A STUDY OF PRODUCTION FACTORS AFFECTING SEED VIGOUR IN GARDEN PEAS (*Pisum sativum* L.) AND THE RELATIONSHIPS BETWEEN VIGOUR TESTS AND SEED LOT FIELD AND STORAGE PERFORMANCE

A thesis presented in partial
fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN SEED TECHNOLOGY
at Massey University, Palmerston North,
New Zealand

ABRAHAM G. CASTILLO
1992

ABSTRACT

Results of studies on seed vigour of 206 seed lots from six cultivars of garden peas (*Pisum sativum* L.), conducted at Massey University, Palmerston North, New Zealand are reported in this thesis. The relationship between vigour tests and field emergence of garden pea seed lots with varying seed quality characters was evaluated in 1988 for 82 seed lots from six cultivars under unirrigated conditions and under both irrigated and unirrigated conditions in 1989 for 23 seed lots from three cultivars (Section One). Vigour of seeds produced from various plant populations, row spacings, sowing times, methods of harvest and pod positions from field experiments in the 1988-1989 and 1989-1990 cropping seasons was recorded from 96 seed lots for two cultivars (Section Two). The performance of five seed lots of varying seed quality characters stored under eight different conditions formed the basis for a discussion of potential storage, relative storability and prediction of storage life in garden peas (Section Three).

Stressful conditions, i.e. extremely dry or very wet conditions, can limit germination and field emergence in garden peas. The 1988 environment (favourable rainfall and temperature) allowed good field emergence. However, low rainfall in November 1989 (unirrigated sowings) and excessive water following rain at the 30 October and 20 December 1989 (irrigated) sowings, caused reductions in field emergence. The germination test was strongly correlated with field emergence when conditions for sowing were favourable and when low germinating seed lots were included in the analysis. However, when low germinating seed lots (less than 85%) were excluded, the relationship between germination and field emergence was low and unreliable. Differences in field emergence between seed lots were a reflection of differences in vigour which were detected by the conductivity test. The conductivity test was strongly correlated with field emergence of garden pea seed lots under all sowing conditions.

Expected field emergence (EFE) did not differ from the conductivity test for cv. Small Sieve Freezer under stress conditions, but it did not predict field emergence under all sowing conditions and for all cultivars. Multiple linear regression equations derived from the results differed among cultivars and for various sowing conditions, but none resembled the EFE equation currently used commercially. Removing the hollow heart effect from the EFE increased the relationship between EFE and field emergence under

favourable conditions but reduced the relationship under stress conditions. Hollow heart is therefore an important component of seed lot performance under stress sowing conditions. In order to include the effect of hollow heart in the prediction of field emergence, EFE should be used. Further, use of EFE allows the determination of the quantity of seed needed for sowing to achieve a specific population, which the conductivity test result alone cannot provide. The EFE approach should be further evaluated.

Conductivity and controlled deterioration test results illustrated seed vigour differences resulting from various production practices i.e.:

- seeds from a population of 200 plants m^{-2} and a 10 cm row width harvested at 15% seed moisture content (SMC) had lower vigour than less dense plantings. Furthermore, there was a high hollow heart incidence, especially in bottom pod seeds. At lower population densities (50 and 100 plants m^{-2}), the top pod seeds harvested at 15% SMC had higher leachate conductivity than the bottom pod seeds. These effects on seed quality were attributed to high temperature and RH within the crop canopy. The temperature within the crop canopy was 2°C - 5°C higher than the air temperature, especially at the 200 plants m^{-2} population density. The relative humidity within the canopy at the 200 plants m^{-2} population density was 5% - 10% higher than within the canopy at the 50 and 100 plants m^{-2} population densities.
- seeds harvested at 40% SMC were of low vigour when machinery was used in harvesting. Although the seeds had attained physiological maturity, they were prone to damage when harvested at this seed moisture content. Higher vigour seeds were produced when harvesting was done at 25% SMC than at 15% SMC, even when machinery was used.
- seeds from a December sowing were higher in vigour than seeds from a November sowing, which was attributed to a more favourable environment during seed development and maturity. For the later sowing, seeds developed and matured during February / March when the temperature (2°C - 5°C lower than January) and RH (5% - 10% lower than January) were more suitable for seed development.
- seed deterioration in the field was increased by windrowing because during the time seeds were in the swath prior to harvest, they were exposed to high temperature and relative humidity.

Decline in germination and field emergence was faster in low vigour seed lots than high vigour seed lot in all storage conditions. Results from the conductivity and controlled deterioration tests (vigour tests) provided better data for determining potential storability in garden peas than the germination test. The conductivity and 6 day CD tests had the best relationships in most of the controlled storage conditions and were good predictors of germination and field emergence after storage. However, better prediction of storage life was obtained under controlled storage conditions than under ambient storage conditions, probably because of greater uniformity in the germination decline. Further work is required to develop a test for predicting storage life in ambient conditions.

Probit analysis of the decline in germination under the eight different storage conditions produced variable results. Under controlled storage (e.g. 25°C / constant 13% SMC) which produced a high decline in germination, the germination data when transformed into probits followed a curve, rather than the expected straight probit line for all seed lots. This may be attributed to the indeterminate character of peas which causes variable seed quality parameters at harvest, and therefore the production of heterogeneous seed lots. The data suggest that the probit model is not entirely appropriate for the prediction of storage life in garden peas, and more work is required to determine the effect of heterogeneity on storage performance.

ACKNOWLEDGEMENTS

A thesis produced from enormous research identifies a person, but can only be completed through the efforts of many helping hands. My sincerest thanks and gratitude to my chief supervisor, Dr. John G. Hampton of the Seed Technology Centre, Massey University, for his patience and wise supervision throughout the conduct of the experiments and the writing of the manuscript.

Appreciation and thanks are extended to Dr. Peter Coolbear and Dr. Hugo Varela-Alvarez, my co-supervisors. The encouragement and guidance during the conduct of the experiments and patience shown in the improvement of the manuscript by Dr. Peter Coolbear was extremely valuable. The guidance of Dr. Hugo Varela-Alvarez in the analysis of data was vital in the completion of the manuscript.

My sincere thanks are also extended to:
Professor Murray J. Hill, Director of the Seed Technology Centre, Massey University, for his guidance and parental care, especially for my family while we were in New Zealand.

All the staff of the Seed Technology Centre, Massey University, for their valuable help in so many ways which allowed the successful completion of this study.

The students of the Seed Technology Centre for their friendship and help in very many ways, especially Roger, Songvut, Luck, Joe and Nit.

The New Zealand Government, particularly the Ministry of External Relations and Trade in giving financial assistance for me and my family while we enjoyed the beautiful atmosphere of New Zealand.

I also extend my great appreciation to the Philippine Government, specifically the University of Southern Mindanao, for allowing me to study in New Zealand.

Lastly, I thank all my relatives, particularly my wife and children for their great support and sacrifice during the conduct of the experiments and writing of the manuscript. This work is dedicated to them, especially to my late mother.

Finally, I thank the LORD for all HIS blessings during our wonderful stay in this scenic AOTEAROA, NEW ZEALAND.

PREFACE

This thesis is composed of studies concerned with seed vigour in garden peas (*Pisum sativum* L.) and is presented in three sections. Each section is presented as a complete piece of work, containing an introduction, review of literature, materials and methods, results and discussion.

Section One (Relationships between seed quality and field emergence in garden peas (*Pisum sativum* L.)) presents the vigour problems associated with field emergence. The vigour test methods used in the prediction of field emergence under various sowing environments are discussed.

Factors affecting seed vigour during seed development and maturation are discussed in Section Two (Seed vigour associated with mother plant environment and method of harvest in garden peas (*Pisum sativum* L.)). Particular attention is paid to the environmental factors associated with the mother plant and how they affect vigour of the seeds produced.

Section Three (Laboratory methods for the prediction of storage life in garden peas (*Pisum sativum* L.)) discusses the problems of storage in garden peas, factors affecting seed storage life and the prediction of seed storage life. Results from 24 months storage of garden peas under various storage conditions are presented and discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

SECTION ONE

RELATIONSHIPS BETWEEN SEED QUALITY AND FIELD EMERGENCE IN GARDEN PEAS (*Pisum sativum* L.)

CHAPTER ONE

INTRODUCTION

Most pea (*Pisum sativum* L.) crops in New Zealand are spring sown. Generally, the spring environment is good for germination and growth of pea seeds. However, although the sowing time is short (ten weeks), there can be extremely variable environmental conditions which may affect pea field emergence and thus create problems in obtaining good field establishment (Gane *et al.,* 1984). For many agricultural and horticultural crops, specified plant populations are currently recommended for maximising yield and/or quality (Hampton and Coolbear, 1990). The pea population should be optimal to maximise yield, and this desired level is well established. In the U.K. the maximum economic yield of vining peas is reached at around 90 plants m^{-2}, and the achievement of this target population is of economic importance because of the cost of seed and the negative yield effects associated with variation from the optimal population (Gane, 1985). In New Zealand, garden peas are usually sown at 250-300 kg ha^{-1}, which with average seed weight and germination, produces populations of around 80-100 plants m^{-2}. Under dry land Canterbury conditions, populations less than 80 plants m^{-2} produce significantly lower yield (Stoker, 1975). One of the key factors in achieving these optimum populations is the use of high quality seeds - the quality of a seed lot being traditionally determined through seed testing for germination, analytical purity and sometimes seed moisture.

The relationship between field emergence and pea seed quality characters can be inconsistent. The standard germination test remains the principal and accepted criterion for seed viability (AOSA, 1978). The germination test is used to find the percentage of seeds which are capable of germinating to produce a normal seedling under optimal growing conditions in the laboratory (ISTA, 1985). Regulations within the European Economic Community demand that all commercial seed lots meet a minimum laboratory germination standard; the specific requirement for peas is 80% (Gane *et al.*, 1984; Powell, 1985). In New Zealand, there are no germination standards, but farmers are strongly advised to check seed analysis certificates before they purchase seed. A germination test result less than an accepted standard usually indicates deterioration and the seed lot will exhibit symptoms of seed ageing, such as reduced rates of germination and emergence, decreased tolerance to suboptimal

conditions and poor seedling growth (Powell *et al.*, 1984). In other words, the seed lot possesses poor vigour (Roberts, 1986). In such cases therefore, the germination test result alone indicates that the quality of the seed lot is suspect and there is usually a good correlation between germination and field emergence (Thompson, 1979). Scott and Close (1976) reported a correlation coefficient of 0.76 between eight day germination results and spring field emergence in ninety eight seed lots of four garden pea cultivars when germination values ranged from a low of 47% to a high of 98%. However, when only peas with high germination results (90%-98%) were evaluated, a low correlation coefficient of 0.27 was obtained (Scott and Close, 1976).

Performance differences in field emergence between seed lots which the germination test indicates are of similar quality are attributed to seed vigour, and therefore require a more sensitive differentiation of potential seed performance (Hampton and Coolbear, 1990). Roberts (1984) concluded that the standard germination test is adequate to indicate quality attributes of the seed except at high germination values when, because of the nature of the normal distribution on which the survival curve is based, a small difference in percentage germination represents a large difference in the progress of deterioration (Ellis and Roberts, 1980c). It is in these circumstances that vigour testing is necessary.

The detection of low vigour lots before sowing takes place has been the objective of much effort in many countries, leading to the development of various vigour tests. One such test of pea seed quality is the conductivity test, based on the leaching of solutes from seeds into water (Powell, 1985). The loss of electrolytes into water provides a simple and rapid method of determining leakage, i.e. the measurement of electrical conductivity of seed leachates. Thus a high leachate conductivity is indicative of greater solute loss than low conductivity. Substantial leaching of solutes from seeds occurs naturally during the early stages of imbibition (Powell, 1986) and increases after ageing even though tetrazolium testing showed that the seeds were still made up of completely living tissue. This is strong evidence that membrane deterioration is an early event in ageing. Decreases in many cellular activities involving membranes and reduced enzyme activity due to respiration and synthesis of macromolecules during ageing would all follow on from the initial deterioration of membranes (Roberts, 1973a).

Hollow heart is a physiological condition which occurs in most cultivars of wrinkle-seeded garden peas, and reports from many countries have associated it with low vigour (Perry, 1980). The condition can delay germination and reduce seedling growth. In New Zealand, the condition is considered important enough to be used as an assessment of pea seed vigour (Hampton and Scott, 1982). However, hollow heart is not widely used in the prediction of field emergence in other countries.

In New Zealand, results from the germination test, conductivity test and hollow heart assessment have been combined to predict field emergence (Scott and Close, 1976; Hampton and Scott, 1982). These results are expressed as the expected field emergence (EFE) (Scott and Close, 1976), which has proved a very successful multiple testing approach (Hampton and Coolbear, 1990), providing a more accurate guide to predicting field emergence than any of the individual parameters (Scott and Close, 1976). However, initial results were obtained from only one trial at one site and with one sowing date using 98 seed lots of three cultivars. Further evaluation with different cultivars and a wider range of environments is required (Hampton and Coolbear, 1990).

A greater understanding of the appropriate methods for determining seed vigour in peas will help to improve crop stand and yield. It is also important to appreciate how the vigour tests were derived, and their limitations, so that in the future, even better methods may be used to predict field emergence more effectively.

The objective of this study was to examine as rigorously as possible the relationship between seed quality and field emergence in garden peas, using currently available testing methodology. In particular, the use of conductivity and EFE testing was evaluated.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. GERMINATION AND FIELD EMERGENCE

Germination, to the physiologist, is the protrusion of the radicle, whereas to the seed analyst, a normal seedling must be produced before germination is considered to have taken place (Matthews and Powell, 1986). Germination can fail if requirements for water, oxygen, and a suitable temperature are not provided. In peas, the standard laboratory germination test is done between paper or in sand, with incubation at 20°C, an initial evaluation at five days and the final count on the eighth day (ISTA, 1985). This exposes the seeds to the favourable conditions (i.e. water, oxygen and temperature) necessary for the seed to germinate (Matthews and Powell, 1986).

Seed lots that emerge poorly relative to their laboratory germination are said to be of low vigour; their emergence is usually also slow and spread over a longer period. High vigour lots emerge rapidly, uniformly, and to a high level. At the same time, both high and low vigour lots are indistinguishable with respect to germination in terms of the accepted standards of the seed trade.

Unsatisfactory establishment therefore can occur when requirements for germination and pre-emergence growth are not met because of field conditions. Some occur because of environmental constraints such as inadequate or excess moisture, low temperatures, soil crusting on silt soil, and poorly prepared seed beds (Powell, 1988). However, the impact of less-than-ideal conditions can be especially great and economically very damaging when low vigour seed has been sown. In most growing situations, control of the soil environment is not possible. However, it is possible to control the vigour of the seed in order to improve the probability of the successful stand establishment of a vigorous crop (Matthews and Powell, 1986).

2.2. SEED VIGOUR

Seed vigour has been defined as the sum total of those properties of the seed which determine the potential level of activity and performance of the seed lot during germination and seedling emergence (Perry, 1980; ISTA, 1985). It is a concept which refers to those properties of seed which influence the speed and uniformity of germination and the ability to germinate and emerge under a wide range of field conditions (AOSA, 1978; ISTA, 1985). Seed vigour is a very important character in peas and must be high during planting so that the seed can resist the many environmental factors affecting germination and field establishment.

Good establishment in the field is important in many crops. Poor establishment can create problems (Matthews and Powell, 1986) such as:

1. Emergence failure that necessitates resowing, could mean a delay in harvest, resulting in a fall in market prices, and lower profits from the harvest (Matthews and Powell, 1986).
2. Reduced overall yield. Hampton and Scott (1982) obtained reduced yields from low vigour peas when poor emergence resulted in reduced plant stand.
3. Variability in uniformity of product (size, quality). The smaller seeds in a seed lot are likely to be immature, have a smaller embryo, or have suffered stress during development and cause low vigour in a seed lot (Gray, 1987).

These problems are common when low vigour seeds are used in the establishment of garden peas (Perry, 1980). Seed vigour has become an umbrella term for a multitude of diverse aspects of seed condition and physiology (Perry, 1980) although Ellis and Roberts (1980c) regarded low seed vigour as the result of seed deterioration processes, i.e. ageing, or the accumulation of irreversible degenerative changes until eventually the ability to germinate is lost (Powell, 1988). Maximum seed quality occurs at physiological maturity, the point when maximum dry seed weight is attained, after which vigour and viability may decline both during ageing on the plant (Delouche, 1980), during harvesting and

processing, and during storage (Powell *et al.*, 1984). Thus seed ageing has come to be recognised as a major cause of reduced vigour and viability in many species (Powell, 1988).

There are many pathways (e.g. lipid peroxidation, loss of membrane integrity, loss of enzyme activity, loss of ribosome integrity) by which deterioration may progress in unimbibed seeds (Anderson and Gupta, 1986; Bewley, 1986; Cherry and Skadsen, 1986). It is possible that many or all of these forms of degradation can occur to some extent within a single seed, but no doubt certain deterioration processes will be more important than others, depending on species and ageing environment (Priestley, 1986). Powell (1988) in a review of the physiological and biochemical changes which occur during seed ageing, presented evidence strongly supporting the hypothesis that the deteriorative metabolic changes observed in aged seeds are the inevitable consequence of initial cell membrane deterioration. Similarly the physical disruption of the membranes, i.e. rapid uptake of water during imbibition (Powell *et al.*, 1984), prevents normal cell organisation and hence leads to impaired performance. It seems increasingly likely that cell membrane integrity, determined by deteriorative biochemical changes, and/or physical disruption, can therefore be considered to be a fundamental cause of differences in seed vigour (Powell, 1985; Matthews and Powell, 1986; Powell, 1988).

Lack of or low vigour can be due to a number of distinct, though interacting factors such as genetic constitution, environment during seed development, mechanical damage during harvest and processing, and storage conditions. These factors can all be linked to seed ageing, due to the damage done to the integrity of cell membranes during seed development, handling and storage.

2.2.1. GENETIC CONSTITUTION

A fundamental factor which determines seed vigour is the inherent capacity of the seed to resist both environmental and mechanical effects on seed quality (Heydecker, 1969). In large seeded legumes, quality is often reduced by imbibition damage caused by faulty testas, but genotypic

characters can also be involved (Hampton, 1990). White seeded cultivars of dwarf bean, and lighter seeded types of chickpea were found to have high rates of water uptake and therefore a high incidence of imbibition damage, leading to lowered vigour and poor field emergence (Powell *et al.*, 1986).

