinetin	0 mg. ℓ^{-1}	0 ^{k}	63.16 ^{a}	2.63 ^{jk}	5.26 ^{hijk}	17.76 ^{bc}
		0.2 mg. ℓ^{-1}	0 ^{k}	41.67 ^{bcd}	0 ^{k}	8.33 ^{hijk}	12.50 ^{de}
		0.3 mg. ℓ^{-1}	0 ^{k}	27.78 ^{defg}	0 ^{k}	11.11 ^{ghijk}	9.72 ^{e}
		0.5 mg. ℓ^{-1}	0 ^{k}	31.58 ^{defg}	0 ^{k}	2.63 ^{jk}	8.55 ^{e}
Mean	12.13 ^{c}						
Mean			13.33 ^{b}	32.85 ^{a}	2.09 ^{c}	2.69 ^{c}	

LSD 't' Main effect chemical ($P<0.05$) = 2.65 *

LSD 't' Main effect concentration ($P<0.05$) = 3.06 *

LSD 't' Main effect periods ($P<0.05$) = 4.15 *

LSD 't' chemical x concentration ($P<0.05$) = 5.31 *

LSD 't' chemical x periods ($P<0.05$) = 7.19 *

LSD 't' concentration x periods ($P<0.05$) = 8.30 N.S.

LSD 't' chemical x concentration x periods ($P<0.05$) = 14.37 *

* $P < 0.05$ = Significant, N.S. = Not Significant

From Table 4.7 and Figure 4.9 it is clear that the germination of *L. temulentum* seeds were significantly ($p < 0.05$) suppressed by high (100 mg. ℓ^{-1}) concentrations of gibberellic acid during these periods. Hydroxylamine also suppressed germination during the 0-3 day incubation period, but stimulated germination during the 3-7 day incubation period. In contrast to this, kinetin had no effect during the 0-3 day period, but caused suppression of germination during the 3-7 day incubation period at all chemical concentrations applied.

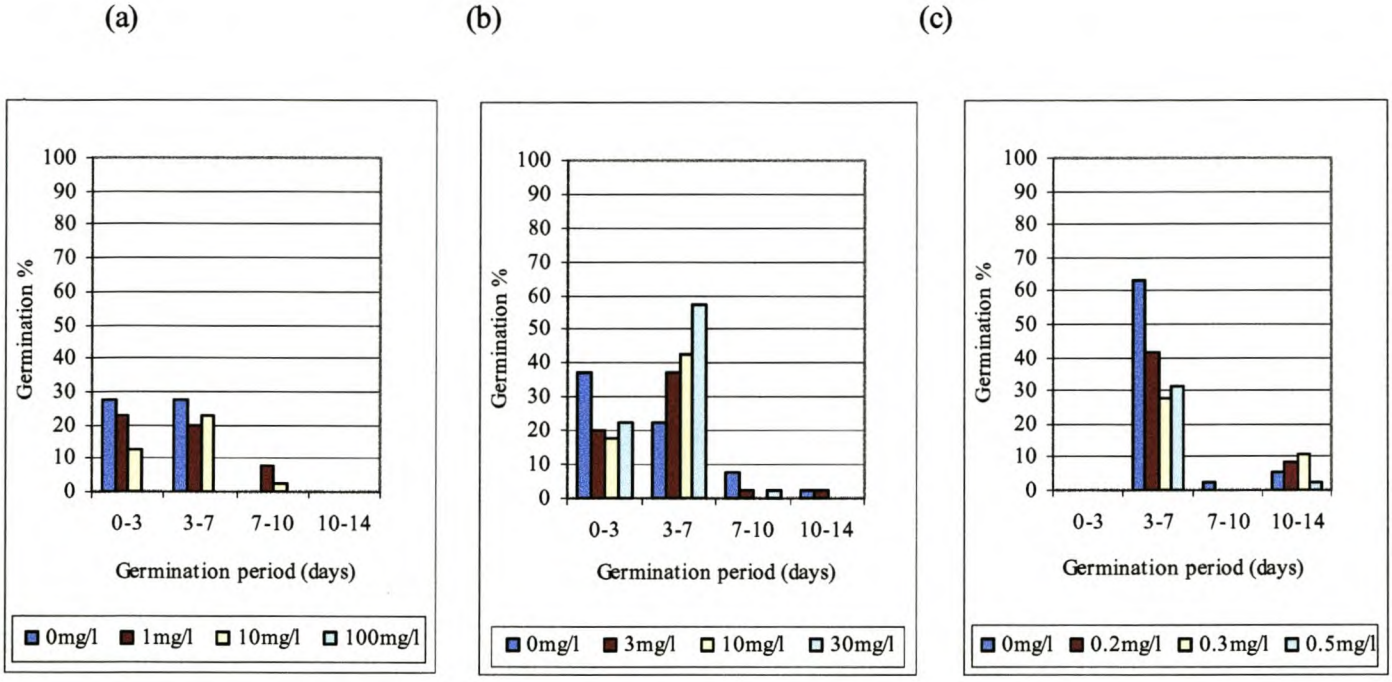

Figure 4.9 Germination of *L. temulentum* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

These somewhat confusing results were clarified by Figure 4.10, which showed the cumulative effects of the different chemicals, namely a dramatic suppression of germination by gibberellic acid and a stimulation of germination due to the application of high (30 mg. ℓ^{-1}) concentrations of hydroxylamine. Both low and high concentrations of kinetin however, caused a suppression of germination. In the case of gibberellic acid, no seed germinated when treated with 100 mg. ℓ^{-1}, while more than 70% of the *L. temulentum* seeds germinated within 14 days when the above mentioned concentration of hydroxylamine was applied.