Kuo (1989) found that a small number of soybean cultivars had seed coats which exhibited delayed permeability, i.e. seeds were not hard, but imbibition did not begin until at least one hour after soaking began. Selection for this character has the potential to allow the production of soybeans with high viability and vigour, and improved storage performance (Kuo, 1989), because such seeds would firstly be less susceptible to cycles of wetting and drying prior to harvest, and secondly would absorb moisture more slowly from the ambient atmosphere during open storage. A higher incidence of hollow heart has been found in wrinkled than unwrinkled seeded peas, which means the former possess lower seed vigour than unwrinkled cultivars (Perry, 1980). There are also cultivars which are more susceptible to pathogens and less favourable factors in the environment which will give non-uniformity of plants in an area, or low population density. Plant breeders have often inadvertently selected for increased seed vigour (Copeland and McDonald, 1985), but there is a need for more specific selection where enhanced seed vigour is a primary objective.

2.2.2. ENVIRONMENT DURING SEED DEVELOPMENT

A seed is a living system, and is therefore subject to degenerative or deterioration processes which culminate in death. These processes include loss in cell integrity which affects the biochemical mechanisms controlling the physiological processes of growth. During this deterioration there is a progressive reduction in the rapidity, uniformity and intensity of growth, and a decreasing tolerance to adverse environmental conditions. Vigour therefore decreases as the level of deterioration increases. Factors affecting this physiological response include:

- the environment during seed development, i.e. high temperatures, which induce rapid drying of immature pea seed and produce hollow heart (Halligan, 1986);
- seed maturity at harvest: either premature harvesting of immature seed, or conversely, over maturity through delays in harvesting (Matthews and Powell, 1986);
- seed size: often a larger embryo is correlated with increased seed and seedling vigour (Delouche, 1980; Powell, 1988).

A decline in seed vigour may occur during four stages of seed production; while the seed is still on the mother plant, during harvest, during processing, or in storage. Major factors influencing the extent of ageing are seed moisture content and temperature; an increase in either or both accelerates ageing. Seed ageing on the plant is frequently referred to as "weathering", reflecting the influence of the weather on these factors (Matthews and Powell, 1986). The degree of seed ageing that occurs in the "weathered" field clearly cannot be controlled, but it is important to recognise that delaying harvest after maturation may result in deterioration due to weather conditions. These losses of vigour occur as a result of membrane damage while the seed is undergoing development, as influenced by environmental factors (Matthews and Powell, 1986).

The environment plays a vital role in the development of the seed from the flower to seed maturity. It is important that the characteristic changes occurring in the developing seed are well understood in a normally growing legume (Gane *et al.*, 1984). These physical changes in the seed are coupled with physiological activities. The climatic components of the environment are probably the most important determinants in the location of seed production (Delouche, 1980). Low humidity, minimal rainfall, and favourable temperatures reduce the spread of seed borne diseases as well as the risk associated with inclement weather during the late maturation and harvest periods. The advantages of producing seed in areas specially adapted to seed production are: seed set, seed yield, and recovery in harvesting are high and relatively stable; seed germination and seed vigour are consistently high; and seed borne diseases can often be avoided or are more easily controlled (Delouche, 1980).

Unfavourable conditions may produce drastic effects on the yield and quality of seeds. Browning and George (1981) found that 450 mg N plus 255 mg P, and 450 mg N plus 422 mg P per plant produced pea seeds with a high incidence of hollow heart compared to treatments with lower amounts of P. High nitrogen levels (800 and 1050 mg N per plant) produced an increase in the number of bleached seeds.

Seeds attain physiological maturity at moisture contents ranging from 32-35% (e.g. corn, sorghum, rice) to 50-55% (e.g. soybeans, peanut, beans, cotton). Following maturation the seeds continue to dry down until they reach harvest maturity. Climatic conditions during this post-maturation preharvest period have a great influence on the quality of seed harvested (Delouche, 1980). Adverse weather conditions during the preharvest period cause seed quality problems (Delouche, 1974). Delayed harvest of soybean seed caused by inclement weather resulted in a reduction in viability and an increase in mechanical damage during harvest (Green *et al.*, 1966). Conversely, immature seeds at harvest lower the percentage viability of the lot and have a greater mortality in soil (Matthews, 1973). Immature seeds have high solute leaching into steep water because the high moisture content at harvest results in more damage during harvest and seed processing compared with mature seeds (Matthews, 1973). Heavy rainfall just prior to harvest reduces the percentage viability of dried seed and increases the leaching of solutes from the dried seed into steep water.

2.2.3. THE IMPORTANCE OF SEED INTACTNESS (MECHANICAL DAMAGE)

To obtain sound and healthy seed, the crop must be harvested under good conditions and handled with care (Gane *et al.*, 1984). There is plenty of evidence which shows that however good the initial quality of the seeds, they deteriorate more rapidly if they have been injured in some way (Roos, 1980). Freedom from mechanical damage is an 'accessory' factor, unrelated to the inherited or original physiological potential of the seeds;

but it is nevertheless thought by many seed technologists that its absence is frequently the key to the maintenance of the vigour of seeds (Heydecker, 1972).

One of the most important causes of low vigour in pea seed is seed coat cracking incurred during harvesting very dry seeds (Gane *et al.*, 1984). Mechanical damage, quite apart from curtailing the food supply available during germination and the early stages of growth, or even injuring the embryonic organs, provides a focus for colonisation by saprophytes (Heydecker, 1972). The effect is insidious and probably widespread. Colonised necrotic areas in seeds almost always increase in size during storage, and damaged and colonised seeds become agronomically useless well ahead of uninjured seeds even if they are still, strictly speaking, viable, because the attack, once started, is almost impossible to arrest (Christensen and Suer, 1982).

Damage may be caused during maturation even without any interference by man (Delouche, 1980; Perry, 1980; Matthews and Powell, 1986). More frequently it is, however, due to faulty threshing or processing methods (Gane *et al.*, 1984) or careless handling of sacks of seeds in transit (Gleeson, 1987).

2.2.4. STORAGE CONDITIONS

Damage and any other environmental conditions which hasten the development of the microorganisms which may have accumulated on the seed surface during maturation accelerate the inevitable deterioration, or ageing of seeds (Christensen and Suer, 1982). It appears to be particularly for this reason that storage conditions can be critical, especially after a moist harvest season (Halloin, 1986). With certain seeds, dry conditions appear preferable to cold ones since they safeguard a longer period of vigour after the seeds have been taken out of the store (Roberts and Ellis, 1984).

Ultimately, membrane damage and/or chromosome aberrations may weaken even stored seeds that have not suffered from microbial interference (Dourado and Roberts, 1984). Chromosome aberrations are usually formed as a result of initial lesions (damage which is not immediately manifested as breaks) (Evans, 1977). The subsequent breakage results only during replication. The damage only affects one chromatid, in particular a single duplex of DNA, and results from misrepair of one of the chromatids (Dourado and Roberts, 1984).

It is apparent that low vigour seeds have the following characteristics:

1. slow rate of germination
2. slow rate of seedling growth
3. low oxygen uptake during the early stages of germination
4. exhibit poor retention of solutes when placed in water because of dead cells or cells with damaged membranes.

2.3. TESTS THAT MEASURE SEED VIGOUR IN GARDEN PEAS

2.3.1. CONDUCTIVITY TEST

The electrical conductivity test is a measurement of electrolytes leaking from plant tissues. It was first adapted for seed testing by Presley (1958) to measure cotton seed viability. It was later developed into a vigour test for the prediction of field emergence of wrinkled-seeded peas (Matthews and Bradnock, 1968).

Cell membranes lose their integrity as seeds dry at maturity but during imbibition, this membrane integrity is re-established (Simon and Raja Harun, 1972; Short and Lacy, 1976; Bramlage *et al.*, 1978). Vigorous seeds probably re-establish these membranes at a faster rate with less leakage than less vigorous seeds. The integrity of membranes is important for many biochemical reactions in living cells. Changes in membrane ultrastructure and permeability in ageing seeds have been detected by the electron microscope (Harman and Granett, 1972) and by the conductivity

test (Harman and Granett, 1972; Gill and Delouche, 1973). The extent of leakage from low vigour seeds also causes secondary effects. Nutrients exuded from seeds during germination stimulate microorganism activity and secondary infection. A direct correlation has been reported between seed rot and quantity of carbohydrates exuded from seeds of peas (Matthews and Bradnock, 1968).

Membranes are constituted of lipid and proteins, the most important class of lipids being phospholipids such as phosphatidylcholine, phosphatidy-ethanolamine and phosphatidylinositol. The structural stability of the membrane rests largely on the solubility properties of these molecules and is now interpreted as the Fluid Mosaic Model (Singer and Nicolson, 1972). The phosphate group and the nitrogenous bases of these phospholipid molecules are highly polar and soluble in water. The fatty acid chains are apolar, having no electrical properties, and are completely insoluble in water. The cytoplasm is usually 70% water, and the intercellular space is also filled with water, so the lipid bilayer and associated proteins maintain their stability in this aqueous system by aggregating in a bilayer with the apolar fatty acid chains oriented to the inside of the layer (Singer and Nicolson, 1972; Simon, 1974).

When a seed desiccates during ripening, the cell membranes undergo dramatic changes as the water content falls (Simon, 1974). The cellular environment may be no longer sufficiently aqueous to stabilise the membrane bilayer and Simon (1974) has suggested that lipid inversion occurs into a hexagonal (H_{II}) phase. At this stage leakage is not a problem as there is no diffusion out of the dry cells (Bewley and Black, 1982). On rehydration, leakage may occur during the reorganisation from the non-bilayer phase (H_{II}) to the membrane bilayer. However, Crowe *et al.* (1989) have recently suggested a different mechanism for membrane leakage in this situation. They believe that the membrane in dry seeds maintains a bilayer form, but in a gel state. Upon rehydration, as the phospholipid bilayer passes from the gel to the liquid crystalline phase, there is an increase in permeability as the membrane passes through a phase transition, leading to leakage. This transitional state is extended because different

parts of the membrane are composed of different phospholipids, and each will undergo the phase transition at different times. The latter suggestion (Crowe *et al.*, 1989) would appear to be more acceptable, firstly because at physiological temperatures and pressures most phospholipids do not exhibit the H_{II} phase; and secondly, sugars known to be present in cells prevent the formation of the H_{II} phase in model systems and favour the transition from gel to liquid crystalline states under physiological conditions. However, no direct evidence for this theory is yet available in seeds.

There are few tissues in the living world which can successfully survive desiccation and subsequent rehydration. Seeds can do it because of the efficiency of two sets of enzyme controlled mechanisms during the reorganisation process:

a. repair enzymes - synthesizing new phospholipid and protein to replace membrane components damaged during dehydration and rewetting.
b. a detoxification system - removing dangerous reactive groups which form during seed storage and can cause great damage to membranes, i.e. free radicals like O_2^-, which are removed by the action of the enzyme superoxide dismutase (SOD) (Bewley and Black, 1986).

The leakage of solutes during early imbibition can be a good indication of the health of seed tissue and thus, by inference, seed vigour. Essentially leakage is a function of:

a. the level of seed coat cracking/permeability
b. the rate of membrane reorganisation within the seed (Matthews and Powell, 1987b).
c. the amount of solute available to leak out.
d. the number of broken cells (which will lose all their contents).

In the U.K., the use of the conductivity test to measure vigour in wrinkle-seeded garden peas is well established (Matthews and Bradnock, 1968; Bradnock and Matthews, 1970; Perry, 1970; Perry and Harrison, 1970; Carver and Matthews, 1975). The conductivity test has also been found to be useful in the prediction of field emergence in New Zealand (Scott and Close, 1976; Hampton and Scott, 1982).

However, in some countries like Poland there is no clear indication that the conductivity test can predict field emergence in garden peas. Duczmal and Minicka (1989) reported that predicting emergence on the basis of seed evaluation with all laboratory methods failed and the least useful methods were electroconductivity and germination tests. However, their sowings were made under favourable environmental conditions, i.e. good rainfall and no temperature stress. Ladonne (1989) on the other hand showed in his experiments that higher significant correlations were observed between conductivity and field emergence than between germination and field emergence. The results overall suggest that the conductivity test is useful for predicting field performance of pea seed lots under suboptimal conditions.

2.3.2. HOLLOW HEART TEST

Hollow heart is a physiological disorder of germinating pea seeds characterised by a sharply defined sunken area of white dead tissue on the adaxial surface of the cotyledons. The symptoms vary from a small shallow depression to a large cavity, often with cracks across the affected area, and both cotyledons are usually similarly affected (Perry and Harrison, 1973). The disorder was first described by Myers (1948) who found no pathogen associated with it and distinguished it from marsh spot caused by manganese deficiency (Perry and Harrison, 1973). Hollow heart occurs in most cultivars of wrinkle-seeded garden pea and in seed from many countries (Perry and Howell, 1965).

Several causes of the disorder have been suggested including deficiency during seed imbibition, physical stresses during maturation (Moore, 1964) and drying seeds too rapidly (Allen, 1961; Perry and Howell, 1965). Perry and Harrison (1973) showed that hollow heart in pea seeds was caused by high ambient temperatures during their maturation on the plant, and by drying them when immature. These results were supported by the findings of Halligan (1986) who showed that plants exposed to high temperature at seed moisture contents of 70% to 80% (about 10 days prior to pod wrinkle)

produced seed with the highest incidence of hollow heart and at all stages of development the incidence increased with the length of exposure to the high temperature. Perry and Harrison (1973) found that hollow heart symptoms will develop during germination, and the proportion of seeds affected in any sample depends on the rate of water imbibition. Moore (1964) found that more seeds developed hollow heart when water imbibition was rapid. Although Heydecker and Kohistani (1969) stated that slow water uptake and moisture stress enhanced symptom development, there is a positive causal correlation between incidence of hollow heart and microbial infection of the cotyledons in wet conditions (Heydecker and Feast, 1969).

Hollow heart delays germination and reduces seedling growth. Plants from seeds with the disorder were smaller and yielded less than those from normal seeds. Affected cells die, but immobilisation of starch reserves within them could not wholly account for the reduced growth, suggesting the presence of a germination and growth inhibitor (Harrison and Perry, 1973). However, Heydecker and Kohistani (1969) stated that hollow heart does not directly affect germination and seedling growth but leads to rotting of the cotyledons, thus predisposing seedlings to fungal infection.

Although results of experiments vary, it is evident that hollow heart can cause lower field emergence and therefore should be a factor to consider when planning for pea production (Scott and Close, 1976).

2.3.3. EXPECTED FIELD EMERGENCE

Laboratory tests developed to identify pea seed lots liable to emergence failure under field conditions include the conductivity test (Matthews and Bradnock, 1967; Matthews and Powell, 1986) hollow heart test (Myers, 1948; Perry and Howell, 1965; Heydecker and Feast, 1969; ISTA, 1985), seed size or weight (Heydecker, 1969), seedling evaluation (Perry, 1969), and speed or energy of germination as assessed by the first and the final

count in a laboratory germination test (Scott and Close, 1976). However, no single test principle necessarily satisfies all requirements for vigour testing (Hampton, 1984).

Scott and Close (1976), working with 98 seed lots of three garden pea cultivars demonstrated that several different laboratory test methods were each independently related to field emergence in Canterbury, New Zealand, but that a more accurate guide to field emergence could be obtained when these results were incorporated into a single predictive equation. However, although 98 seed lots and three cultivars were used, the data were obtained only at one sowing site and with one sowing date. Nevertheless this approach led to the production of a guide to the planting value of garden peas, or Expected Field Emergence (EFE) derived as follows (Hampton, 1984):

EFE = 26.8 + (% G) - 0.34 (% H H) - 0.23 (C);

where:

EFE = the Expected Field Emergence

G = Germination

H H = Hollow heart

C = Conductivity

The equation is a function of the germination test, hollow heart test and conductivity test estimated using multiple regression analysis (Scott and Close, 1976) where:

$Y = a + b_1x_1 + b_2x_2 + ... + b_kx_k$ (Edwards, 1976; Snedecor and Cochran, 1980).

x_1, x_2, x_k = are the independent variables

Y = the dependent variable

a = the y-intercept; the value of y when x is equal to zero.

b = slope of the equation line; the rate at which y changes with unit change in x.

The germination test is positively correlated to the expected field emergence. An increase of one percent in germination will give an increase of 0.7 percent in EFE.

Hollow heart and conductivity are negatively correlated to EFE; that is as hollow heart and/or conductivity increase, the EFE decreases. For hollow heart, an increase of one percent will contribute to a 0.34 percent decrease in EFE, while an increase of one micro Siemen per gram seed conductivity gives a reduction of 0.28 percent in the EFE.

In using this equation to predict pea seed field emergence, the laboratory germination test result to be used is the final count on the eighth day. When the interim fifth day count data were tried, the relationship was not as strong (Scott and Close 1976). The hollow heart data are obtained by splitting the cotyledons of normal germinated seeds, and looking for hollow depressions in the cotyledons. Both the germination test data and hollow heart data must be obtained from a sample which truly represents the seed lot. ISTA (1985) recommends 400 seeds for every seed lot for both the laboratory germination test and hollow heart determination.

2.3.3.1. Advantages of EFE

Although no guarantee of the accuracy of any vigour test can be given, experience has shown that in New Zealand, EFE is a better indicator of field emergence than the laboratory germination test (D.J. Scott, pers. comm.). Hampton and Scott (1982) found that vigour test results, expressed as expected field emergence (EFE) gave better predictions of field emergence than the standard laboratory germination test for five lots of garden peas, cv. 'small sieve freezer', sown in three adjacent replicated plot trials in the Manawatu. Differences in seed vigour between lots when equal numbers of seeds were sown were reflected in reduced emergence from low vigour lots, resulting in lower plant populations and a significant yield loss of green and seed peas.

Vigour data, including EFE values are presented on seed analysis certificates for garden peas issued by the New Zealand Official Seed Testing Station. This information can be used to determine

firstly whether the seed lot is suitable for sowing, and secondly to determine the time and rate of sowing (Hampton, 1984). Emergence of a seed lot with low vigour may be greater if sown later in the season than if sown early in the season when environmental conditions are likely to be more severe; the desired plant population can be achieved by compensating for reduced vigour by sowing more seeds per unit area. When sowings were made at rates which compensated for low vigour, so that equal plant populations were obtained, no yield differences were recorded (Hampton and Scott, 1982).

2.3.3.2. Limitations of EFE

There are some limitations, however, in the use of the expected field emergence equation.

Some factors which may affect field emergence are not included in the equation, as only those factors which had a highly significant correlation with emergence in the trial were included (Scott and Close, 1976). The incidence of storage and field fungi might also have some effect on the emergence and field establishment of garden peas. The EFE established by Scott and Close (1976) is for spring sown garden peas derived from one planting at one location with 98 seed lots from three cultivars with a wide range of laboratory germination. The equation might have lower predictability in early or late pea sowings especially in seed lots with high germination.

The EFE is suitable for garden peas but not for other types of peas such as field peas. There are now several new cultivars of garden peas grown in New Zealand (Casey, 1987) and in U.K. (Gane *et al.*, 1984). These cultivars vary in physical characteristics and differ in quality characters. Scott and Close (1976) found that the

EFE could predict field emergence in cv. Victory Freezer but not in cv. Dark Skinned Perfection. In this case, cultivar differences become a limitation in the use of EFE.

Soil types vary in the pea growing areas of New Zealand (Hampton and Scott, 1982). Areas with poor drainage tend to get wet easily and cause water logged conditions while other soil types may have poor water holding capacity. Extremely dry or wet conditions during sowing affect the establishment of garden peas (Delouche, 1980; Powell, 1988). Because the EFE relationship was derived from one set of trials in one season, it may not be valid under these extreme conditions. Hampton and Scott (1982) found significant block effects for hollow heart of harvested seed in three adjacent trials, and for electroconductivity in two trials, irrespective of the vigour of the parent lots. The reasons for this require further investigation.

CHAPTER THREE

MATERIALS AND METHODS

3.1. SEED LOTS

The garden pea seed lots used during the course of this study were obtained from the Official Seed Testing Station of the Ministry of Agriculture and Fisheries at Palmerston North. They were commercial lots which had been submitted for official testing in 1987 and 1988. Eighty two seed lots were used in 1988 and 23 seed lots were used in the 1989 experiment. These seed lots were chosen because evaluation at the Official Seed Testing Station showed that they possessed a range of vigour qualities and differed in expected field emergence.

3.2. DETERMINATION OF SEED QUALITY

The quality characteristics of each seed lot were determined in the laboratory using the appropriate ISTA methods (ISTA, 1985). The seed qualities determined were:

3.2.1. SEED MOISTURE CONTENT

Moisture content for each seed lot (ISTA, 1985) was obtained by weighing two replicates of 10 g seeds, grinding, placing in a weighed container and drying at 130°C for 1 hour. The moisture content of the seed was calculated using the formula:

$$\% \text{ Seed Moisture Content} = (M_2 - M_3) \times \frac{100}{M_2 - M_1}$$

where:

M_1 = is the weight in grams of the container and its cover,

M_2 = is the weight in grams of the container, its cover and its contents before drying, and

M_3 = is the weight in grams of the container, cover and contents after drying.

3.2.2. GERMINATION TEST

A standard laboratory germination test (ISTA, 1985) was conducted. Four replicates of fifty seeds were germinated between paper at 20°C for 8 days. Seedlings were evaluated and classified into normal, abnormal, and dead seeds respectively using the description of ISTA (1985). The data obtained were expressed as percentages.

3.2.3. HOLLOW HEART TEST

Hollow heart incidence was determined using the normal seedlings from the germination test. Normal seedlings were dissected by splitting the cotyledons by hand to expose the adaxial surfaces. The presence of depressions in either or both of the cotyledons was recorded as hollow heart. The data obtained were expressed as a percentage based on the total number of seeds evaluated in the germination test.

3.2.4. CONDUCTIVITY TEST

Conductivity testing was carried out according to Matthews and Powell (1987b). Fifty seeds in four replications were used from each seed lot. Each replicate of 50 seeds was weighed before being put into a 500 ml Erlenmeyer flask containing 250 ml deionised water at 20°C. Flask tops were sealed with parafilm to prevent evaporation and contamination. A control flask containing only deionised water was prepared. Conductivity of leachate was measured after 24 hours using a conductivity meter (CDM-83 Radiometer). The conductivity reading was obtained by dipping the conductivity meter electrode into the water with the seeds. Care was taken so the tip of the electrode did not come into contact with any seed. The

reading from the deionised water was subtracted from the reading obtained from the seeds. The conductivity results were expressed in micro Siemens per gram of seed ($\mu S\ g^{-1}$ seed).

3.2.5. EXPECTED FIELD EMERGENCE

Expected field emergence data were computed from the results obtained from the germination, conductivity and hollow heart tests using the formula provided by the Official New Zealand Seed Testing Station for commercial seed lots; i.e.

$$EFE = 26.8 + 0.7(\%\ \text{germination}) - 0.34(\%\ \text{hollow heart}) - 0.23\ (\text{conductivity}\ \mu S\ g^{-1}\ \text{seed})$$

3.3. FIELD EMERGENCE

3.3.1. EXPERIMENTAL FIELD

Field emergence experiments were done in the Old Orchard area, one of the experimental fields of Massey University, Palmerston North, New Zealand (40°S, 175°E). The 1988 sowing was done on the western side and the 1989 sowing on the eastern side. All sowings were made by hand into a Tokomaru silt loam soil (Cowie *et al.*, 1972) classified as an aeric fragiaqualf (gleyed yellow-grey earth) (Cowie, 1978; Scotter *et al.*, 1979), part of the rolling hill country at the foot of the western Tararua ranges (Barker, 1983).

3.3.2. 1988 FIELD EMERGENCE

Two sowing dates were used in 1988, the first on 20 November and the second sowing on 20 December.

For each sowing time, a randomised complete block design was used with three replications. A replicate was made up of 50 seeds from a seed lot, hand sown 3 cm deep into a 2 m long row. The distance between rows was 40 cm.

Field evaluation was done by counting normal seedlings emerged when more than 50% of the seedlings had attained the two leaf stage (between 10 and 15 days after sowing).

3.3.3. 1989 FIELD EMERGENCE

In 1989, field emergence data were obtained from seven hand sowings on 21 October, 30 October, 10 November, 21 November, 30 November, 11 December, and 20 December.

For each sowing, a randomised complete block design was used with four replications. Each replicate was made up of 50 seeds from each seed lot, which were hand sown 3 cm deep into a 2 m long row, each seed lot occupying one row in each replicate. The distance between rows was 15 cm. The plots were covered with polyethylene mesh net to protect the seeds from bird damage.

For all sowings except the first, two adjacent areas were sown, one of which was irrigated, and one which was not. Irrigation water was applied once for two hours immediately after sowing using a 'Gardena' oscillating sprinkler which delivered 1000 litres of water to 100 m^2 per hour.

Field emergence was obtained by counting the number of normal seedlings when more than 50% of the seedlings had attained the two leaf stage. This varied between 10 and 27 days after sowing, depending upon time of sowing. The 21 November unirrigated sowing was evaluated twice, at 14 and 27 days after sowing. The second evaluation was done because initial seedling emergence was unusually low.

3.4. WEATHER DATA

Weather data were obtained from a site one kilometre from the trial area, at the Grasslands Division of the Department of Scientific and Industrial Research in Palmerston North, New Zealand. The weather data are presented as weekly means for rainfall, mean maximum air temperature and 10 cm soil temperature.

3.5. DATA ANALYSIS

The experiments carried out in this study were divided into two groups. For the 1988 experiment where 82 seed lots were assessed, the relationship between seed quality and field emergence was analysed for each single factor and for the combined factors (germination, hollow heart and conductivity combined). Simple linear correlation analyses were used in determining the relationship between mean field emergence and means from single seed lot quality characters, while the combined effects of these factors (germination, conductivity and hollow heart) were analysed using multiple regression analysis.

For the 1989 sowing experiment, more emphasis was placed on the relationship between seed quality and field emergence under various field conditions.

Analysis of variance was used in determining the differences between seed lot quality characters and field emergence data.

Regression and correlation analysis was employed in determining the relationship between seed quality characters and field emergence.

CHAPTER FOUR

RESULTS

4.1. 1988 SOWING

4.1.1. WEATHER AT SOWING

The climatic factors recorded varied within the spring sowing season for garden peas. In 1988, total November rainfall was 63.3 mm, while that for December was 57.0 mm. For the November 20 sowing, 13.0 mm rain fell in the week of sowing, and 24.4 mm in the week following sowing (Table I.1). In contrast for the 20 December sowing, there was no rain during the week of sowing and only 4.6 mm in the week following sowing (Table I.1).

The mean maximum air temperature (Table I.1) for the month of November was 19.8°C while for December it was 22.9°C. For the November 20 sowing, the mean maximum air temperature was 19.7°C during the week of sowing, but increased to 26.3°C the week following sowing. A higher mean maximum air temperature was observed for the week of the second sowing (22.8°C), with a mean of 25.1°C in the following week. The mean 10 cm soil temperature was consistently higher for the month of December (Table I.1). A mean of 15.1°C was observed for the week of the November sowing and 17.2°C the following week compared to 18.7°C and 18.6°C, respectively, for the December sowing.

4.1.2. SEED QUALITY CHARACTERS

The seed lots were divided into two laboratory germination groups and five cultivar groups for further analysis (Table I.2). Firstly, data from all seed lots together were analysed and are presented as "all seed lots". Seed lots having a germination of 85% and above were then analysed separately and

Table I.1. Climate data for the months of November and December 1988.

WEEK	DAYS	RAINFALL (mm) NOV	RAINFALL (mm) DEC	AIR TEMP Mean Max (°C) NOV	AIR TEMP Mean Max (°C) DEC	10 cm SOIL TEMP Mean Max (°C) NOV	10 cm SOIL TEMP Mean Max (°C) DEC
1	1 - 7	11.8	4.9	16.7	21.2	13.7	17.4
2	8 - 14	3.6	1.1	18.6	21.8	13.5	17.1
3	15 - 21	13.0	0.0	19.7	22.8	15.1	18.7
4	22 - 28	24.4	4.6	26.3	25.1	17.2	18.6
	29 - 31	10.5	46.4	24.5	24.6	19.5	20.6
TOTAL		63.3	57.0				
MEAN				19.8	22.9	15.2	18.2

SOWING DATES

20 November 1988
20 December 1988

Table I.2. Range and median for germination and expected field emergence for 1988 seed lots.

SEED LOT	GERMINATION (%) RANGE	GERMINATION (%) MEDIAN	EXPECTED FIELD EMERGENCE (%) RANGE	EXPECTED FIELD EMERGENCE (%) MEDIAN
ALL LOTS (82)[1]	48 - 99	91.5	43 - 94	81.5
ABOVE 85% GERM (67)[1]	85 - 99	93.5	69 - 94	83.1
PANIA[2] (21)[1]	48 - 99	91.5	43 - 91	80.5
PANIA (18)[1]	85 - 99	92.5	69 - 91	80.6
PATEA[2] (12)[1]	86 - 99	95.0	76 - 93	83.1
SSF[2] (22)[1]	69 - 99	90.0	67 - 90	82.3
SSF (16)[1]	85 - 99	93.5	78 - 90	85.3

1 = Number of seed lots analysed
2 = Cultivar

are presented as "above 85% germ". Cultivars with ten or more seed lots were then analysed separately, Pania and Small Sieve Freezer (SSF) cultivars being further divided into two laboratory germination groups (all seed lots and seed lots with above 85% germination). The Pania analysis using all seed lots is presented as Pania (21) and those with above 85% germination are called Pania (18) corresponding to the number of seed lots analysed in each group. Similarly SSF (22) group contains all seed lots for the cultivar while the SSF (16) group contains only those seed lots with high germination.

4.1.2.1. Germination and Expected Field Emergence

The germination of the 82 seed lots ranged between 48% and 99% with a median of 91.5%, while expected field emergence ranged between 43% and 94% with a median of 81.5% (Table I.2 and Appendix I.1). Pania (21) germination did not differ from that of all seed lots group, but removing lots with less than 85% germination slightly increased the median.

For the expected field emergence, the removal of low germinating seed lots increased the median for SSF (16) (85.3%) and the above 85% germination group (83.1%).

4.1.2.2. Conductivity and Hollow Heart

Electroconductivity results obtained from the all seed lots group ranged between 11 and 47 $\mu S\ g^{-1}$ seed with a median of 20 $\mu S\ g^{-1}$ seed (Table I.3). SSF (22) had the highest conductivity median of 25 $\mu S\ g^{-1}$ seed. Lower conductivity readings were obtained in the seed lots group with high germination.

Hollow heart incidence ranged between 0.1% and 42% with a median of 5.8% in the all seed lots group, which was comparable to the above 85% germination group (Table I.3). Pania (21) had

Table I.3. Range and median for conductivity and hollow heart for 1988 seed lots.

SEED LOT	CONDUCTIVITY ($\mu S\ g^{-1}$ seed) RANGE	MEDIAN	HOLLOW HEART (%) RANGE	MEDIAN
ALL LOTS (82)[1]	11 - 47	20	0.1 - 42	5.8
ABOVE 85% GERM(67)[1]	11 - 37	19	0.1 - 42	6.0
PANIA[2] (21)[1]	15 - 47	21	1.5 - 42	18.0
PANIA (18)[1]	15 - 37	20	1.5 - 42	17.0
PATEA[2] (12)[1]	14 - 31	19	0.1 - 40	4.5
SSF[2] (22)[1]	14 - 33	25	0.5 - 14	2.8
SSF (16)[1]	14 - 31	18	0.5 - 14	2.5

1 = Number of seed lots analysed
2 = Cultivar

the highest hollow heart content with a median of 18% and a range between 1.5% and 42%. SSF had a lower hollow heart incidence, ranging between 0.5% and 15%.

4.1.2.3. Field Emergence

Field emergence in the November 1988 sowing ranged between 39.0% and 93.3% for all seed lots group and between 37.0% and 98.0% in the December 1988 sowing (Table I.4).

In each case Pania (21) gave the widest variation of any sub groups within the total seed lots planted. Pania (18), and SSF (16) had less variation in field emergence, the lowest results being 68.7% and 76%, respectively in December 1988 sowing.

4.1.3. RELATIONSHIP BETWEEN FIELD EMERGENCE AND SEED QUALITY

4.1.3.1. Germination

Positive correlations were observed between field emergence and germination in both the November and December sowings (Table I.5, Figure I.1 and Appendix I.2). Significant correlations between germination and field emergence were exhibited by the all seed lots group, Pania (21), SSF (22) and SSF (16) for both the November and December sowings. In the groups where only high germination seed lots were included, low or non significant correlations were obtained, with the exception of cv. SSF.

Table I.4. Range and median for field emergence in November and December 1988 sowings.

SEED LOT	NOVEMBER FIELD EMERGENCE (%) RANGE	NOVEMBER FIELD EMERGENCE (%) MEDIAN	DECEMBER FIELD EMERGENCE (%) RANGE	DECEMBER FIELD EMERGENCE (%) MEDIAN
ALL LOTS (82)[1]	39.0 - 93.3	80.0	37.0 - 98.0	86.7
ABOVE 85% GERM(67)[1]	55.3 - 93.3	81.3	64.7 - 98.0	88.7
PANIA[2] (21)[1]	39.0 - 93.3	82.2	37.3 - 96.0	85.4
PANIA (18)[1]	63.0 - 93.3	83.3	68.7 - 95.7	86.0
PATEA[2] (12)[1]	63.3 - 85.3	80.3	65.0 - 94.0	88.0
SSF[2] (22)[1]	61.3 - 89.3	79.4	69.3 - 94.7	85.4
SSF (16)[1]	64.7 - 89.3	81.3	76.0 - 95.7	89.3

1 = Number of seed lots analysed
2 = Cultivar

Table I.5. Correlation between field emergence and germination, conductivity, hollow heart and expected field emergence (with and without hollow heart effect) for November and December 1988 sowings.