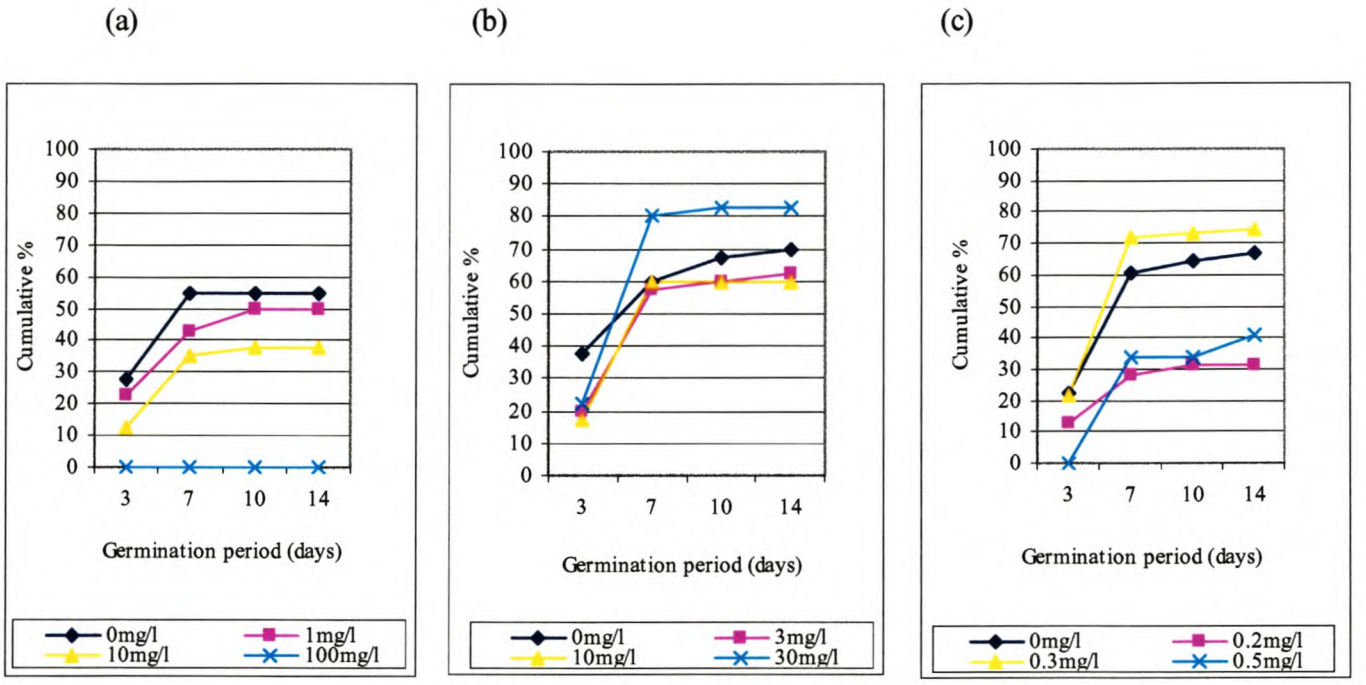

Figure 4.10 Cumulative germination of *L. temulentum* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Raphanus raphanistrrum

Germination of *R. raphanistrum* seeds was also significantly affected by chemicals used, concentration rates and period of incubation as main factors (Table 4.8). Although mean germination rates for different incubation periods were generally low (less than 20%), significant interactions between concentration rates and chemicals used, resulted in high germination rates during specific incubation periods.

Table 4.8 Germination response (%) of *Raphanus raphanistrum* to three chemicals at four concentrations, over a period of 14 days at 20 °C.

			Periods				
Weed species	Chemical	Concentration	0-3 days	3-7days	7-10 days	10-14 days	Mean
Raphanus raphanistrum	Gibberellic acid	0 mg. ℓ^{-1}	7.5 ^{fgh}	0 ^{h}	0 ^{h}	0 ^{h}	1.88 ^{e}
		1 mg. ℓ^{-1}	2.5 ^{h}	0 ^{h}	0 ^{h}	0 ^{h}	0.63 ^{e}
		10 mg. ℓ^{-1}	12.5 ^{efgh}	7.5 ^{fgh}	5 ^{gh}	10 ^{efgh}	8.75 ^{d}
		100 mg. ℓ^{-1}	2.5 ^{h}	22.5 ^{cdefg}	40 ^{bc}	25 ^{cdef}	22.5 ^{ab}
Mean	8.44 ^{a}						
	Hydroxylamine	0 mg. ℓ^{-1}	7.5 ^{fgh}	0 ^{h}	0 ^{h}	0 ^{h}	1.88 ^{e}
		3 mg. ℓ^{-1}	2.5 ^{h}	0 ^{h}	0 ^{h}	0 ^{h}	0.63 ^{e}
		10 mg. ℓ^{-1}	0 ^{h}	5 ^{gh}	2.5 ^{h}	2.5 ^{h}	2.5 ^{e}
		30 mg. ℓ^{-1}	5 ^{gh}	7.5 ^{fgh}	0 ^{h}	0 ^{h}	3.13 ^{e}
Mean	2.03 ^{b}						
	Kinetin	0 mg. ℓ^{-1}	2.6 ^{h}	2.6 ^{h}	10.5 ^{efgh}	13.2 ^{efgh}	7.23 ^{d}
		0.2 mg. ℓ^{-1}	2.6 ^{h}	5.3 ^{gh}	15.8 ^{efgh}	13.2 ^{efgh}	9.23 ^{d}
		0.3 mg. ℓ^{-1}	0 ^{h}	0 ^{h}	16.7 ^{efgh}	19.4 ^{cdefg}	9.03 ^{d}
		0.5 mg. ℓ^{-1}	0 ^{h}	0 ^{h}	25 ^{cdef}	16.7 ^{efgh}	10.43 ^{d}
Mean	8.98 ^{a}						
Mean			3.77 ^{b}	4.2 ^{b}	10.04 ^{a}	8.33 ^{a}	

LSD 't' Main effect chemical (P<0.05) = 2.43 *

LSD 't' Main effect concentration (P<0.05) = 2.81 *

LSD 't' Main effect periods (P<0.05) = 3.08 *

LSD 't' chemical x concentration (P<0.05) = 4.86 N.S.