	GERMINATION AND FIELD EMERGENCE		EFE AND FIELD EMERGENCE				CONDUCTIVITY AND FIELD EMERGENCE		HOLLOW HEART AND FIELD EMERGENCE	
			NOVEMBER		DECEMBER					
	NOV	DEC	WITH H.H.	W/OUT H.H.	WITH H.H.	W/OUT H.H.	NOV	DEC	NOV	DEC
ALL SEED LOT(82)[1]	0.70**	0.72**	0.66**	0.73**	0.76**	0.77**	-0.66**	-0.75**	-0.02	-0.18
ABOVE 85% GERM (67)[1]	0.39**	0.45**	0.25*	0.43**	0.49**	0.54**	-0.37**	-0.55**	0.08	-0.21*
PANIA[2] (21)[1]	0.81**	0.83**	0.75**	0.84**	0.78**	0.86**	-0.85**	-0.85**	0.01	-0.03
PANIA (18)[1]	0.25	0.24	0.18	0.35	0.24	0.34	-0.48*	-0.46	0.05	-0.06
PATEA[2] (12)[1]	0.53	0.45	0.54	0.63*	0.58	0.59*	-0.62*	-0.71*	-0.08	-0.17
SSF[2] (22)[1]	0.79**	0.81**	0.83**	0.82**	0.86**	0.85**	-0.61**	-0.68**	-0.01	-0.03
SSF (16)[1]	0.68**	0.66**	0.68**	0.73**	0.72**	0.75**	-0.45	-0.53*	-0.27	-0.33

1 = Number of seed lots analysed

2 = Cultivar

* = Significant at 5% level

** = Significant at 1 % level

H.H. = Hollow Heart

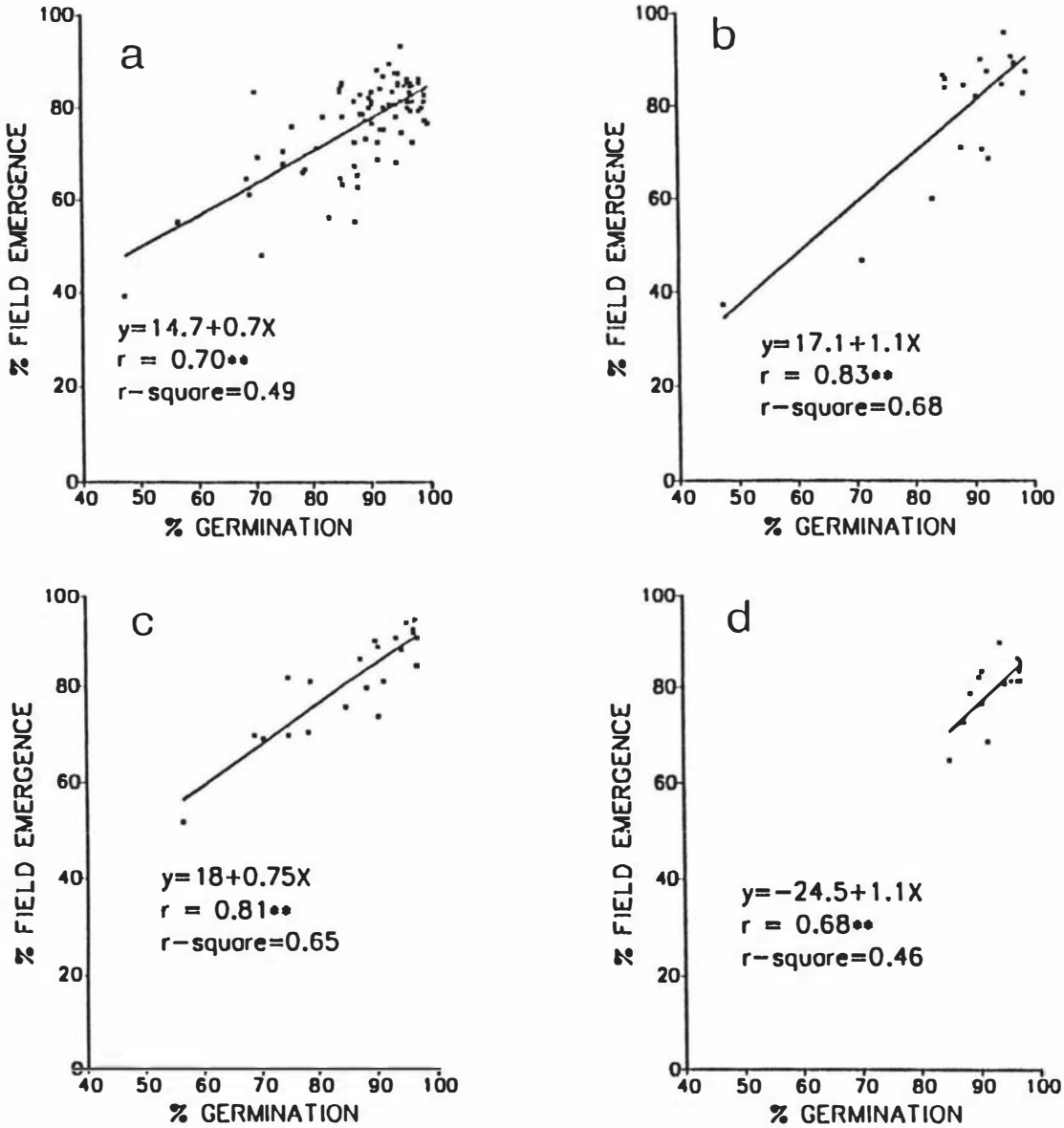


Figure I.1. Example of relationships between germination test results from various groups and field emergence in the 1988 sowings. (a) all seed lots November sown, (b) Pania 21, December sown; (c) SSF 22, December sown and (d) SSF 16, November sown.

4.1.3.2. Expected Field Emergence

The correlation coefficient between all seed lots expected field emergence (with hollow heart) and field emergence for November sown peas was 0.66 while for the December sowing it was 0.76, both of which were highly significant (Table I.5). Although significant correlations were exhibited by the above 85% germ group for both sowings, lower coefficients of determination were obtained, that for the November sowing accounting for only a tiny portion of the variation R^2=6.0% (Appendix I.2).

The significant result had been obtained due to the high chances of getting significant correlation using 82 data pairs (replications) but is, of course, spurious because of very low coefficient of determination. For cv. Pania the correlations were significant for all seed lots (Pania 21) but were very low and non significant when low germinating lots were excluded (Pania 18).

Highly significant relationships between expected field emergence and field emergence for both November and December sowings were shown by both SSF (22) and SSF (16) (Table I.5 and Figure I.2). Better correlations were obtained once again from all seed lots of the cultivar. The EFE of cv. Patea was not correlated with field emergence. However, an increase in the relationship between EFE and field emergence in all groups was obtained when hollow heart was not included as a component of the EFE equation in both November and December sowings.

4.1.3.3. Conductivity

Negative correlation coefficients between conductivity and field emergence for November (Figure I.3) and December sowings were found for all the groups analysed although not all were significant

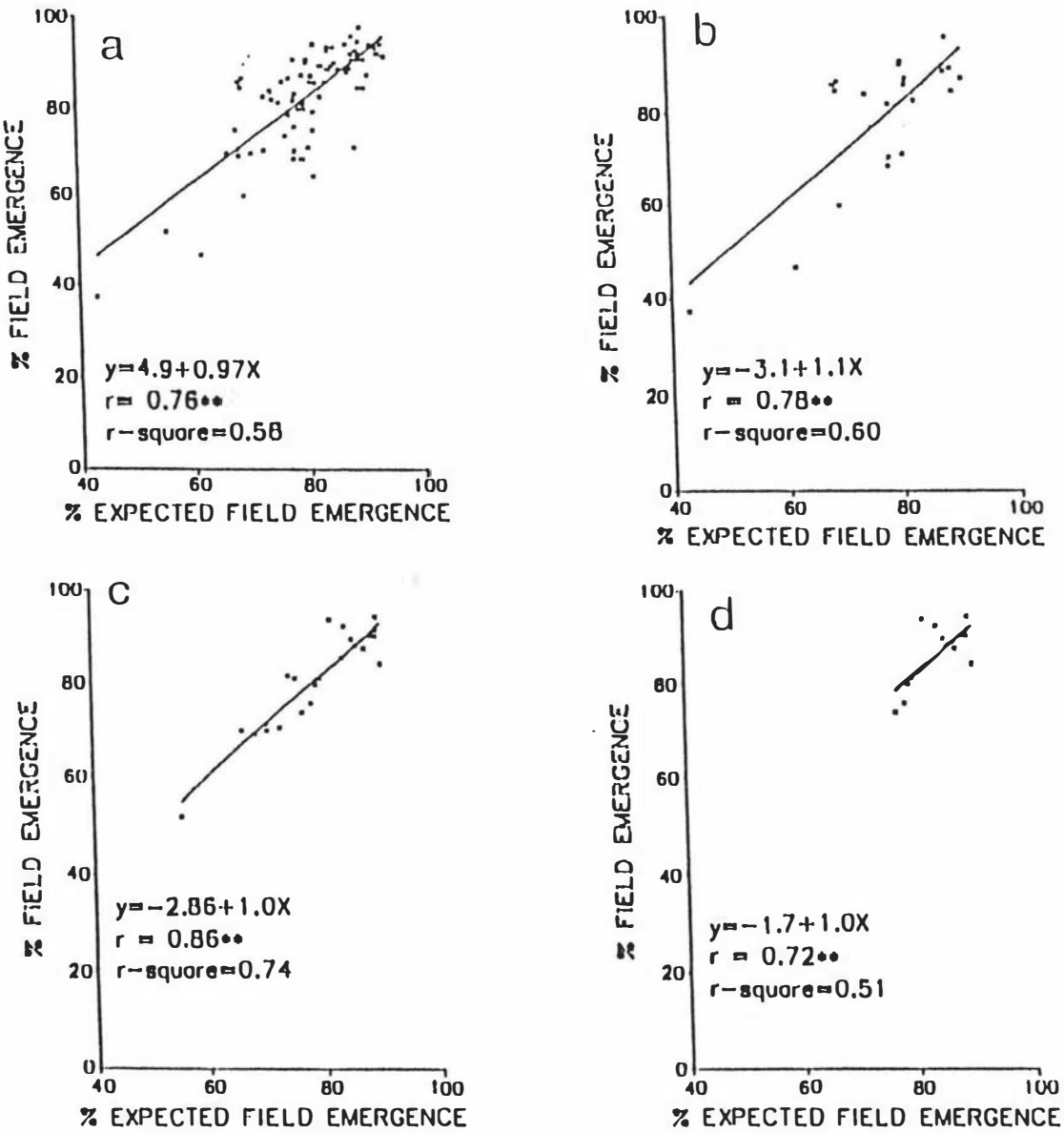


Figure I.2. Example of relationships between expected field emergence from various groups and field emergence from December sowing. (a) all seed lots group, (b) Pania 21, (c) SSF 22, (d) SSF 16.

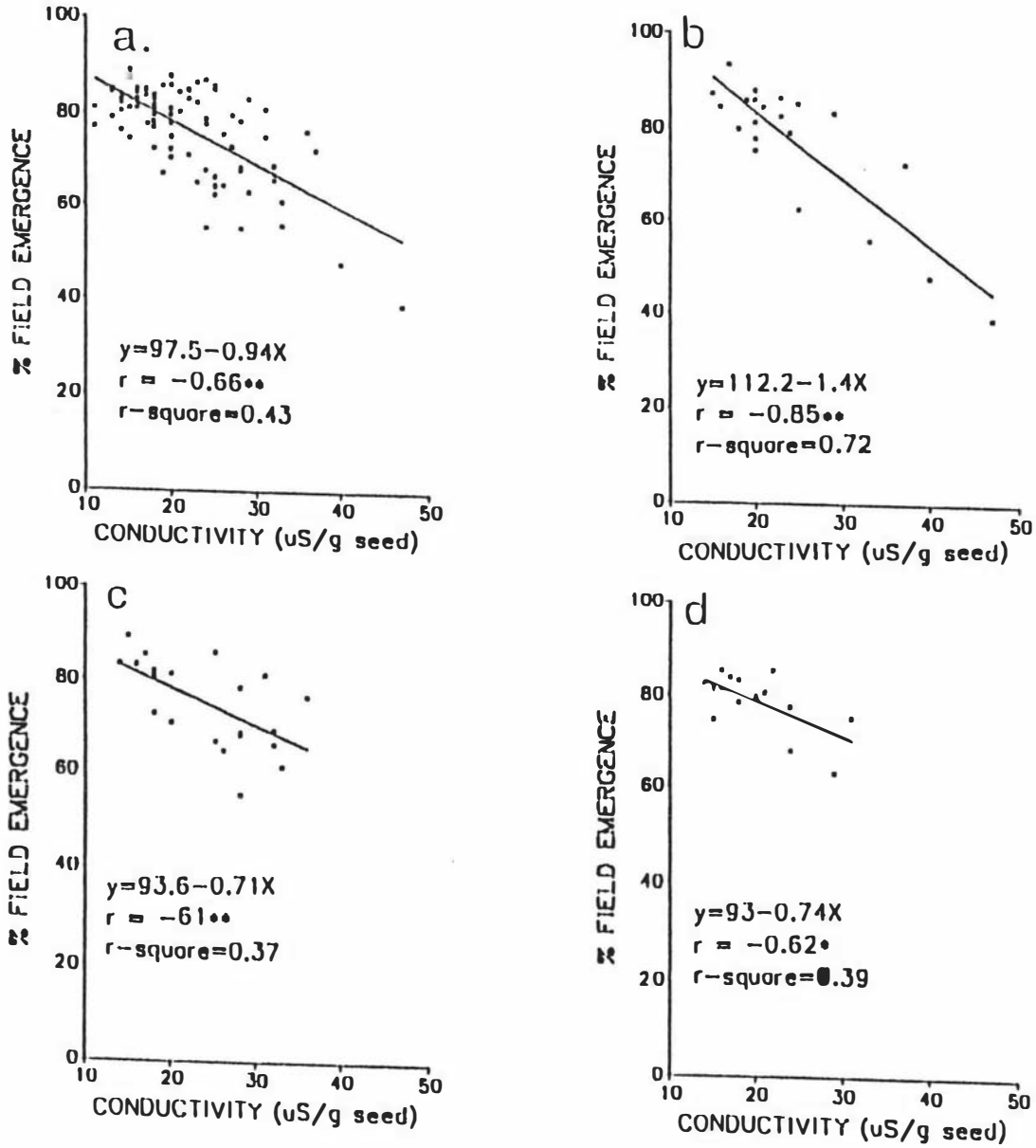


Figure I.3. Example of relationships between conductivity test results from, different groups and field emergence from the November 1988 sowing. (a) all seed lots group, (b) Pania 21, (c) SSF 22, (d) cv. Patea.

(Table I.5 and Appendix I.3). Removing low germinating seed lots from the analysis reduced the correlations with field emergence for the all seed lots group, cv. Pania and cv. SSF.

4.1.3.4. Hollow Heart

There was no relationship between hollow heart and field emergence in all the seed lot groupings. Correlations were very low for both the November and December sowings (Table I.5).

4.1.3.5. Comparison of the Effects of Germination, Conductivity and EFE

Germination, expected field emergence and conductivity predicted field emergence to some extent (Table I.5). However, for the above 85% germ group, conductivity was a better predictor than EFE for both sowings, and better than germination for the December sowing. Conductivity was a better predictor than germination and EFE for Pania (21), Pania (18) and cv. Patea. For cv. SSF, EFE was the best predictor.

4.1.3.6. Combined Effects of Germination, Conductivity and Hollow Heart

The combined effects of germination, conductivity and hollow heart in relation to field emergence for November sown peas for the different groups are shown in Table I.6. Significant regression equations were obtained for all groups except Pania (18) and Patea, but only for Pania (21) and SSF (22) did these factors account for more than 60% of the variation recorded. Removing the low germinating lots substantially reduced the significance of the relationship and for the coefficient of determination.

Very similar results were obtained for the December sowings (Table I.7).

Table I.6. Multiple linear regression table for the November 1988 sowing.

SEED LOT	CONSTANT TERM	GERMINATION SLOPE	CONDUCTIVITY SLOPE	HOLLOW HEART SLOPE	Coefficient of Determination	Y[3]
ALL LOTS (82)[1]	50.50**	0.43**	-0.60**	0.14	0.57	**
ABOVE 85% GERM (67)[1]	44.40*	0.45*	-0.43*	0.17*	0.25	**
PANIA[2] (21)[1]	61.20*	0.42	-1.00**	0.19	0.79	**
PANIA (18)[1]	80.80	0.15	-0.66	0.12	0.27	
PATEA[2] (12)[1]	40.60	0.52	-0.53	-0.07	0.47	
SSF[2] (22)[1]	30.70	0.60**	-0.25	-0.12	0.69	**
SSF (16)[1]	-13.60	1.05*	-0.15	-0.17	0.54	*

1 = Number of seed lots analysed
2 = Cultivar
3 = level of significance of regression equation
* = Significant at 5% level
** = Significant at 1 % level

Table I.7. Multiple linear regression table for the December 1988 sowing.

SEED LOT	CONSTANT TERM	GERMINATION SLOPE	CONDUCTIVITY SLOPE	HOLLOW HEART SLOPE	Coefficient of Determination	Y[3]
ALL LOTS (82)[1]	58.10**	0.48**	-0.77**	-0.05	0.66	**
ABOVE 85% GERM (67)[1]	58.30**	0.43*	-0.60**	-0.0009	0.35	**
PANIA[2] (21)[1]	55.70	0.58	-0.98*	0.14	0.78	**
PANIA (18)[1]	86.80	0.11	-0.63	0.05	0.22	
PATEA[2] (12)[1]	64.90	0.45	-1.02	-0.14	0.55	
SSF[2] (22)[1]	47.50	0.55**	-0.52	-0.08	0.76	**
SSF (16)[1]	7.40	0.94*	-0.29	-0.10	0.57	*

1 = Number of seed lots analysed
2 = Cultivar
3 = level of significance for regression equation
* = Significant at 5% level
** = Significant at 1 % level

4.2. 1989 SOWING

4.2.1. WEATHER DATA

Weekly rainfall in October ranged from 12.3 mm to 47.8 mm with a total of 123.1 mm for the month (Table I.8). This was higher than the total November and December rainfall which totalled 23 mm and 56.8 mm, respectively. December rainfall was highly variable with 15.4 mm in the first week, no rain in the second week and increasing rainfall towards the later weeks of the month. However, the orchard adjacent to the experimental area was irrigated on 20 December which flooded the irrigated plots during the night. This resulted in the 20 December irrigated sowing being under very wet soil conditions.

Unirrigated sowings made on 21 and 30 November were under environmentally stressed (low moisture) conditions. The rainfall was very low before, during and after the sowing week. The irrigated sowings on 31 October and 20 December were under very wet soil conditions and are considered as excessive moisture stress conditions.

Air temperatures were below 20°C during the first three weeks of October. December had a consistently high air temperature with a mean maximum of 20.1°C. October had a mean maximum 10 cm soil temperature of 13.0°C which was lower than November and December soil temperature mean maxima of 16.2°C and 16.1°C, respectively.

4.2.2. SEED QUALITY CHARACTERS

In 1989, seed lots used were those having high germination as determined by a standard laboratory germination test, i.e. seed lots where normal seedlings ranged between 85% and 100% (Table I.9). Although all the seed lots had high germination, significant differences were recorded (Appendix I.3). The various seed lots gave significantly different conductivity results.

Table I.8. Climate data for the months of October, November and December 1989.

WEEK	DAYS	RAINFALL (mm) OCT	NOV	DEC	AIR TEMPERATURE Mean Maximum (°C) OCT	NOV	DEC	10 cm SOIL TEMP Mean Maximum (°C) OCT	NOV	DEC
1	1-7	28.4	4.2	15.4	17.2	20.0	19.3	13.1	15.2	16.2
2	8-14	47.8	12.0	0.0	17.5	20.2	20.2	13.0	16.6	15.8
3	15-21	21.4	2.8	4.5	16.6	19.2	20.7	10.8	16.7	16.1
4	22-28	12.3	3.6	19.5	19.1	21.1	20.7	13.8	16.7	16.0
	29-31	13.2	0.4	17.4	21.6	17.9	19.0	15.9	14.6	17.3
TOTAL		123.1	23.0	56.8						
MEAN					18.0	20.0	20.1	13.0	16.2	16.1

SOWING DATES:

21 October 1989
30 October 1989
10 November 1989
21 November 1989
30 November 1989
11 December 1989
20 December 1989

Table I.9. Range and median for seed quality data for 1989 sowings.

PARAMETERS	ALL SEED LOTS (23)** RANGE	MEDIAN	CV. PATEA (13)* RANGE	MEDIAN	CV. SSF (8)* RANGE	MEDIAN
% GERMINATION	85 - 100	96.0	85 - 100	96.0	88 - 97	95.4
CONDUCTIVITY(uS/g)	14 - 36	18.3	14 - 25	18.3	16 - 36	18.1
% HOLLOW HEART	0 - 40	4.0	0 - 40	5.5	1 - 15	3.0
% E. F. E.	76 - 92	85.7	76 - 92	85.7	76 - 90	86.0
% F. E. 1ST UNIR[a]	48 - 87	75.5	48 - 86	75.0	72 - 87	79.3
% F. E. 2ND IRRIG[b]	19 - 60	47.0	19 - 60	49.5	25 - 53	42.8
% F. E. 2ND UNIR[b]	64 - 82	73.0	65 - 77	71.5	70 - 82	74.5
% F. E. 3RD IRRIG[c]	55 - 93	68.5	59 - 83	70.0	61 - 93	67.0
% F. E. 3RD UNIR[c]	43 - 68	53.5	48 - 65	54.5	44 - 68	54.8
% F. E. 4TH IRRIG[d]	46 - 83	66.0	46 - 83	69.5	56 - 76	63.3
% F. E. 4TH UNIR1[d]	26 - 66	45.5	29 - 66	52.5	26 - 55	43.3
% F. E. 5TH IRRIG[e]	53 - 96	81.0	52 - 96	82.0	76 - 94	79.5
% F. E. 5TH UNIR[e]	47 - 89	74.0	47 - 86	78.5	53 - 89	65.8
% F. E. 6TH IRRIG[f]	70 - 97	90.0	70 - 95	90.5	84 - 97	88.8
% F. E. 6TH UNIR[f]	63 - 91	83.0	63 - 91	84.0	69 - 87	75.3
% F. E. 7TH IRRIG[g]	53 - 86	74.0	53 - 85	74.0	53 - 86	75.5
% F. E. 7TH UNIR[g]	69 - 92	80.5	69 - 92	85.0	74 - 88	78.8

* Number of seed lots analysed

** Total number of seed lots (Patea 13, SSF 8, Pania 2)

SOWING DATES

a = 21 October 1989
b = 30 October 1989
c = 10 November 1989
d = 21 November 1989
e = 30 November 1989
f = 11 December 1989
g = 20 December 1989

The electrical conductivity readings had a median of 18.3 $\mu S\ g^{-1}$ seed for cv. Patea and the all seed lots group (Table I.9) but the all seed lots group had a wider range of between 14 and 36 $\mu S\ g^{-1}$ seed.

Significant differences between seed lots in the incidence of hollow heart were recorded (Appendix I.3). Hollow heart ranged between 0.0% and 40% in the all seed lots group and Patea cultivar (Table I.9) but cv. Patea had a higher median of 5.5%. SSF cultivar gave a hollow heart range between 1.0% and 15% which was lower than the all seed lots group and cv. Patea.

The expected field emergence of the seed lots differed significantly (Appendix I.3). However, the EFE was close to the actual field emergence from only one irrigated sowing (11 December) in the all seed lots group (Table I.9). For cv. SSF, only the field emergence obtained from 21 October, 30 November and 11 December irrigated sowings were similar to the expected field emergence. All field emergence percentages from cv. Patea and stress sowing conditions in the all seed lots group and cv. SSF were not similar to EFE.

4.2.3. FIELD EMERGENCE

For the October sowings, a wide range of field emergence was encountered (Table I.9), and significant differences were recorded between seed lots (Appendices I.4, I.5a and I.5b).

For the irrigated sowings, field emergence were lower in 30 October and 20 December sowings where high moisture was observed. The irrigated sowings during November and 11 December have high field emergence.

For unirrigated sowings, the 21 November sowing had very low field emergence with a range between 26% and 66%. The field emergence from other unirrigated sowings were very much higher than the field emergence of 21 November sowing.

The same trend of results was obtained from cv. Patea and cv. SSF.

4.2.4. RELATIONSHIP BETWEEN SEED QUALITY AND FIELD EMERGENCE FOR 1989 SOWINGS

4.2.4.1. Relationships in the All Seed Lots Group

The relationships between the seed quality tests and field emergence obtained from the various sowing dates in both irrigated and unirrigated plots and analysed using all the seed lots are presented in Table I.10 and Appendix I.6. The variation obtained from the field emergence data were high enough to allow regression and correlation analysis. The germination test result was not significantly correlated to field emergence at any of the sowing times irrespective of whether plots were irrigated or unirrigated.

Under irrigation, EFE was significantly correlated with actual field emergence only at the last sowing (20 December, Figure I.4). However, in unirrigated plots, EFE was significantly correlated with field emergence at all but the first sowing. Better relationships between EFE and field emergence were encountered at the 21 November, 30 November and 11 December sowings. Although significant relationships were recorded between field emergence and EFE, often higher and better relationships were recorded between conductivity and field emergence (Table I.10). EFE was better than hollow heart in the prediction of field emergence. When hollow heart was not included in EFE, low correlations with field emergence were obtained, especially in stress condition sowings (Table I.10).

Highly significant negative correlation was shown between hollow heart and field emergence at the 20 December irrigated sowing (Figure I.5 and Table I.10). For unirrigated sowings, significant

Table I.10. The relationship between field emergence and germination, conductivity, hollow heart and expected field emergence (with and without hollow heart effect), as measured by the coefficient of correlation in irrigated and unirrigated sown garden peas for the all seed lots group.

DATE OF SOWING	GERMINATION		EXPECTED FIELD EMERGENCE				CONDUCTIVITY		HOLLOW HEART	
	IRRIG	UNIRRIG	IRRIGATED		UNIRRIGATED		IRRIG	UNIRRIG	IRRIG	UNIRRIG
			WITH H.H.	W/OUT H.H.	WITH H.H.	W/OUT H.H.				
21 OCT 89		0.16			0.33	0.21		-0.21		-0.28
30 OCT 89	0.06	0.28	0.35	0.27	0.47*	0.29	-0.65**	-0.15	-0.26	-0.41
10 NOV 89	0.13	0.20	-0.03	0.003	0.51*	0.32	0.35	-0.44*	0.04	-0.44*
21 NOV 89	0.25	0.14	0.39	0.29	0.62**	0.37	-0.22	-0.76**	-0.30	-0.55*
30 NOV 89	0.20	0.24	0.31	0.23	0.55**	0.45*	-0.16	-0.73**	-0.24	-0.37
11 DEC 89	0.21	0.20	0.29	0.26	0.59**	0.38	-0.25	-0.63**	-0.17	-0.50*
20 DEC 89	0.13	0.08	0.67**	0.28	0.46*	0.26	-0.82**	-0.60**	-0.62**	-0.43*

* Significant at 5% level.
** Significant at 1% level
IRRIG = Irrigated
UNIRRIG = Unirrigated
H.H. = Hollow Heart

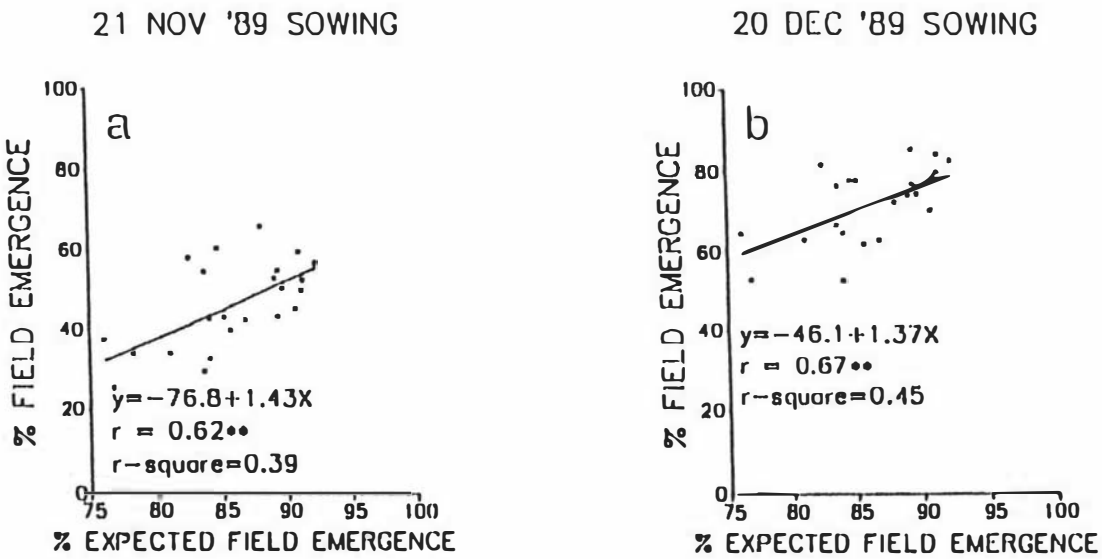


Figure I.4. Relationship between expected field emergence and field emergence in the all seed lots group for (a) 21 November 1989 unirrigated sowing and (b) 20 December 1989 irrigated sowing.

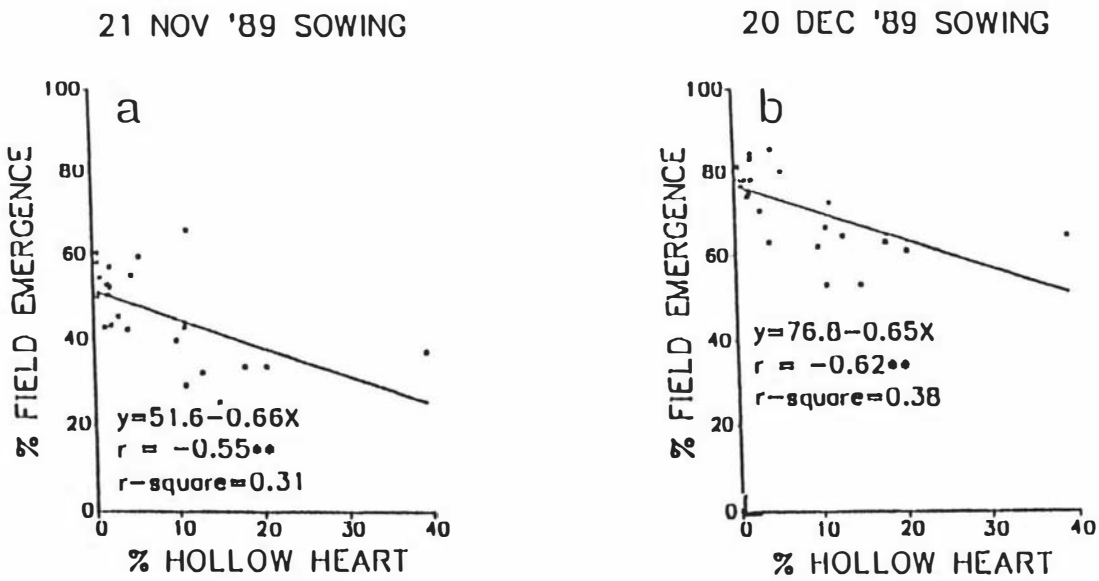


Figure I.5. Relationship between hollow heart test and field emergence in the all seed lots group for (a) 21 November 1989 unirrigated sowing and (b) 20 December 1989 irrigated sowing.

correlations were found between hollow heart and field emergence at 21 November (Figure I.5), 11 December and 20 December sowings (Table I.10).

Significant negative correlations were shown between electroconductivity and field emergence at the 30 October and 20 December irrigated sowings (Figure I.6) with r-values of -0.65 and -0.82 respectively (Table I.10). For unirrigated sowings, highly significant correlations were found between conductivity and field emergence at the 21 November (Figure I.6), 11 December and 20 December sowings, while a significant relationship was also found at the 10 November sowing. Correlations between conductivity and field emergence were not significant for the October sowings.

4.2.4.2. Relationships in Cultivar Patea

For the cultivar Patea, the same trend of results was obtained as from the all seed lots group. No significant correlations were obtained between the germination test and any of the field emergence data (Table I.11 and Appendix I.7). For EFE, a significant correlation at the 20 December irrigated sowing was observed, while the conductivity test gave significant negative correlations with field emergence from irrigated sowings on 30 October and 20 December sowing. Hollow heart was significantly correlated with field emergence from irrigated plots only at the 20 December sowing.

In unirrigated plots, EFE was significantly related to field emergence at the 10 November, 21 November and 11 December sowings, but removing hollow heart as a component of EFE reduced the correlation coefficient especially in sowings under stress conditions (Table I.11). Highly significant negative correlations between conductivity and field emergence were

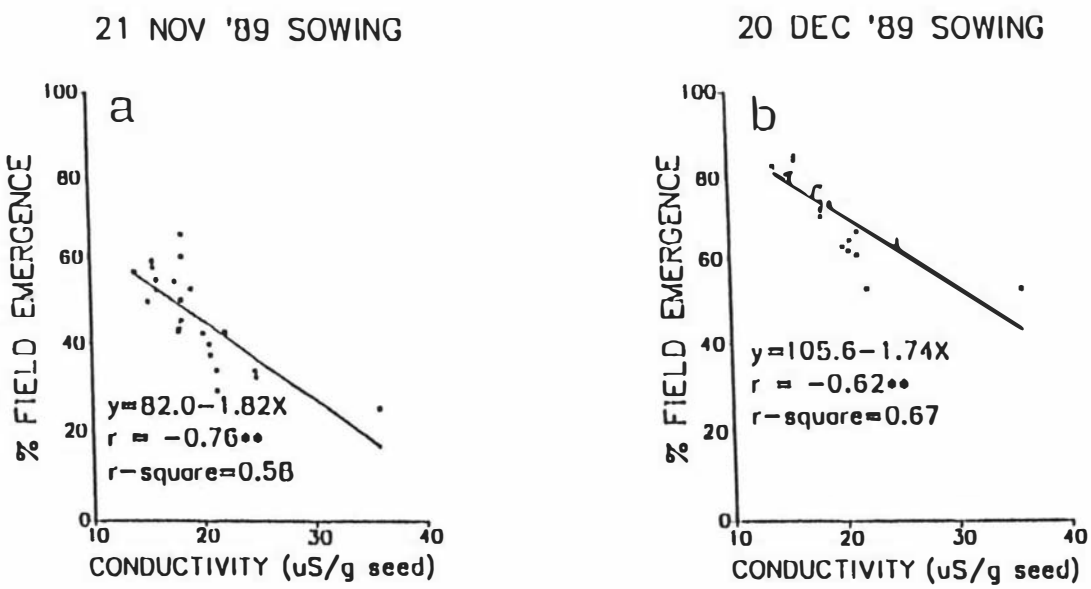


Figure I.6. Relationship between conductivity test and field emergence in the all seed lots group for (a) 21 November 1989 unirrigated sowing and (b) 20 December 1989 irrigated sowing.

Table I.11. The relationship between field emergence and germination, conductivity, hollow heart and expected field emergence (with and without hollow heart effect), as measured by the coefficient of correlation in irrigated and unirrigated sown garden peas for CULTIVAR PATEA sown 1989.

DATE OF SOWING	GERMINATION		EXPECTED FIELD EMERGENCE				CONDUCTIVITY		HOLLOW HEART	
			IRRIGATED		UNIRRIGATED					
	IRRIG	UNIRRIG	WITH H.H.	W/OUT H.H.	WITH H.H.	W/OUT H.H.	IRRIG	UNIRRIG	IRRIG	UNIRRIG
21 OCT 89		0.31			0.51	0.46		-0.73**		-0.28
30 OCT 89	-0.05	0.15	0.27	0.01	0.41	0.23	-0.62**	-0.38	-0.26	-0.34
10 NOV 89	-0.04	0.42	-0.03	-0.10	0.67*	0.55	0.23	-0.66*	-0.04	-0.41
21 NOV 89	0.17	0.04	0.51	0.27	0.57*	0.21	-0.48	-0.73*	-0.43	-0.56*
30 NOV 89	0.17	0.17	0.46	0.27	0.52	0.35	-0.50	-0.82**	-0.37	-0.38
11 DEC 89	-0.02	0.01	0.10	0.07	0.56*	0.18	-0.36	-0.73**	-0.07	-0.57*
20 DEC 89	0.04	-0.02	0.63*	0.24	0.48	0.15	-0.89**	-0.72**	-0.61*	-0.50

* Significant at 5% level.
** Significant at 1% level
IRRIG = Irrigated
UNIRRIG = Unirrigated
H.H. = Hollow Heart

recorded for the 21 November, 30 November, 11 December and 20 December sowings. Hollow heart was significantly related to field emergence in unirrigated plots at the 21 November, and 11 December sowings (Table I.11).

4.2.4.3. Relationships in Cultivar SSF

For irrigated plots, the germination test was significantly correlated with field emergence at the 11 December sowing (r=0.71, Table I.12), but field emergence from other sowing dates in irrigated plots showed no significant relationship with germination. Expected field emergence and field emergence were significantly correlated at the 20 December irrigated sowing (Figure I.7). For unirrigated plots, EFE was significantly related to field emergence at 21 November and 11 December sowings. However, the removal of the hollow heart component of EFE resulted in a non significant correlation coefficient.

Field emergence from the 30 October and 20 December sown irrigated plots and the unirrigated sowings in 21 and 30 November were negatively correlated to electroconductivity (Table I.12). Hollow heart incidence was positively and significantly correlated with field emergence from the 10 November sown irrigated plots, while a significant negative relationship was exhibited with field emergence from the 20 December sown irrigated plots. Field emergence from the 21 November unirrigated sowing gave significant negative correlation with hollow heart (Table I.12).

4.2.5. COMBINED EFFECTS

Highly significant regression equations were obtained from unirrigated sowings on 21 November, 30 November, 11 December and 20 December (Table I.13) for the all seed lots group. A highly significant regression was

Table I.12. The relationship between field emergence and germination, conductivity, hollow heart and expected field emergence (with and without hollow heart effect), as measured by the coefficient of correlation in irrigated and unirrigated sown garden peas for CULTIVAR SSF sown 1989.