LSD 't' chemical x periods (P<0.05) = 5.34 *

LSD 't' concentration x periods (P<0.05) = 6.17 N.S

LSD 't' chemical x concentration x periods (P<0.05) = 10.69 *

* P < 0.05 = Significant, N.S. = Not Significant

The application of gibberellic acid did not affect the germination of *R. raphanistrum* during the 0-3 day incubation period (Table 4.8 and Figure 4.11). At all other incubation periods, germination rates were significantly improved if 100 mg. ℓ^{-1} gibberellic acid was applied. Hydroxylamine and kinetin did not have any effect. The germination of *R. raphanistrum* at all kinetin treatments increased with an increase in incubation period.

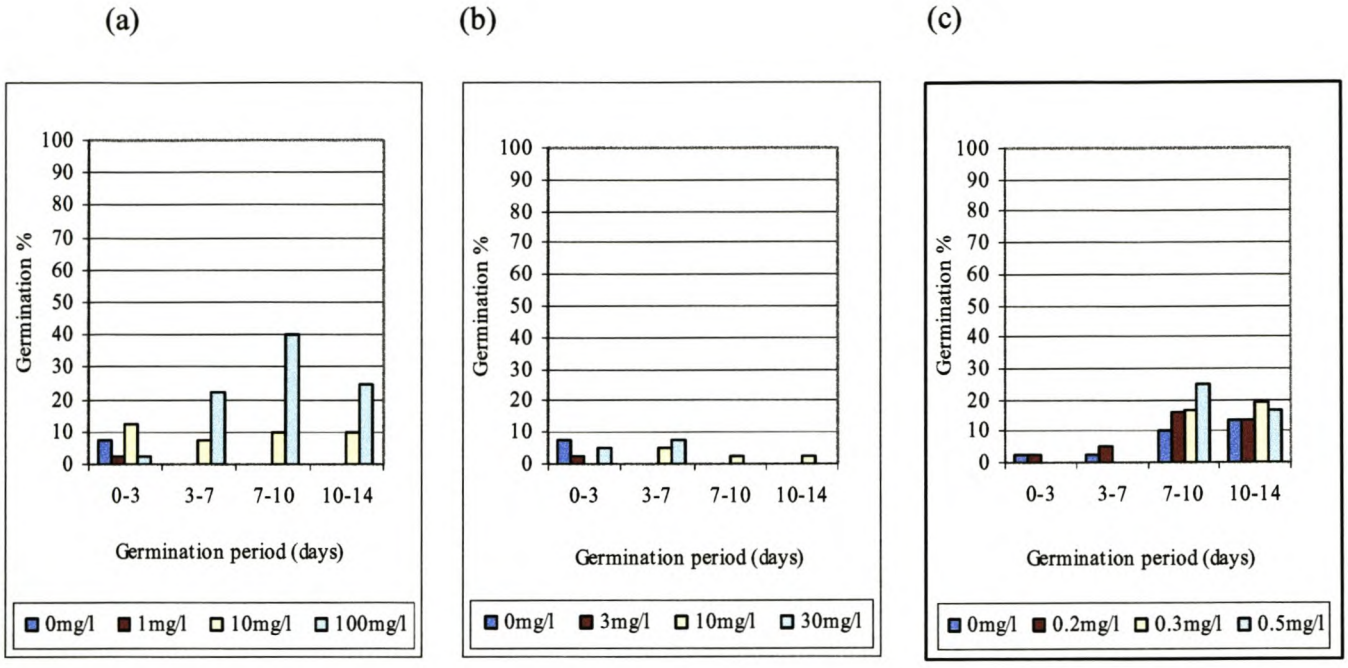

Figure 4.11 Germination of *R. raphanistrum* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Cumulative values (Figure 4.12) confirmed the stimulating effects of gibberellic acid on the germination of *R. raphanistrum* seeds since the application of 100 mg. ℓ^{-1} gibberellic acid caused more than 90% of the seed to germinate within 14 days of incubation, while kinetin also showed a stimulating effect at the highest concentration.