DATE OF SOWING	GERMINATION		EXPECTED FIELD EMERGENCE				CONDUCTIVITY		HOLLOW HEART	
	IRRIG	UNIRRIG	IRRIGATED		UNIRRIGATED		IRRIG	UNIRRIG	IRRIG	UNIRRIG
			WITH H.H.	W/OUT H.H.	WITH H.H.	W/OUT H.H.				
21 OCT 89		0.12			-0.13	0.05		0.09		0.41
30 OCT 89	0.06	0.40	0.63	0.43	0.31	0.39	-0.84**	-0.15	-0.70	0.03
10 NOV 89	0.21	-0.03	-0.42	-0.09	0.39	0.18	0.56	-0.44	0.79*	-0.58
21 NOV 89	0.30	0.07	-0.14	0.13	0.72*	0.46	0.23	-0.89**	0.57	-0.85**
30 NOV 89	0.48	0.17	0.009	0.31	0.59	0.46	0.15	-0.71*	0.53	-0.55
11 DEC 89	0.71*	0.46	0.49	0.71*	0.72*	0.65	-0.31	-0.63	0.11	-0.51
20 DEC 89	0.18	0.29	0.75*	0.55	0.67	0.54	-0.89**	-0.69	-0.77*	-0.60

* Significant at 5% level.
** Significant at 1% level
IRRIG = Irrigated
UNIRRIG = Unirrigated
H.H. = Hollow Heart

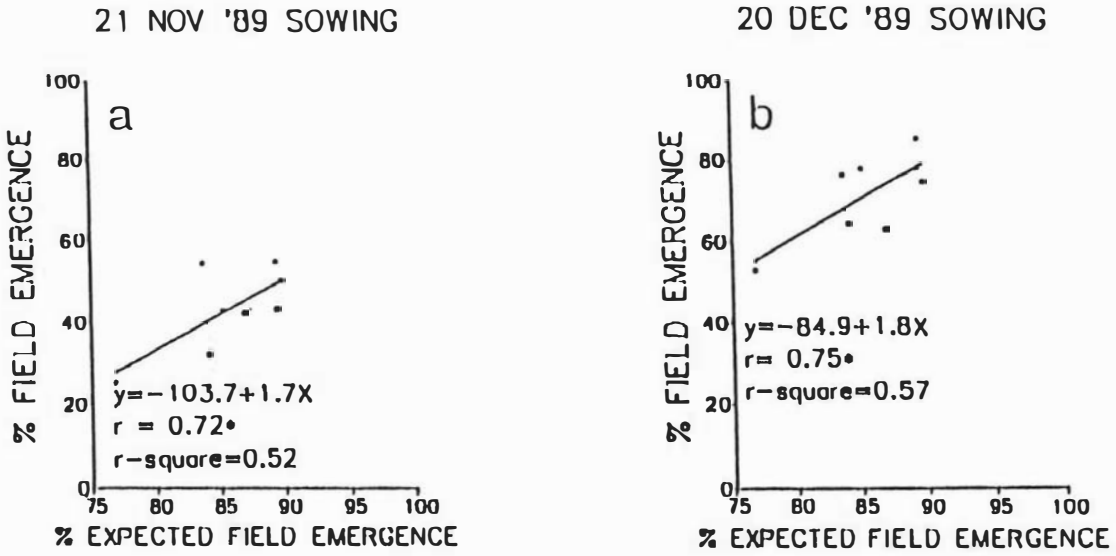


Figure I.7. Relationship between expected field emergence and field emergence in cv. Small Sieve Freezer for (a) 21 November 1989 unirrigated sowing and (b) 20 December 1989 irrigated sowing.

Table I.13. Predictive equation for field emergence as obtained from the different sowing dates in irrigated and unirrigated sowing conditions in all seed lots group.

SOWING DATE	CONDITION	PREDICTIVE EQUATION DERIVED	R^2	Y^3
21 0CT 89	UNIRRIGATED	Y= 40.90 + 0.40 (G) - 0.063 (C) - 0.27 (H)	0.11	
30 OCT 89	IRRIGATED	Y= 107.00 - 0.309 (G) - 1.74 (C) + 0.136 (H)	0.44	**
	UNIRRIGATED	Y= 37.60 + 0.359 (G) + 0.169 (C) - 0.232 (H)	0.28	
10 NOV 89	IRRIGATED	Y= -1.60 + 0.57 (G) + 0.98 (C) - 0.217 (H)	0.21	
	UNIRRIGATED	Y= 36.80 + 0.28 (G) - 0.37 (C) - 0.24 (H)	0.29	
21 NOV 89	IRRIGATED	Y= 9.40 + 0.62 (G) + 0.006 (C) - 0.315 (H)	0.16	
	UNIRRIGATED	Y= 77.10 + 0.016 (G) - 1.54 (C) - 0.28 (H)	0.62	**
30 NOV 89	IRRIGATED	Y= 33.90 + 0.51 (G) + 0.04 (C) - 0.26 (H)	0.10	
	UNIRRIGATED	Y= 85.40 + 0.226 (G) - 1.75 (C) - 0.032 (H)	0.54	**
11 DEC 89	IRRIGATED	Y= 66.00 + 0.29 (G) - 0.25 (C) - 0.068 (H)	0.09	
	UNIRRIGATED	Y= 76.00 + 0.217 (G) - 0.79 (C) - 0.24 (H)	0.45	**
20 DEC 89	IRRIGATED	Y= 104.00 - 0.019 (G) - 1.44 (C) - 0.295 (H)	0.73	**
	UNIRRIGATED	Y= 100.00 - 0.0044(G) - 0.71(C) - 0.111(H)	0.38	**

G = % Germination
C = Conductivity reading ($\mu S\ g^{-1}$ seed)
H = % Hollow Heart
R^2 = Coefficient of Determination
Y^3 = level of significance of regression equation
* = Significant at 5% level
** = Significant at 1% level

also derived from irrigated plots at the 20 December sowing. These predictive multiple linear regression equations gave significant coefficients of determination but the 21 November unirrigated and 20 December irrigated sowings gave the highest R^2-value of 0.62 and 0.73 respectively. However, the regression equations derived were different for each sowing time and none resembled the EFE equation.

Although significant regression equations were obtained, the constant terms differ between equations.

In cv. Patea (Table I.14), the multiple linear regression equation derived from the 20 December irrigated sown peas was highly significant with a coefficient of determination value of 0.80. Unirrigated sowings on 21 October, 10 November, 21 November, 30 November and 11 December produced significant multiple linear regressions for field emergence using germination, conductivity and hollow heart as predictors for cultivar Patea.

No significant multiple linear regressions were obtained in SSF cultivar (Table I.15).

Table I.14. Predictive equation for field emergence as obtained from the different sowing dates in irrigated and unirrigated sowing conditions in cv. PATEA.

SOWING DATE	CONDITION	PREDICTIVE EQUATION DERIVED	R^2	Y^3
21 0CT 89	UNIRRIGATED	Y= 83.47 + 0.36 (G) - 2.42 (C) + 0.16 (H)	0.60	*
30 OCT 89	IRRIGATED	Y= 145.20 - 0.52 (G) - 2.62 (C) + 0.23 (H)	0.44	
	UNIRRIGATED	Y= 65.47 + 0.12 (G) - 0.21 (C) - 0.07 (H)	0.19	
10 NOV 89	IRRIGATED	Y= 44.60 + 0.11 (G) + 0.94 (C) - 0.2 (H)	0.11	
	UNIRRIGATED	Y= 26.79 + 0.47 (G) - 0.84 (C) - 0.08 (H)	0.56	*
21 NOV 89	IRRIGATED	Y= 49.35 + 0.40 (G) - 0.91 (C) - 0.27 (H)	0.29	
	UNIRRIGATED	Y= 97.07 - 0.052 (G) - 2.21 (C) - 0.20 (H)	0.56	*
30 NOV 89	IRRIGATED	Y= 73.36 + 0.35 (G) - 1.25 (C) - 0.16 (H)	0.27	
	UNIRRIGATED	Y= 132.22 + 0.02 (G) - 3.27 (C) - 0.17 (H)	0.69	*
11 DEC 89	IRRIGATED	Y= 126.91 - 0.21 (G) - 1.06 (C) + 0.16 (H)	0.18	
	UNIRRIGATED	Y= 122.28 - 0.09 (G) - 1.66 (C) - 0.15 (H)	0.56	*
20 DEC 89	IRRIGATED	Y= 136.47 - 0.16 (G) - 2.58 (C) - 0.09 (H)	0.80	**
	UNIRRIGATED	Y= 123.65 - 0.16 (G) - 1.34 (C) - 0.04 (H)	0.53	

G = % Germination

C = Conductivity reading ($\mu S\ g^{-1}$ seed)

H = % Hollow Heart

Y^3 = level of significance for regression equation

* = Significant at 5% level

** = Significant at 1% level

Table I.15. Predictive equation for field emergence as obtained from the different sowing dates in irrigated and unirrigated sowing conditions in cv. SSF.

SOWING DATE	CONDITION	PREDICTIVE EQUATION DERIVED	R^2
21 0CT 89	UNIRRIGATED	Y= 159 - 0.62 (G) - 1.53 (C) + 2.03 (H)	0.65
30 OCT 89	IRRIGATED	Y= 143.45 - 0.72 (G) - 1.94 (C) + 0.97 (H)	0.77
	UNIRRIGATED	Y= 40.72 + 0.38 (G) - 0.05 (C) + 0.01 (H)	0.16
10 NOV 89	IRRIGATED	Y= 94.40 - 0.14 (G) - 1.17 (C) + 2.68 (H)	0.72
	UNIRRIGATED	Y= 4.00 + 0.46 (G) + 0.89 (C) - 1.88 (H)	0.40
21 NOV 89	IRRIGATED	Y= 106.71 - 0.26 (G) - 1.38 (C) + 2.05 (H)	0.71
	UNIRRIGATED	Y= 98.60 - 0.29 (G) - 1.28 (C) - 0.22 (H)	0.81
30 NOV 89	IRRIGATED	Y= 99.25 + 0.04 (G) - 1.59 (C) + 2.34 (H)	0.78
	UNIRRIGATED	Y= 153.80 - 0.46 (G) - 2.29 (C) + 1.26 (H)	0.55
11 DEC 89	IRRIGATED	Y= 78.03 + 0.34 (G) - 1.35 (C) + 1.52 (H)	0.87
	UNIRRIGATED	Y= 14.95 + 0.74 (G) - 0.26 (C) - 0.37 (H)	0.51
20 DEC 89	IRRIGATED	Y= 129.50 - 0.24 (G) - 1.80 (C) + 0.45 (H)	0.80
	UNIRRIGATED	Y= 65.89 + 0.26 (G) - 0.42 (C) - 0.14 (H)	0.50

G = % Germination

C = Conductivity reading ($\mu S\ g^{-1}$ seed)

H = % Hollow Heart

* = Significant at 5% level

** = Significant at 1% level

CHAPTER FIVE

DISCUSSION

Under field conditions, rapidity of germination in garden peas is helped by close contact with reasonably fine moist soil (Gane, 1985). Rapidity of establishment is helped by a friable tilth, while uninterrupted and unimpaired growth demands good soil structure, freedom from capping and over consolidation, and a sufficiently fissured profile to allow a free root run. Good drainage is essential for adequate oxygen supply to the roots (Crawford, 1977), without which nodulation is impaired. Poor cultivation limits the availability of the requirements for germination in the field. Germination can fail if the requirements for water, oxygen, and a suitable temperature are not provided (Matthews and Powell, 1986).

One of the limitations for the requirements of germination can be attributed to dry spells resulting in low soil moisture content (Chopra and Chaudhary, 1981; Roberts, 1984), or conversely heavy rain and/or poor drainage resulting in excessive soil moisture content (Fausey and McDonald, 1985). A low soil moisture content means that moisture is unavailable to the seed (Gane, 1985) while excessive moisture in the soil produces a too rapid uptake of water causing cell disruption and reduces the availability of oxygen (Crawford, 1977) needed for germination. Such a situation, where there is limited or excessive moisture in the soil is a form of stress condition.

The 1988 natural environment did not appear to cause any stress on the pea seeds, because good rainfall and favourable temperatures provided the requirements for good germination and establishment. In contrast, sowings during 1989 were significantly affected by the seed bed environment, and in particular by water availability. Low rainfall during November or conversely excessive water under irrigation at the 30 October and 20 December sowings caused significant reductions in field emergence (Table I.9). The November findings follow the results obtained by Roberts (1984) with weeds and vegetable species, and Chopra and Chaudhary (1981) with chickpea, that low moisture content can reduce the rate of germination. On the other hand, results at the 30 October and 20 December sowings were similar to the work of Fausey and McDonald (1985), who found that increasing soil moisture content to the point of flooding reduced the emergence of maize.

Seed quality differences occurred between seed lots for germination, conductivity and hollow heart. These differences are the basis for determining vigour of pea seeds. Seed lots with high laboratory germination, and low conductivity and hollow heart are of higher vigour. However, there were seed lots with high germination, but high conductivity and hollow heart which are considered as low vigour seed lots. Vigour differences are manifested by the conductivity test and hollow heart test but not the germination test (Heydecker, 1969; Perry, 1980) because they are more strongly related to field emergence. These seed lots tend to have lower field emergence compared to seed lots with low conductivity in both favourable and unfavourable conditions. Differences of such seed quality characters are a reflection of vigour differences (Perry, 1980; Roberts, 1986). These seed lots had lower field emergence which made the range wider and the median lower. Complicating relationships still further though is that seed lots with high germination, high conductivity and low hollow heart, or high germination, low conductivity and high hollow heart were detected (Appendices I.1 and I.3), and such seed lots are also regarded as being of low vigour (Hampton, 1984).

In the 1988 sowings, germination was as effective in predicting field emergence as expected field emergence and conductivity for the all seed lots group, as conductivity for cv. Pania and as EFE for cv. SSF. The relationship between germination and field emergence was strengthened by the inclusion of low germinating seed lots. Scott and Close (1976) reported that the relationship between germination and field emergence was high when low germinating seed lots were included in the analysis, but the relationship decreased as the low germinating seed lots were discarded from the analysis. Although the correlation coefficient was significant it was of low value. This also occurred in 1988, and for example in cv. Pania, the removal of the three low germinating lots reduced the correlation from 0.81^{**} to 0.25 (Table I.5 and Figure I.1) for the November sowing, and similarly for the December sowing. The use of many seed lots in correlation analysis would increase the probability of getting a significant result, but when the coefficient of determination (R^2) is low this may be spurious.

In 1988, the relationship between germination and field emergence for all seed lots was strong (Figure I.1) because of favourable sowing conditions. Under such favourable conditions, the germination test can predict the field emergence of garden peas with some degree of precision (Perry, 1980; Duczmal and Minicka, 1989; Ladonne, 1989).

However, for the 1989 sowings, only one germination result, for cv. SSF, showed a significant relationship with field emergence (11 December, Table I.12) presumably because all the seed lots used had germinations of 85% or better (Table I.9), and the environment exerted little stress. More frequently, field sowing of garden peas gave varied stands even when high laboratory germinating seed lots were used (Table I.9). Sowings made on 30 October and 20 December (irrigated) and 21 November (unirrigated) were strongly under stress (Table I.8), and produced low field emergence even where the germination of seed lots was high. Germination alone could not predict field emergence under these conditions and this illustrates the importance of vigour tests (Hampton and Coolbear, 1990). Low germination seed lots should not be included in vigour studies because they are already considered unfit for planting purposes and may mask other quality parameters.

For the 1988 sowings, the conductivity test was generally a better predictor of field emergence than germination or EFE, when low germination seed lots were discarded from the evaluation. An exception was for cv. SSF where EFE gave a better prediction than conductivity (Table I.5).

Among the laboratory tests, the conductivity test was a better predictor of field emergence both under excess moisture (20 December 1989 irrigated sowing) and low moisture (21 and 30 November 1989 unirrigated sowings) (Table I.10). When seed lots with low germination were not included in the analysis, conductivity still gave significant correlations, which implies that under all conditions conductivity is better able to reflect field emergence than germination. The conductivity test is well established for garden peas (Matthews and Bradnock, 1968; Scott and Close, 1976; Hampton and Scott, 1982) and an increase in conductivity tends to decrease field emergence (Perry, 1970; Carver and Matthews, 1975; Hampton and Scott, 1982; Ladonne, 1989).

However, in their study, Duczmal and Minicka (1989) found that the conductivity test was the least useful method of field emergence prediction. Their findings could have been due to favourable (i.e. non stress) conditions during the time of sowing, as observed in this study under November irrigated sowings (Table I.10) where the conductivity test was not significantly correlated with field emergence. As stress

conditions occurred in the field before, during and after sowing, field emergence became more strongly related to conductivity results (21 November unirrigated and 20 December irrigated sowings) a result also reported by Perry (1980) and Ladonne (1989).

The results strongly suggest that the conductivity test alone can be sufficient in the prediction of field emergence in garden peas, being more applicable than EFE under all conditions. However, the conductivity results can not be used in the determination of the number or weight of seeds to be sown. The EFE can be used in the prediction of field emergence, and is therefore a very useful tool for the estimation of seeds to be sown to achieve a specified population.

In the 1989 sowings, hollow heart was significantly related to field emergence at some sowing dates (Table I.10). Better relationships were obtained under moisture stress conditions, which implies that hollow heart incidence can be an important character to consider in sowing peas under stress conditions. As the conditions became more and more stressful, the higher was the relationship of field emergence to hollow heart. However, hollow heart does not impair the planting value of the seed under all sowing conditions. Under non-stress conditions, hollow heart was poorly related to field emergence (Tables I.5 and I.10) and even had a significant positive correlation at the 10 November irrigated sowing in cv. SSF (Table I.12). This could be attributed to favourable conditions during sowing where seeds with hollow heart develop normally (Gane *et al.*, 1984) especially in the absence of microbial infection which causes rotting (Heydecker and Feast, 1969). Hollow heart might not be a factor for cv. SSF but results may be related to other factors, i.e. favourable environment and absence of microbial infection.

Combined factors used for predicting field emergence have been considered to have an advantage over any single quality factor analysis, due to the measurement of the effects of the several factors (Scott and Close, 1976; Hampton and Scott, 1982). In this study, for some groups and especially cv. SSF (Tables I.5 and I.12), the relationship between EFE and field emergence was significant (Figures I.2 and I.7); however the present results do not always agree with earlier literature, in that EFE and conductivity were comparable predictors for the all seed lots group in the 1988 sowings (Table I.5) and in 1989 sowings (Table I.10). Although EFE was a better

predictor in cv. SSF compared to germination (Table I.10) and hollow heart (Table I.5), it could not predict field emergence under all sowing conditions (Table I.10) and for all cultivars.

The very poor relationship between field emergence and hollow heart in 1988 and with germination in 1989 made EFE a lower predictor of field emergence than the conductivity test. The removal of hollow heart effects from the EFE equation (Table I.5) increased the relationship between EFE and field emergence in the 1988 sowings. This result would suggest that hollow heart is not a valid component of EFE under favourable conditions.