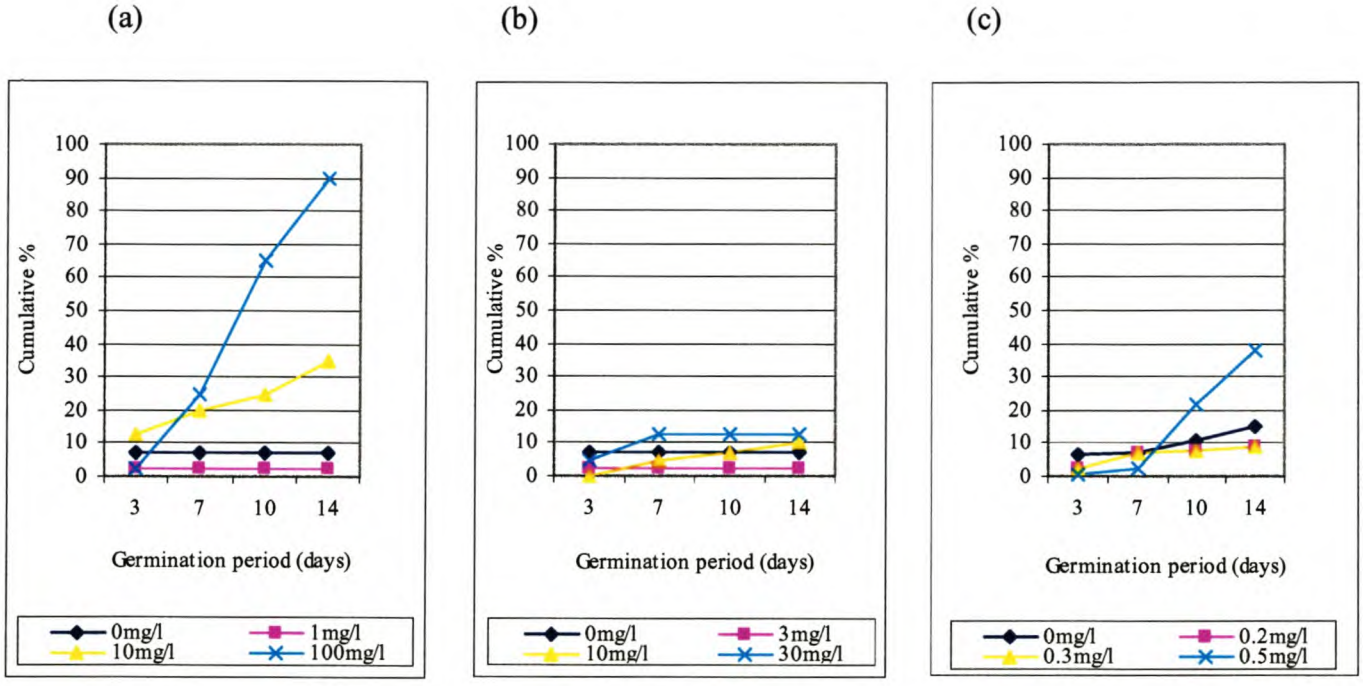

Figure 4.12 Cumulative germination of *R. raphanistrum* due to (a) gibberellic acid, (b) hydroxylamine and (c) kinetin treatments.

Discussion

In general it can be said that results of this study supported earlier findings by Murdoch & Carmona (1993). They investigated ways to deplete seed banks by stimulating seeds to germinate that resulted in insufficient reproducible results for commercial application. Although individual weed species did respond to specific concentrations of the chemicals tested, no chemical/concentration proved to be successful in stimulating the germination of all species tested.

Percentage germination values of below 40% for *A. calendula* for all treatments tested after the 14 day incubation period, indicated that seeds of this species were in a dormant state and that this dormancy was most probably not due to the shortage of growth stimulators such as gibberellic acid, kinetin or hydroxylamine. These results supported earlier findings by Mayer & Poljakoff (1982). Ellery & Chapman (2000) showed that light may reduce dormancy in *A. calendula* seeds, while Chaharsoghi & Jacobs (1998) found that germination of this species can be enhanced by scarification.

Although low germination percentages for the control treatments of *B. diandrus* and *R. raphanistrum* indicated that seeds of these species were also dormant, germination of both species were significantly improved (or inhibited) by specific concentrations of one or more of the chemicals tested. Dormancy in these species, as also found by Harradine (1986), were therefore most probably the result of some chemical obstruction.

In contrast to this, high cumulative germination values of the control treatments of *A. fatua, E. australis* and *L. temulentum* clearly indicated that seeds of these species used in the experiment were not dormant. Germination of *A. fatua* seeds, as also found by Andersen (1968) and Metzger (1983), were stimulated by high concentrations of gibberellic acid, but inhibited by low and medium concentrations of kinetin and high concentrations of hydroxylamine. Germination of *E. australis* seed were increased to nearly 100% after 14 days of incubation by high concentrations of hydroxylamine as well as low and medium concentrations of kinetin. Similar responses with regard to hydroxylamine were obtained with non-dormant seed of *L. temulentum,* which supported the results of earlier studies done on non-dormant seed of maize (*Zea mays*) (Wang *et al.,* 1996). Germination of all three species therefore responded to the chemical treatments, but not to the same chemical / concentration.

In conclusion it can be said that although this study did provide some useful information regarding the germination requirements of the weed species tested, it did not provide us with a practical method to improve weed control in wheat fields infested by several weed species.

Conclusions

Although this study did provide some useful information regarding the germination requirements of weed species tested, it did not produce a practical method to improve weed control in wheat field infested by weed species. But it showed that different chemical concentrations are needed to break dormancy of different weed seeds. This is because different weed seeds differ according to the state and longevity of dormancy as well as the physiological basis of dormancy.

Povilaitis (1956) also supported the concept of stimulating dormant weed seed to germinate with a purpose of controlling weeds. Povilaitis (1956), stated that the application of chemicals to the soil to stimulate weed seeds germination might be an alternative method of weed control and could result in the weed population being destroyed in one season rather than by repeated annual applications of herbicides as the case now. The conclusion cannot be based on whether a certain chemical stimulated germination of either monocotyledonous or dicotyledonous seeds because no specific chemical resulted in a simultaneous stimulation of germination of either monocotyledonous or dicotyledonous seeds.

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Chapter 5

The competitive effect of six weed species on growth and production of wheat

Abstract

An additive series experiment consisting of four replications was conducted in plastic pots in a glasshouse. The study was undertaken with the aim of determining the competitiveness of *A. calendula*, *A. fatua*, *B. diandrus*, *E. australis*, *L. temulentum* and *R. raphanistrum* when grown together with wheat, and to decide when weed control will be cost-effective. The influence of the above-mentioned weed species on wheat plant height, tiller number at different growth stages, dry mass (mass of dry material) and grain mass was determined. The results showed that all six weed species caused a significant effect ($p < 0.05$) on wheat plant height during tillering, stem elongation and heading growth stages, whereas weed densities caused a significant ($p < 0.05$) reduction during the ripening growth stage. The total wheat plant above-ground dry mass was significantly ($p < 0.05$) reduced by an increase in weed density.

Keywords: competitiveness, dry mass, grain mass, tiller number, weed densities, wheat plant height.

Uittreksel

'n Additiewe reeks eksperiment wat uit vier herhalings bestaan het, is in plastiekpotte in 'n glashuis uitgevoer. Die doel daarvan was om die kompetisievermoë van *A. calendula*, *A. fatua*, *B. diandrus*, *E. australis*, *L. temulentum* en *R. raphanistrum* te bepaal as dit saam met koring groei en om te besluit wanneer onkruidbeheer koste effektief sal wees. Die invloed van voorgenoemde ses onkruidspesies op koring planthoogte, halmgetal by verskillende groeistadiums, droë massa (massa van droë materiaal) en graanmassa (opbrengs), is bepaal. Die resultate het aangetoon dat al ses onkruidspesies 'n betekenisvolle effek ($p < 0.05$) het op koring planthoogte tydens stoelvorming, stingelverlenging en aarvorming, terwyl onkruiddigthede 'n betekenisvolle verlaging ($p < 0.05$) tydens rypwording veroorsaak het. Die totale bogrondse massa van koringplante is betekenisvol verlaag ($p < 0.05$) deur 'n verhoging van onkruiddigtheid.