However in 1989, removing hollow heart reduced the relationship between EFE and field emergence (Table I.10) in unirrigated sowings. The 1989 results would suggest that hollow heart is an important component in EFE under stress conditions. These results agree with the findings of Gane *et al.,* (1984) that in adverse conditions many seedlings affected by hollow heart fail to survive, although in good conditions they develop normally. This therefore suggests that EFE can not be used as a predictor of field emergence for garden peas under all sowing conditions. However, EFE should be used in the prediction of field emergence under stress conditions, such as low soil moisture or excessive moisture conditions, to allow for the influence of hollow heart. But, there is a need to develop an EFE equation applicable in a greater range of environments.

When data obtained in this study were used to derive the best multiple regression equation for the prediction of field emergence, significant results were obtained in both 1988 and 1989 sowings. However, no results resembled the EFE equation currently used. Furthermore, the constant terms were not the same in all the equations obtained, especially in sowings under stress conditions. It is apparent that the equation derived from the excessive water stress condition had a higher constant term than the equation from the low moisture stress condition, i.e. 20 December irrigated and 21 November unirrigated sowings (Table I.13).

Although the results support the concept that EFE can predict field emergence of garden peas, its use should be limited to sowing conditions likely to be stressful (i.e. low soil moisture or excessive moisture conditions) for better prediction of field

emergence and the determination of the number of seeds to be sown. Under favourable conditions, the EFE could be modified to exclude the hollow heart term, in order to have a more reliable prediction of field emergence. The EFE currently in use can predict the field emergence of cv. SSF with high reliability, but should be modified when other cultivars are used. This requires further study.

In order to improve the EFE, it could be derived by having a separate equation for a certain stress condition, i.e. excessive water stress and low moisture stress conditions. The response of seeds to these environmental conditions are different, and will affect the accuracy of the equation. Furthermore, data from vigour tests such as conductivity should be given more emphasis than the hollow heart and germination results.

Based on these conclusions, it is suggested that further studies should be conducted to include other features that affect field emergence for possible inclusion in the EFE equation. It is also recommended that studies should be conducted at different sites and using recently released cultivars to develop and improve the accuracy of EFE in the different garden pea growing regions. From this work it may then be possible to develop an EFE for garden peas which could be reliable in all pea growing areas of New Zealand.

The influence of moisture in the field and how it affects temperature in the soil and surrounding areas should also be taken into consideration in further studies.

SECTION TWO

SEED VIGOUR ASSOCIATED WITH MOTHER PLANT ENVIRONMENT AND METHOD OF HARVESTING IN GARDEN PEAS (*Pisum sativum* L.)

CHAPTER ONE

INTRODUCTION

Most agronomic studies on garden peas have been concerned with increased seed yield. Few studies have been associated with seed vigour, especially the effects of those factors acting on the mother plant, for instance field studies on garden peas, especially on population density have been mainly concerned with seed yield rather than vigour.

Various environmental stresses may occur following different crop husbandry in peas. Varying population densities may influence the growth of the mother plant and eventual development of high vigour seeds. Glasshouse and laboratory studies have shown that environment within the canopy is detrimental to the development of high vigour seed (Perry, 1980). This has been explained as being due to the increased temperature and relative humidity associated within the canopy of the crop during the developmental period of the seeds which enhance the development of hollow heart (Halligan, 1986). Time of sowing will influence the establishment of the pea crop, growth and development of the seeds and also the environment experienced during seed development. Timing and method of harvest can result in seed deterioration, especially under wet conditions. The effects of these factors on the production of quality garden pea seeds are not well understood.

This study was therefore conducted with the following main objectives:

1. To determine the factors affecting seed vigour during the growth of garden peas.
2. To determine the effects of time and methods of harvest on the seed quality of garden peas.

In order to achieve the main objectives, experiments were conducted with the following specific objectives:

1. To determine the influence of population density, row width and time of sowing on pea seed vigour.
2. To determine the influence of pod position, as influenced by population density, row width and time of sowing on the vigour of pea seeds.

3. To determine the combined effects of (i) population density, pod position and harvest time, (ii) row width, pod position and harvest time and (iii) time of sowing, pod position and harvest time, on garden pea seed vigour.
4. To determine the influence of method and time of harvesting on the vigour of garden peas.
5. To determine the temperature and relative humidity within the crop canopy at various population densities during seed development and evaluate their relationship to seed vigour in garden peas.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. IMPORTANCE OF PEAS

In New Zealand, peas are mainly grown as an export crop which have a good reputation for quality, because of a generally favourable climate at harvest, and high technology inputs in growing and processing (White, 1987). About 70% of the threshed peas and 33% of quick-frozen peas are exported; the most valuable produce are dried peas (marrowfat, white, blue, partridge) going to a wide range of markets including Australia, Singapore, India, Britain and Japan, while most seed peas are garden cultivars sold to Australia (White, 1987).

Farmers grow peas for two main reasons:

1. For cash return: In New Zealand the current gross margin for peas ($608.00 ha^{-1}) is less than for first year milling wheat and autumn sown utility wheat, but higher than for second year milling wheat and utility wheat (Alexander, 1990). Peas have a gross margin which is very much higher than for malting barley, feed barley, oil seed rape and oats (Alexander, 1990). High yield is an essential ingredient for high profitability, as production costs for high yield are little more than those incurred in producing an average to low yield (White, 1987).
2. As a break crop for disease control and soil fertility improvement in a cereal rotation: The pea crop is valuable for providing a break between cereals to assist in the control of diseases such as take-all *Gaeumannomyces graminis var. triticus* (Blair, 1952). This role is now assuming an even greater

significance in Canterbury, where the recent decline in the growing of white clover seed has followed an earlier decline in the area of grazed pasture in cropping rotations (White, 1987).

Peas are considered to benefit grass or cereal in rotation cropping (White, 1987). Nitrogen fixation by peas has been estimated to be between 17 and 83 kg ha^{-1}, although much of the nitrogen is removed in the mature seed (nitrogen harvest index of 0.84; Askin *et al.*, 1985). Higher yields of ryegrass or wheat sown after peas have therefore been generally associated with maintenance of soil nitrogen levels by peas rather than any increased nitrogen content of the soil (Askin *et al.*, 1985).

2.2. SEED DEVELOPMENT AND MATURATION

The environment plays a vital role in the development of the seed from the flower to seed maturity, and it is therefore important that the characteristic changes occurring in the developing seed are well understood in a normally growing legume crop (Delouche, 1980).

The reproductive developmental stages of pea have been closely studied in U.K. (Gane *et al.*, 1984) (Table II.A and Figure II.A). Flower buds may be produced on quick-growing cultivars as early as node 5-6 or, in slow-growing or indeterminate cultivars as late as nodes 15-16. The first stage, R_1, occurs when the largest flower buds in the terminal shoot measure approximately 6 mm in length and the enclosing leaves must be folded back to find them. The buds are held in the growing point until they are quite large, and cannot easily be seen until the peduncle or flower stalk elongates and moves them out (R_2).

Table II.A. Description of the reproductive stages in garden peas *Pisum sativum* L. (Adapted from Gane *et al.*, 1984).

CODE	STAGE	DESCRIPTION
R_1	Detectable buds	Small flower buds (approx. 6mm) enclosed in terminal shoot.
R_2	Visible buds	Flower buds visible outside terminal shoot
R_3	1st open flower	Open flower present on 50% of plants.
R_4	Full flower	Open flowers present on all plants.
R_5	Flat pod	Flat pods, approx. 5 cm long on the first podding truss.
R_6	Pod swell	Pods swollen, but with small immature seeds, on the first podding truss.
R_7	Pod fill	Pods containing green seeds which fill the pod cavity on the first podding truss.
R_8	Green wrinkled pod	Outer surface of pods wrinkled on the first podding truss, seed becoming starchy.
R_9	Yellow wrinkled pod	Pods yellow and wrinkled on the first podding truss, seed starchy.
R_{10}	Dry seed	Pods parchment and seed within dry.

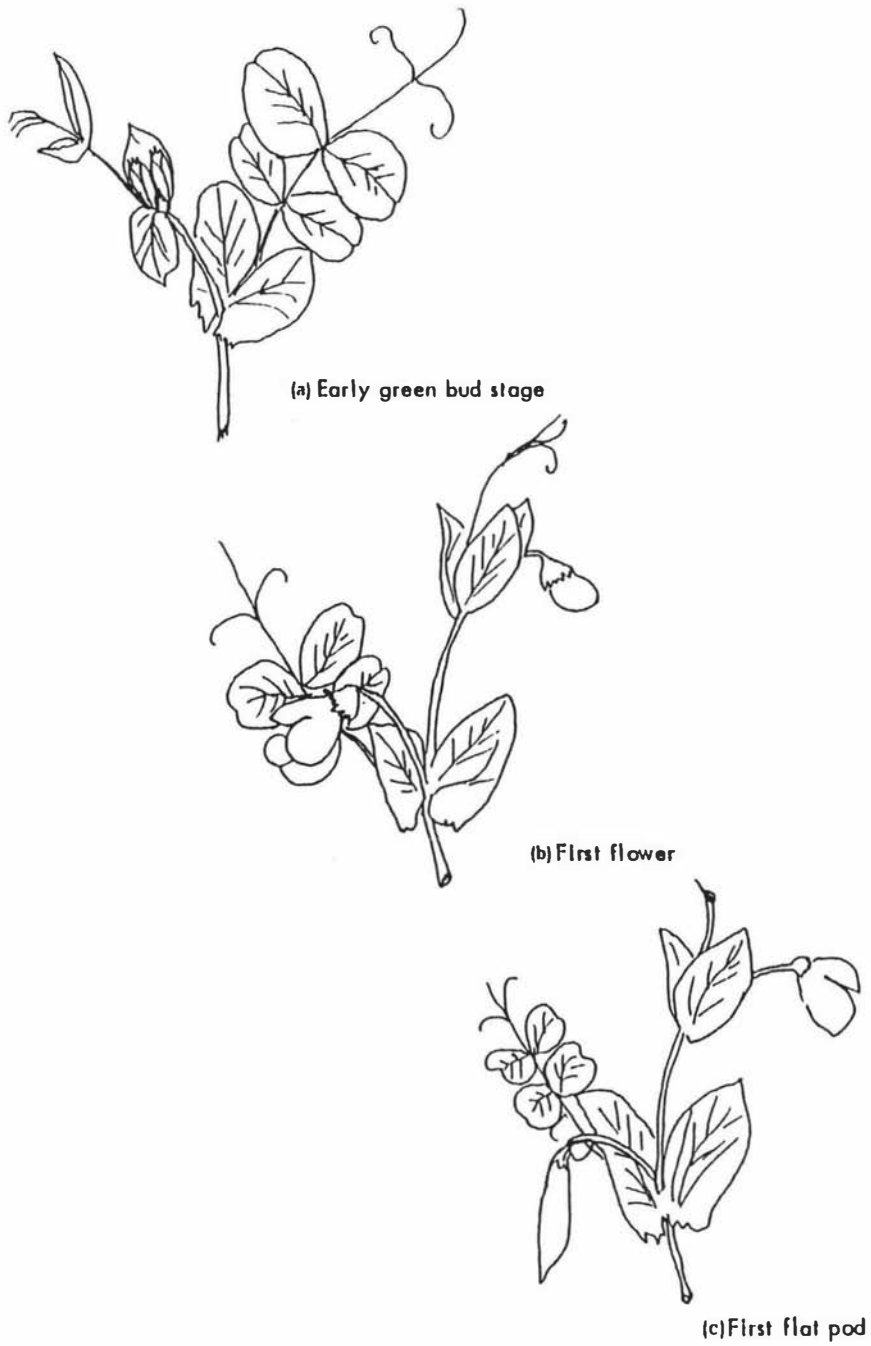


Figure II.A. Reproductive stages in garden peas *Pisum sativum* L. (Adapted from Gane *et al.*, 1984).

One or more flowers may be formed on each truss depending upon cultivar and early growth conditions. A fully opened flower on 50% of plants is taken to be stage R_3, while full flower (R_4) is when all plants have open flowers present. By this time some plants will have some flowers which have set and the very small immature pod can be detected. In the next three stages, R_5-R_7, the development of the pods and seeds can be followed, although the R_6 pod swell stage, where the pods have swollen into their final round cross-section, but the seeds are still small and immature, is less obvious in some cultivars where the pod swells as the seeds develop in size. At the green wrinkled pod stage (R_8) the seed is becoming starchy and has passed a suitable stage for freezing or canning. The pods become increasingly yellow and pitted in appearance (R_9) and the seed increasingly starchy and dry, passing through a 'rubbery' stage at about 34-36% moisture content, to a tougher dry stage at about 20-24% moisture content, by which time the pods are dry and brown (R_{10}).

The growth of the pea fruit during the first week after anthesis is mainly due to the rapid elongation and enlargement of the pod wall which possesses a relative growth rate greater than that of the seed. This is followed by a sharp decline in the relative growth rate of the pod wall and an increase in the relative growth rate of the seeds. From two weeks after anthesis until maturation of the fruit two or three weeks later, further increases in weight of the fruit are mainly the result of seed growth. The growth of the pod wall follows a sigmoid curve, while the growth of the seed follows a double sigmoid curve where the two periods of rapid growth are separated by a short lag phase with a slower growth rate (Eeuwens and Schwabe, 1975).

Seed development in pea consists of three phases marked by variation in the moisture status of the seed (Le Deunff and Rachidian, 1988). The first phase (P1 growth phase) begins with the development of the embryonic axis and cellular structures which ultimately accumulate reserve material (Le Deunff and Rachidian, 1988). Embryo development starts with the early divisions of the zygote which form into apical and basal cells (Bewley and Black, 1986). The basal cell divides transversely to form two suspensor cells and the apical cell divides to form the middle and terminal cells. The suspensor cells divide to become four elongated multinucleate cells while the middle cells undergo free nuclear division, and the embryonic cells commence cell division (Marinos, 1970). The suspensor elongates and then embryo growth occurs into the embryo sac, to eventually utilise the reserves and to occlude the endosperm and the suspensor/middle cell. The mature embryo occupies the whole of the inner region of the seed and is surrounded by the testa (Bewley and Black, 1986). This phase, lasting up to 20 days after anthesis (Flinn and Pate, 1968), ceases when the cell number is fixed in various compartments (Smith, 1973); during this phase the moisture content is high and stable at 85% (Le Deunff and Rachidian, 1988; Le Deunff, 1989).

The second phase (P2 or seed filling) (20-35 days after anthesis, Flinn and Pate, 1968; Pate and Flinn, 1977) is characterised by an enlargement of cotyledonary cells due to the accumulation of macromolecules, including massive storage of proteins in the embryo (Millerd *et al.*, 1978).

A major source of carbon for the developing seed is photosynthesis by the pod, which recycles the respiratory carbon released by the seed into the inner cavity; the pod uses negligible quantities of external CO_2 (Bewley and Black, 1982). An equally important contribution to the carbon status of the seed is provided by photosynthesis of the leaflets of the subtending leaf (i.e. at the same node) (Pate *et al.*, 1980). During early stages of development the seed obtains its nutrients from the endosperm surrounding the embryo in the embryo sac (Bewley and Black, 1986). But the assimilates required later for reserve deposition in the cotyledons are translocated from the mother plant. This is facilitated by a vascular strand which branches from the vascular tissue running through the pod and then passes through the funiculus, into the integuments (incipient seed coat). Passage of

assimilates through the funiculus, and from the seed coat into the cotyledons, is by diffusion as there is no direct vascular connection between parent plant and developing seed, and is aided by the presence of transfer cells. These are specialised cells with ingrowths of the cell wall to increase the surface area for the absorption or export of assimilates (Bewley and Black, 1986).

Sucrose, which is a translocated product of photosynthesis by the stipule and leaf below the pods, is deposited in the cells of the cotyledons as starch grain (Bewley and Black, 1986). Single starch grains becomes visible in the stroma of some chloroplasts within 2-3 weeks after anthesis. The seed dry weight is 35-45% starch.

The formation of protein bodies occurs early during development. Around 12 days after anthesis, the cotyledon cells contain one or two large vacuoles, which occupy the majority of the volume of cell (Bewley and Black, 1986). By day 15 many of the vacuoles are considerably smaller and more spherical in shape, and by day 20 these have become filled with storage protein and form the distinct and discrete protein bodies. The pattern of development, then, is gradual fragmentation over a few days of a highly convoluted central vacuole, and this leads to the formation of the smaller protein bodies. Although deposition of proteins is within the vacuoles, synthesis occurs on the rough endoplasmic reticulum, and molecules pass through the lumen of the endoplasmic reticulum to golgi for packing into vesicles and thus to the storage organelles. The major reserve proteins of the pea are the globulins, legumin and vicilin, which constitute about 70% of the total stored protein in the mature seed (Bewley and Black, 1986).

Sap arrival in the testa and accumulation in the apoplast occurs during P1 and the onset of P2, but during P2 it decreases slowly until physiological maturity, and rapidly thereafter due to the limitations of nutrient source (Flinn and Pate, 1968; Le Deunff and Rachidian, 1988). The time taken to complete development does not appear to be essential in the production of viable seed but is the time required to increase the seed mass, especially through the deposition of reserves (Bewley and Black, 1986). Seed filling is linked to a slight decrease in moisture content (Adams and Rinne, 1980; Bewley, 1979; Le Deunff, 1989) and is terminated

when seed moisture content is close to 55% (relative to fresh weight) and the seed then attains physiological maturity (TeKrony *et al.*, 1979). Some days after physiological maturity germination is complete (up to 100%) (Le Deunff and Rachidian, 1988). When slow artificial drying of immature seeds occurs several days after the onset of phase P2, up to 100% germination and normal seedling growth is achieved (Le Deunff and Rachidian, 1988; Le Deunff, 1989). Seedling growth from immature seeds during P2 is low, but slowly increases until physiological maturity.

Physiological maturity is attained when disruption of the vascular connection between the pod and the mother plant occurs (Le Deunff and Rachidian, 1988). Seed development can be divided into two phases in relation to the ability to withstand air drying: initially there is a desiccation intolerant phase, when drying is fatal as observed in P2, followed by a tolerant phase (acquired during P3), when subsequent rehydration leads to germination (Bewley and Black, 1986). The changes that occur in the seed during the change from intolerance to tolerance of desiccation are completely unknown (Bewley and Black, 1986).