Introduction

Competition can be defined as the struggle between individuals within a population for available resources, when the level of resources is below the combined needs of the members of the population. The resources involved in crop growth are primarily light, water and nutrients (Anonymous, 1991). Weed-crop competition is one of the causes of yield reduction in cereal crop producing areas of the Western Cape.

Cereals are most sensitive to competition from weeds in their early stages of growth. The most critical time is generally when the crop is between about the 3- and 6- leaf stages. The competition between cereal crops and weeds was principally for nitrogen in years of normal rainfall, with the most intense competition in the early stages of crop growth (Blackman & Templeman, 1938). The removal of weeds before this period may lead to greatly improved yields and, within this period, the earlier the weeds are removed the better the yield responses are likely to be (Fryer & Makepeace, 1977). Earlier growth, height and density play a major role in the success of crops in competition (Holzner & Numata, 1982). Weeds that emerge at or near the time of crop emergence tend to have greater yield reduction due to weed competition (Cousens *et al.* 1987). The similar growth period of weeds to that of wheat, the earlier shedding of seeds, and the ability to remain dormant for several years in the soil contributed to the success of wild oats to compete with wheat and other cereals (Martin & Field, 1985).

Wild oats (*Avena fatua*) was found to be the most prevalent and troublesome weed of wheat in the northwest of New South Wales. This was because of the prevalence of continuous winter cereal growing coupled with the low seeding rates of 20 – 35 kg. ha^{-1}. The control practices such as cultivation herbicides and crop rotation was the only options available for control (Martin *et al*, 1987). The results obtained by Bowden & Friesen (1967) suggested that wild oat competition starts at a very early stage, possibly with some competition having already taken place prior to emergence. Wild oats was found to be a strong competitor with wheat, by reducing crop yields when present in large numbers (Bell & Nalewaja, 1968; Chancellor & Peters, 1974). Holzner & Numata (1982) stated that most aggressive weeds show faster and more extensive root systems than most crops, for example, *A. fatua* as compared to cereal crops.

Burghardt & Froud-Williams (1995) found that *Bromus* spp. is one of weeds in cereal crops that usually leads to reduction in crop grain yield and increased crop lodging. *Brome* (*B. diandrus* Roth.) was considered one of the serious grass weeds in field crops (Supasilapa *et al.* 1992), as well as Italian ryegrass (Hashem *et al.*, 1998). Supasilapa *et al.* (1992), also stated that *B. diandrus* is extremely competitive with wheat, as compared to ryegrass at equivalent densities, and that can cause significant grain loss at densities of >50 plants/m^2. Hashem *et al.* (1998), found ryegrass to be highly competitive with winter wheat, with as much as 60% loss in grain yield. In the U.S.A. downy brome was the most prevalent winter annual grass weed in winter wheat fields, and this was due to its ability to germinate successfully over a wide range of moisture and climatic conditions (Challaiah *et al.* 1986). *Bromus diandrus* Roth. was found to be a serious competitive weed of wheat in South African winter rainfall areas (Ferreira & Agenbag, 1993).

Medd *et al.* (1985) stated that grain yield in Australia declined with an increase of rigid ryegrass density (up to 300 plants m^{-2}) when wheat was sown at 58 plants m^{-2}. The effects of ryegrass on the crop can be reduced by high seed rates of wheat (Barrett & Campbell, 1973). An increase in the density of a crop species beyond its optimum planting density resulted in reducing the competitive effect of weeds on the crop and *vice versa* (Radosevich, 1987). Increasing crop density reduced the effects of wild oats (*Avena* spp.) in winter cereals and broadleaf weeds on grain yields (Medd *et al.*, 1985). Barrett & Campbell (1973) obtained evidence from a glasshouse study of early crop development that increasing densities of wheat caused reduction in the effects of ryegrass when the mixtures competed.

The objective of this study is to assess the competitive effects of *A. calendula*, *E. australis*, *R. raphanistrum, A. fatua, B. diandrus*, and *L. temulentum* in wheat in order to assist with decisions on when weed control will be cost-effective.

Materials and Methods

An additive series experiment (Cousens, 1991) with four replications were conducted in plastic pots filled with 5 kg of sandy soil in a glasshouse at Elsenburg. The experiment was conducted at a constant temperature of 15 °C for both night and day temperatures. Each pot was moistened with 150 mλ of water per week.

Treatments consisted of three weed densities (0, 2 and 4 weed plants / pot) of each of the following weed species: *A. calendula, E. australis, R. raphanistrum, A. fatua, B. diandrus, and L. temulentum*, which were grown in combination with wheat (SST 75 cultivar). Five wheat plants were planted with weeds to give a total plant population of 200 (5 wheat), 280 (5 wheat + 2 weeds) and 360 (5 wheat + 4 weeds) plants. m^{-2}. Grids were used to plant the seeds to ensure a consistent spatial arrangement within pots.

Germinated seeds were planted 1 to 2 cm deep. To ensure that all weeds were at the same growth stage, more than the required number of weeds were planted and thinned a week after emergence. To ensure the competitiveness had among crops, fertilizer was applied at seeding as well as growth stages 5 and 15, while pots were subjected to definite wet and dry cycles. Each pot was top-dressed with 0.36 g/pot (140 kg. ha^{-1} LAN) of Limestone Ammonium Nitrate (LAN) which is equivalent to 39.2 kg. ha^{-1} N (28% N) during seeding, while during growth stages 5 and 15 each pot was fertilized with 0.4 g/pot of LAN (156 kg. ha^{-1} LAN) which is equivalent to 43.7 kg. ha^{-1} N (28% N)).

Plant height (height of plant from soil surface to leaf-end) of the wheat plants were measured at different stages of growth and tillering (main-stem excluded), while the dry mass production (plant material) and yield (grain mass) were determined during the final harvest. Dry mass production was measured by drying plant material in an oven at 60 °C for three days. Mass of dry material and grain as well as plant height were expressed as the mean of plants per pot.

Statistical analysis

Data from the glasshouse experiment were subjected to analysis of variance to assess the effect of six weed species and density on plant height, dry material and grain mass of wheat. The data were analysed using SAS (Statistical Analysis Systems). A general linear model (GLM) was used for data with missing values. SAS (1987) was used for regression and GLM procedure.

Results

Summary of Analysis of variance

Species as main effect significantly influenced wheat plant height during tillering, stem elongation and heading growth stages, while densities caused significant ($p < 0.05$) reduction during the ripening growth stage (Table 5.1). Densities also had a significant effect ($p < 0.05$) on tiller number, dry mass (plant-material) and grain mass. During tillering a significant ($p < 0.05$) difference was found due to the species x treatment interaction.

Table 5.1 Summary of Analysis of variance (Anova) for plant height, dry mass and grain mass of wheat.

		Significancy level (Pr > F)								
		Plant height (mm)								
Source of Variation	Df	Seed.	Till.	Stem.	Head.	Flow.	Ripe.	Till no.	DM	GY
Species (S)	5	0.839	**0.002**	**0.003**	**0.041**	0.549	0.413	0.267	0.460	0.059
Densities(D)	2	0.716	0.936	0.711	0.764	0.088	**0.004**	**0.001**	**0.001**	**0.001**
S X D	10	0.667	**0.008**	0.353	0.487	0.431	0.272	0.221	0.315	0.465
Cv (q_v)		24.14	11.77	13.54	14.31	11.70	8.76	131.10	22.59	23.60

Cv = Coefficients of variation
Seed = Seedling stage; Till = Tillering stage; Stem = Stem elongation
Head = Heading stage; Flow = Flowering; Ripe = Ripening
Till no = Number of tillers; DM = Dry mass (g); GY = Grain mass (g)

Plant height (wheat)

Table 5.2 showed that species as main factor did not cause any significant difference to wheat plant height during seedling, flowering and ripening growth stages. Significant differences ($p < 0.05$) due to species were however found during tillering, stem elongation and heading growth stages. The tallest wheat plants were found during all these growth stages where wheat was grown together with either *R. raphanistrum* or *B. diandrus* with *A. fatua* in the third place. The smallest plants were found where wheat was grown with either *A. calendula* or *E. australis.*

Although only significant at the tillering stage, plant heights differed in response to different weed species. With *R. raphanistrum* and *B. diandrus* which resulted in the tallest wheat plants, plant height increased as number of weed plants were increased in the pots. With *A. calendula* and *E australis* that on the other hand resulted in the shortest wheat plants, plant heights decreases as number of weed plants were increased. As an increase in plant height is normally an indication of competition for sunlight and a decrease of plant height an indication of competition for water and nutrients, these results showed that different species most probably differed in their competitive strategy. At ripening stage, all weed species caused a decrease in the height of wheat plants as weed numbers increased, indicating that competition for water and/or nutrients were more important than competition for sunlight.

Table 5.2 Plant height of wheat at different growth stages.

Plant height (wheat) in mm Growth Stages							
Species	Density	Seedling	Tillering	Stem elongation	Heading	Flowering	Ripening
A. calendula	5 wheat	129	326 [a]	428	550	717	769
	5 wheat + 2 weeds	133	297 [ab]	395	506	656	725
	5 wheat + 4 weeds	125	253 [b]	345	436	584	670
Mean		**129**	**292** [c]	**389** [bc]	**497** [b]	**652**	**712**
E. australis	5 wheat	131	319	409	527	712	801
	5 wheat + 2 weeds	113	285	357	477	646	723
	5 wheat + 4 weeds	108	293	365	482	633	750
Mean		**117**	**299** [bc]	**377** [c]	**495** [b]	**664**	**758**
R. raphanistrum	5 wheat	99	327	450	567	712	766
	5 wheat + 2 weeds	136	338	449	554	658	663
	5 wheat + 4 weeds	129	353	476	606	705	723
Mean		**122**	**339** [a]	**458** [a]	**576** [a]	**692**	**717**
A. fatua	5 wheat	108	355	454	574	758	782
	5 wheat + 2 weeds	127	314	418	541	689	751
	5 wheat + 4 weeds	127	331	430	538	677	708
Mean		**121**	**333** [a]	**434** [ab]	**551** [ab]	**708**	**747**
B. diandrus	5 wheat	116	290 [b]	411	531	684	770
	5 wheat + 2 weeds	126	380 [a]	468	559	622	646
	5 wheat + 4 weeds	139	381 [a]	480	613	723	748
Mean		**127**	**350** [a]	**453** [a]	**568** [a]	**676**	**721**
L. temulentum	5 wheat	142	330	418	517	652	711
	5 wheat + 2 weeds	134	333	435	548	690	729
	5 wheat + 4 weeds	120	315	392	504	652	691
Mean		**132**	**326** [ab]	**415** [abc]	**523** [ab]	**665**	**710**
LSD (Species)		**25** [N.S]	**31** *	**47** *	**63** *	**65** [N.S]	**52** [N.S]
LSD (S X D)		**43** [N.S]	**54** *	**81** [N.S]	**115** [N.S]	**140** [N.S]	**100** [N.S]

S = Species; D = Density.

* P<0.05 = Significant, [N.S] = Not significant at P<0.05.

Tillering

Number of tillers per plant (main tiller excluded) were affected by the weed density only (Table 5.1). Figure 5.1 clearly shows a significant ($p < 0.05$) decrease in number of tillers per plant with an increase in weed plants from zero to two plants per pot, but not between

two and four plants per pot. Competition for either light or/and nutrients (nitrogen fertilizer) may reduce tiller number of wheat (Gooding & Davies, 1997). Results for plant height (Table 5.2) showed that although some weed species did affect wheat plant height at early stages due to competition for light, all weed species tested competed with the wheat for water and/or nutrients at later growth stages.

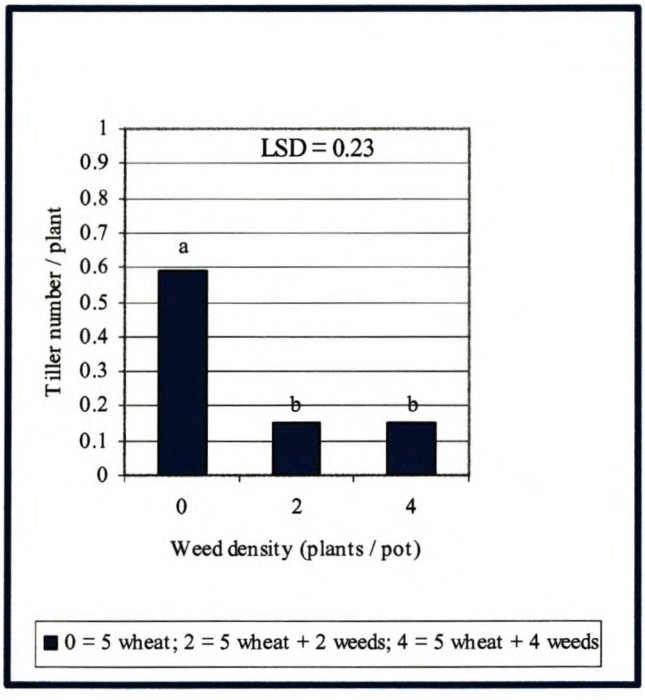

Figure 5.1 Effect of weed density on number of tillers of wheat plants.

Dry mass

Dry mass production (dry material) of wheat was also not affected by species as a main factor (Table 5.1), but were significantly reduced ($p < 0.05$) with an increase of weed densities from zero to two plants per pot (Figure 5.2). Further increase in weed density again did not affect dry mass production.

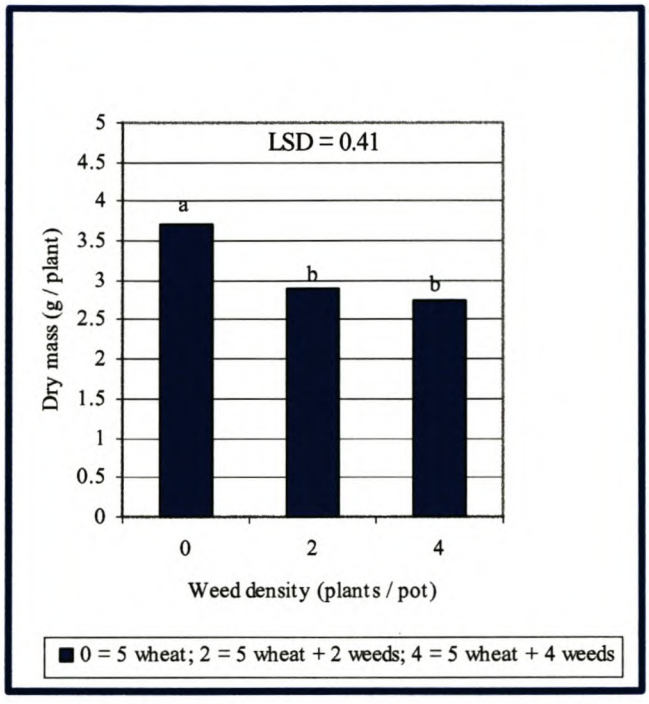

Figure 5.2 Effect weed density on dry mass production.

Grain mass

Grain yield declined with an increase in weed density (Figure 5.3) as was expected due to the decrease in both number of tillers and dry mass of wheat plants. McLennan *et al.* (1991) also showed that a reduction in the number of tillers caused a reduction in wheat yield. These results are also in agreement with that of Medd *et al.* (1985). Medd *et al.* (1985) also found that a combination of high densities of ryegrass and low wheat densities produced low yields, whereas high wheat densities neutralized ryegrass competition at any density tested. Neither species as a main factor or species by densities interaction had a significant effect on grain yield, indicating that the species tested did not vary with regard to their competitiveness.

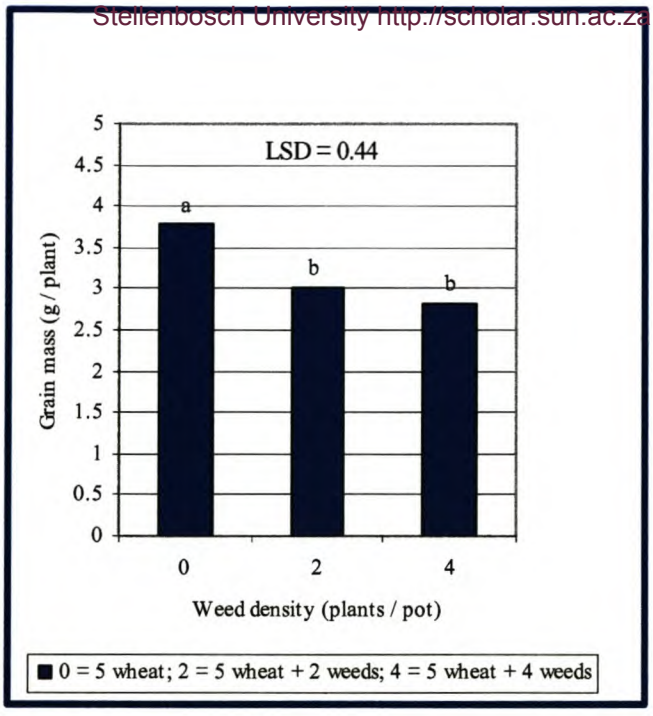

Figure 5.3 Effect of weed density on grain mass (wheat).

Discussion and Conclusion

The results obtained in this study showed that at early stages, species did differ with regard to their effect on plant height. Some species such as *A. calendula* caused a reduction in plant height, indicating competition for nutrients and/or water, while other species such as *R. raphanistrum* and *B. diandrus* caused an increase in plant height, indicating competition for light. Allelopathy might have also played a role in the effect on wheat. During the later growth phases all species tested caused a reduction in number of tillers per plant, dry mass produced and grain mass per plant. As plants received fertilizer at planting, tillering and stem elongation stages only and were irrigated only once a week, it is obvious that the measured effects must be due to competition for water and nutrients. Sandy soil was used as a growing medium and since sandy soil is unable to hold moisture and nutrient for longer period, this might have contributed in limiting the resources. These differences between species at the early growth stages however indicated that production techniques like seeding density and fertilization rates reduce the effect of specific species. No significant differences were found between weed population rates of 2 and 4 plants per pot, making it very difficult to predict any threshold values, at which weed control will become an economic proposition. Further studies with more densities under field conditions are needed.

In conclusion it can be said that this study showed that different species do differ with regard to their competitiveness with wheat at early growth stages and therefore may require different control strategies.

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Chapter 6

General conclusions

Weed control is one of the most expensive practices in crop production, therefore more research needs to be done in order to find the best possible and cheapest way of reducing weeds in fields. The ability of weed to develop resistance to herbicide treatment require a proper knowledge on the physiology and environmental requirement of such weeds in order to develop strategic weed control. According to research done in South Africa, the increased use of herbicides in wheat and maize exceeded R115 million in 1997. Therefore as the cost of herbicide usage increases, there might be a need to develop other strategies for weed control that will not involve herbicide usage. The development of integrated and biological weed control strategies can be made successful through knowledge of environmental conditions for weed seed germination and establishment in soils.

The primary aims of this study were to i) determine the effect of temperature regimes on the germination of *A. calendula*, *A. fatua*, *B. diandrus*, *E. australis*, *L. temulentum* and *R. raphanistrum* species, ii) evaluate the efficiency of three growth regulators applied at four different application rates to break dormancy and enable simultaneous germination of the mentioned species and iii) determine the competitiveness of the mentioned weed species with wheat and to decide when weed control will be cost-effective.

Many studies on the effect of temperature on germination of weed seeds have been conducted but literature on the effect of temperature on germination of *E. australis* and *R. raphanistrum* is scarce. Therefore research on the effect of temperature on common weed species in wheat producing areas of the Western Cape was undertaken. Different weed species have different temperature requirements for germination and that is shown by species such as *A. calendula*, *A. fatua*, *B. diandrus* and *R. raphanmistrum* which germinated best at 10 / 15 °C whereas *E. australis* and *L. temulentum* showed poor germination. Most of the species tested germinated best when subjected to a temperature regime of 10 / 15 °C, except for *E. australis* and *L. temulentum* which showed little response and this indicated that germination of those species can be expected all year round, provided germination requirement such as soil moisture content are met. The results indicated that *A. fatua* showed a positive respond at 10 / 15 °C temperature regimes

by high cumulative germination of nearly 90% as compared to *R. raphanistrum*, which showed low cumulative germination of less than 12%. This large difference was due to the change in regard to either the length of their period of primary dormancy or specific germination requirements such as light stimulus. The other reason is that some weed seeds respond well in the dark, some in light and some in both light and dark condition. Therefore as wheat seed germinate best in either light or dark, it thus possible for either light or dark favoured weeds to affect wheat yield. The temperature x periods interaction was significant across all six weed species. This result indicated that both temperature and period affected germination of those six weed species significantly. This creates a challenge in a winter wheat producing areas like the Western Cape on how to tackle the weed control problem since most farmers cannot afford the cost of herbicides and they are trying to avoid the residual effects of other herbicides on crops.

The study on stimulation of germination of dormant weed seeds for germination provided useful information on which chemical / concentration will be effective in breaking dormancy of a specific species. Seeds differ according to their physiology and dormancy state, therefore each species require a specific chemical concentration to overcome its dormancy mechanism. Although this study did provide some useful information regarding the germination requirements of weed species tested, no practical method to improve weed control in wheat field infested by weed species could be suggested. It also provided the solution to farmers having dormancy problem on how to manipulate seeds in the soil to germinate at a certain period. The chemical x concentration x periods interaction was significant across all six weed species and this is an indication of a significant effect by different chemicals, concentrations and periods. It can be concluded from this study that no chemical / concentration proved to be successful in stimulating the germination of all species tested. This was confirmed by the findings that high concentration of hydroxylamine stimulated germination of *E. australis* to nearly 100% and inhibited germination of *R. raphanistrum* at all hydroxylamine concentrations.

The competition study showed a significant difference due to species x density interaction during the tillering growth stage only. The species x density interaction did not cause any significant difference on tiller number, dry mass and grain mass of wheat. This study made it possible to explore the relationships between crop and weed competition on crop yield. Weed density markedly influenced wheat dry matter yields. At high weed

densities, wheat tiller number, dry matter and grain mass were strongly suppressed. Wheat tiller number, dry matter and grain mass was higher for low weed density and changed rapidly for weed density of > 2 weed plants / pot. The results agree with those of other researchers, who found that high weed density reduce wheat yield significantly. The results showed that competition during the early stages of crop growth was for nutrients and other factors required for germination but not for factors like light. The reason was because wheat plants were not growing faster and producing larger leaves. As cereals are known to be sensitive to competition from weeds in their early stages of growth, the significant effect due to weed species and species x treatment interaction during tillering growth stage caused a greater impact on wheat yield. It was also found that tiller number plays an important role on cereal crop yield because poor development results in low grain production.

Overall this study provided three alternative solutions for reducing weed impact on crops, namely, (i) knowledge of environmental conditions required for weed seeds germination, (ii) knowledge of the chemicals and concentration which can help in breaking dormancy of seeds from the weed seed-bank and, (iii) knowledge on how to reduce competition impact of weeds by applying techniques such as increasing density of crops and reducing weed density.

Herbicide programs for control of weeds in wheat have been developed, and not all wheat growers can afford to purchase herbicides, especially in developing countries such as South Africa. An alternative method to minimize weed competition in wheat would be to increase the competitive ability of wheat through increased crop density. It is suggested that information from this study might result in many differences regarding germination requirements since seeds used was collected from one location, therefore more studies need to be done on seeds from different localities.