Physiological maturity is followed by a P3 phase (maturation phase 35 days after anthesis until maturity Flinn and Pate, 1968) during which severe dehydration on the mother plant occurs (Le Deunff and Rachidian, 1988; Le Deunff, 1989). This maturation brings the moisture content of the seed down to 20-18% (Le Deunff, 1989). The seed can germinate later upon rehydration and its axis develops into a normal seedling (Le Deunff and Rachidian, 1988).

Finally, all the fruit parts decline in fresh weight and the pod wall also loses considerable amounts of dry matter, with the result that more than three quarters of the total dry weight of the mature fruit is the weight of the seeds (Eeuwens and Schwabe, 1975).

2.3. SPECIALISED SEED PRODUCTION AREAS

Canterbury is the most important province for pea growing in New Zealand, because of its well drained soils and generally settled weather conditions. Low humidity, minimal rainfall, and favourable temperatures reduce the spread of seed

borne diseases as well as the risk associated with inclement weather during the late maturation and harvest periods, while good soils, controlled moisture supply through irrigation and bright sunny weather contribute to stability of production, high yields, and high quality of the seed produced (Delouche, 1980).

Most seeds of the garden pea cultivars produced in New Zealand are sold to Australia (White, 1987) although the volume of export for seed peas in New Zealand has not significantly changed for the last five years. In New Zealand, garden pea seed is produced in both Wairarapa (moist, humid) and Canterbury (hot, dry) provinces, and although there are seasonal variations, vigour is generally greater in seed produced from Canterbury, because the crops are not subjected to the same environmental stresses (Hampton, 1990). This could be the reason that in other countries like the U.S.A., it is always recommended that pea seeds be procured from reliable sources, usually from seed producing areas in the semi-arid west and on the Pacific coast where better seed quality is produced and diseases are less of a problem than elsewhere (Ware and McCollum, 1980).

The advantages of producing seed in areas specially adapted to seed production are: good seed set, yield and recovery at harvest is high and relatively stable; seed germination and seed vigour are consistently high; and seed borne diseases can often be avoided or are more easily controlled (Delouche, 1980).

2.4. SOIL CONDITIONS AND CROP GROWTH

Deep, free-working loams are the soils best for pea production, with sufficient organic matter to ensure adequate aeration and drainage by retaining an open texture, at least until plants are well established (Gane *et al.*, 1984; Jackson, 1985). Peas also need a relatively loose and uncompacted seed bed to germinate and start their early growth vigorously (Freeman, 1987). Poor soil structure, on the other hand, results in a low populations of plants which are incapable of reaching their potential for development and which are susceptible to root rots (Gane, 1985), both of which depress yield (Gane *et al.*, 1984).

Hebblethwaite and McGowan (1980) demonstrated that early growth of peas in compact soil is reduced by about 50%, so that at flowering, peas in the compacted plots had smaller leaves and stems and fewer flowers. An important additional comparison in these trials was a control treatment where plants grown in non-compact soil were thinned to the same number and spatial distribution as the compact treatment. Plants grown in non-compact soil had the capacity to compensate for the low density by tillering and branching and produced more dry matter and green area per plant.

Compaction imposed after sowing by tractor wheeling can reduce yield of vining peas by up to 70% (Gane *et al.,* 1984). The severity of these yield reductions appears to be mediated by rain during the emergence phase (Dawkins and McGowan, 1985). The yield component most often reduced by soil compaction is pods per plant, but compaction also had a profound effect on root development and the extent of soil-water extraction (Gane, 1985). The general overall effect of soil compaction can be summarized as the production of smaller plants with a shallower and less-branched root system. Peas appear very sensitive to physical changes of the soil and good agronomic practices are essential to ensure consistently high yields from pea crops (Dawkins and McGowan, 1985). However, no data were presented on these effects on the subsequent vigour of the seeds produced. From the fact that yield and vegetative growth is hampered, it could be inferred that seed vigour might also be affected, but experiments need to be conducted to determine this.

2.5. SOIL FERTILITY

At present, crop fertiliser requirements tend to be managed for optimising seed yield, rather than seed quality. It is also generally agreed that when soil fertility becomes limiting, plants respond by producing less seed rather than reducing seed quality *per se* (Delouche, 1980). However, this assumption might be misleading and there is a need to consider nutrient requirements for seed quality rather than just quantity (Hampton, 1990). Recent studies have shown that nutrition of the mother plant can affect the quality of the seed produced.

Browning and George (1981) found that two treatments; 450 mg N, 255 mg P and 450 mg N, 422 mg P per plant, produced pea seeds with a higher incidence of hollow heart compared to lower level of phosphorous (88 mg P per plant). High nitrogen nutrition levels (800 and 1050 mg N per plant) produced an increase in the number of plants with bleached seeds. Bleached seeds or ones with hollow heart produced high soak-water conductivity readings and germinated poorly in the field (Browning and George, 1981). Hadavizadeh and George (1989) showed that increasing the nitrogen nutrition supply increased seed dry weight but an increase in seed yield and seed vigour was only achieved by the interaction of high nitrogen (1000 mg per plant) with medium phosphorus supply (500 mg per plant).

Leggatt (1948) demonstrated that pea seed harvested from a boron deficient area produced abnormal seedlings when planted in sand. The addition of a trace of borax to the sand corrected the condition. Soybean seed produced in areas with good molybdenum (Mo) status can have a Mo concentration sufficiently high to obviate the need for seed treatment with sodium molybdate for planting in Mo deficient soils (Harris *et al.*, 1965).

Cox and Reid (1964) identified two types of concealed damage in peanut kernels associated with boron and calcium concentration in the kernel: discoloration of the cotyledons associated with boron deficiency; and the discoloration of the plumule associated with calcium deficiency. Both types of damage were corrected by application of the specific elements. The application of 561-785 kg ha^{-1} of gypsum to large seeded peanut (Virginia type) at early blooming stage is a standard practice (Woodroof, 1973). Yield is increased and the incidence of 'pops' (empty pods) and unsound kernels is reduced. Woodroof (1973) identified additional seedling abnormalities in peanuts associated with low calcium level: watery hypocotyl and physiological root breakdown. Application of gypsum corrected both types of abnormalities.

2.6. SEED SIZE AS INFLUENCED BY FERTILITY AND MOISTURE

Levels of fertility and moisture supply influence seed size and seed weight. There is an association between seed size and/or seed weight and germinability and vigour in most seed species (Austin, 1972; Heydecker, 1972).

Seed size and quality relationships have been studied in soybeans. Smith and Camper (1975) reported that medium and large size seed classes from a single lot produced higher yields than unsized seeds from the same seed lot. However, seed size is not always conserved in soybeans (Burris, 1973). Eua-Umpon (1991) found that thousand seed weight was negatively and highly significantly correlated with field emergence, showing that for the lots tested, small seeded soybeans gave better field emergence than large seeded soybeans. This could have been a result of greater physical and physiological damage in seeds with higher weight (bigger size) as observed by Wang (1989), in *Trifolium pratense* L., where a seed lot with the lowest seed weight had the highest vigour and a lot with the highest weight had the highest amount of mechanically damaged seed, and was thus of low vigour .

2.7. PLANT POPULATION AND PLANT DISTANCES

One of the basic requirements for successfully growing a crop is to know how much seed to sow (Gane *et al.,* 1984; Gane, 1985; Wilson, 1987). Plant population, or plant density, affects not only yield potential, but the growth characteristics of the crop (Gane, 1985). As plant density is raised, yield increases quite rapidly at first and then moves slowly, until a point is reached where no further yield increase takes place (Stoker, 1975; Gane *et al.,* 1984; Gane, 1985). When plant population increases beyond this, yields gradually fall (Gane *et al.,* 1984).

The recommended rate of sowing varies in the different garden pea growing areas of the world. Garden peas are grown in rows for ease of cultivation, weed control and harvest (Gane, 1985). In New Zealand, Stoker (1975) mentioned that producers grow garden peas at 80-100 plants m^{-2} or an average of 94 plants m^{-2}

(White and Anderson, 1974) which is equivalent to 250-300 kg ha^{-1} (Hampton and Scott, 1982). In the U.K., plant population of vining peas is usually 120 plants m^{-2} (Gane *et al.*, 1984), but maximum economic yield is reached at 90 plants m^{-2} when combined with early sowing (February-March). Combining peas reach maximum yield at around 95-100 plants m^{-2}, and maximum economic yield at around 65-100 plants m^{-2} for marrowfat peas sown during February or March (Gane *et al.*, 1984). In Russia peas are usually sown to produce 80-90 plants m^{-2} but this is increased to 120 plants m^{-2} in isolated areas (Makasheva, 1973). However, with the introduction of garden peas which are semi-leafless or leafless types with some degree of determinate growth, higher densities are used, otherwise the advantages of their superior standing ability will be lost (Logan, 1983; Gane *et al.*, 1984).

White and Anderson (1974) studied garden peas (cv. 'Victory Freezer') with populations of 36-371 plants m^{-2} and found the following:

1. Yield increased as population density increased and followed an asymptotic pattern up to a population density of 181 plants m^{-2} but high yield was maintained even at the narrowest spacing of 10 cm x 2.5 cm (371 plants m^{-2}).
2. Greater response of peas was observed to a change of row width than changed intra-row spacing, and yields were greater where the spatial arrangement approached "on the square" planting.
3. Maturity of peas was delayed by three days at lower populations because longer vines which lodged readily were produced.
4. Dense populations, with shorter vines, were self supporting and remained erect, producing a more uniform canopy and leading to higher temperature - important in uniform pod and seed maturity.

Stoker (1975) and Anderson and White (1974) supported these results in their studies under irrigated conditions. On the other hand, Meadley and Milbourn (1970) working on cv. Dark Skinned Perfection sown at 43, 97 and 172 seeds m^{-2} obtained contrasting results. They found that yield of peas did not differ between the population densities studied. At 172 plants m^{-2}, 34% of the pods were wasted due to abscission. The differences in the result of White and Anderson (1974) from the work of Meadley and Milbourn (1970) no doubt arose because trials

were conducted using different cultivars and in different countries. Thus soil type, fertility and moisture which are very important in the growth of garden peas and contribute much to yield (Delouche, 1980; Jackson, 1985; Gane, 1985), would have differed.

Effects of row width have been studied widely in garden peas (White and Anderson, 1974; Stoker, 1975; Gane *et al.*, 1984; Gane, 1985). In New Zealand, yields from row widths of 10 and 20 cm did not differ (Anderson and White, 1974). In the U.K., a 40 cm row width yielded 20% more than a 60 cm row width, and a 20 cm row width yielded 24% more than the 40 cm row for vining peas. The reduction from 60 cm to 20 cm row width in combining peas give a yield increase of 39% but there was no advantage gained by reducing the row width further (Gane, 1985). Peas grown in narrower rows have the advantage of ease of harvesting, and there is improved weed suppression by the crop canopy.

With the introduction of new cultivars with different characteristics from cultivars previously used, there is a need to open up research on the appropriate population density coupled with factors important to the growth, yield and quality of garden peas.

2.8. TIME OF SOWING

In the U.K., peas are sown very early (February), early (March), mid-season (April) and late (May-June). Early sowing results in early harvesting which in turn helps even out seasonal labour demand (Gane *et al.*, 1984). Furthermore, early sowing produces higher quality yield because of better weather, and less pest damage than late sown peas (Gane *et al.*, 1984; Gane, 1985). For each week's delay in sowing in the U.K., the yield of combining peas falls by 125 kg ha^{-1} (Gane *et al.*, 1984).

In New Zealand sowings are done no earlier than mid October because of problems encountered with early sowing. Cold ground temperature gives rise to poor germination, leaving a weakly established crop which has no chance of a high quality yield at harvest (Freeman, 1987).

2.9. CLIMATE DURING SEED DEVELOPMENT

2.9.1. EFFECTS OF TEMPERATURE

The temperature during seed development and seed ripening can influence the subsequent performance of the seed in various ways (Austin, 1972). In peas, the most striking results are the effects of night and day temperatures on the growth and composition of the seeds, particularly on the sugar content (Robertson *et al.*, 1961). At low temperatures (10°C), the conversion of sugar to starch is much delayed and sugar continues to increase in concentration during growth; at high temperatures (23°C) the sugar entering the seeds is rapidly converted to starch; thus the carbohydrate composition of seeds grown at different temperatures is markedly different. Protein synthesis is also delayed at lower temperatures. Water uptake and rate of drying out of the seeds are also affected (Robertson *et al.*, 1961). These factors influence the drying of the whole seed. At low temperature, peas are sweeter and have a higher sugar content than those grown at higher day temperature.

High temperatures have deleterious effects on the development of pea seeds. Halligan (1986) exposed peas to high temperatures (35°C day / 25°C night) at three stages of development (R_7, R_8 and R_9, respectively). Plants exposed to high temperature at stage R_8 produced seed with the highest incidence of hollow heart and at all stages of development the incidence increased with the length of exposure to the high temperature. Where plants at development stage R_8 were exposed to a range of temperature regimes for five days, over 20% of the seeds had hollow heart when the mean day/night temperature was 25°C. Above a mean temperature of 25°C, the percentage of affected seed increased with increasing day or night temperatures. Over 80% of the seeds had hollow heart symptoms after five days exposure to a daily mean temperature of 32.5°C. The degree of development of hollow heart symptoms within any individual seed was not related to temperature - large sunken areas and fissures were observed on cotyledons from seeds through the whole range of temperatures, as were pinprick size depressions and, under laboratory conditions, seed

germination was not affected. Earlier, Nichols *et al.* (1978) had obtained little effect of temperature and moisture stress on subsequent seed germination, conductivity and hollow heart development in both a cool glasshouse (21°C) and a warm glasshouse (24°C), but the seed moisture content declined more rapidly in a warm glasshouse at 24°C. Although the temperature stress (24°C) was considered severe (Nichols *et al.*, 1978), Halligan (1986) has since shown it was too low to cause hollow heart of pea seeds.

Pumphrey and Ramig (1990) found that maximum daily temperatures below 25.6°C had little influence on pea yield. Temperatures above 25.6°C depressed yield; this adverse effect increased exponentially as the maximum daily temperature increased linearly. The predicted decrease in fresh pea yield ranged from 16 kg ha^{-1} per day degree above 27°C to 67 kg ha^{-1} per day degree above 35°C (Pumphrey and Ramig, 1990). Incidence of frost near flowering or high temperatures during flowering were also found to cause a major reduction of yield of peas in Australia (Ridge and Pye, 1985). However neither group evaluated the effects of temperature on seed quality characters.

2.9.2. EFFECTS OF MOISTURE

Rainfall is undoubtedly the most important climatic factor to be taken into account when considering growing peas (Gane *et al.*, 1984). Heavy and prolonged rain is not required, but showers during flowering are likely to increase yield while rainfall at the end of the flowering period is detrimental because it encourages moribund leaves to stick to young pods and become colonised by *Botrytis* which reduces yield and quality (Gane *et al.*, 1984).

Acute deficiencies in moisture supply resulting from temporary but severe drought can have disastrous effects, especially during the seed development period, because they interrupt seed development and result in light,

shrivelled seed (Delouche, 1980). The pea is very sensitive to moisture stress at both flowering and pod filling but it will also not tolerate waterlogging (Logan, 1983; Gane *et al.,* 1984; Gane, 1985).

Ordinary leafed pea plants have been shown to be extremely susceptible to injury by soil waterlogging (Jackson, 1985). Stomatal closure after 24 h of waterlogging is one of the earliest symptoms and is presumably responsible for slower transpiration and at least some of the loss in dry weight gain suffered by flooded plants, although flooding may also disturb the biochemistry of photosynthesis (Bradford, 1983). Concomitant increases in the concentration of ABA suggest that an accumulation of this hormone may be the cause of stomatal closure.

The foliage of waterlogged plants begins to lose its turgidity after about 6 days which is closely associated with membrane damage that disrupts the osmotic relations on which the retention of water by the leaves depends. The cause of this membrane injury is unknown but phosphorous toxicity may be partly responsible (Jackson, 1985). Leafless peas are more resistant to waterlogging compared with leafed peas (Jackson, 1985).

Irrigation rarely increases yield when applied before the start of flowering and petal fall, because it depresses growth (Salter, 1963). Peas should not be irrigated before flowering unless:

1. The seed bed is very dry and adequate germination would not otherwise occur.
2. Increased haulm length is required on short strawed cultivars to facilitate harvesting.
3. The crop is severely wilted because of drought (Gane *et al.,* 1984).

Irrigation is needed at the commencement of flowering when the peas are most responsive because the root system has ceased to grow, making the plant more vulnerable to water shortage (Gane *et al.,* 1984). Yield increases can be very substantial, up to 50%, because more pods and more peas per pod are produced, and the haulm weight is increased (Gane, 1985). At late flowering or petal fall, irrigation did not increase yield, the lack of

response being due to the occurrence of a slight renewal of root growth (Gane *et al.,* 1984). Irrigating peas at the pod swelling stage increased the yield by up to 20%, due to an increase in the number of peas per pod and mean seed weight.

In New Zealand, irrigation is used in garden pea production for the following reasons (Freeman, 1987):

1. Under the garden pea pricing formula, which is based on machine dressed weights, a farmer could have a very substantial dressing loss if peas are not irrigated for maximum pod fill.
2. Irrigation is done twice before budding to promote vine growth for easier harvesting.
3. Irrigating once at the flowering stage and once or twice at the pod filling stage increases yield and reduces the risk of undersize peas.

Therefore drier climates for pea production are preferred, because of the ease of irrigation management, and the absence of wet ground due to rain which can result in stunted growth, poor colour and high mildew incidence (Freeman, 1987). Under Canterbury, New Zealand conditions, irrigation every 14 days with an application of 50 mm at each pass is practiced (Freeman, 1987).

In an experiment on a dry Canterbury soil, irrigating peas at flowering and pod swelling increased green pea yield by 84% and seed yield by 78%, because of increases in pod plant^{-1}, peas pod^{-1} and pea weight (White *et al.,* 1982).

With irrigation, peas pod^{-1} increased at populations of 83 to 109 plants m^{-2} but were not significantly different at 135 plants m^{-2} (Anderson and White, 1974). Stoker (1975) found that under dry land conditions, the optimum population density was 71 plant m^{-2} but with irrigation this could increase to 104 plants m^{-2}, and finally to 121 plants m^{-2} with more frequent border dyke irrigation.

These experiments provided a basis for recommendations in New Zealand (Stoker, 1975). Without irrigation, 70 plants m^{-2} would seem to be the optimum on shallow soils (Stoker, 1975), increasing to 90 plants m^{-2} on deeper soils (Anderson and White, 1974). With irrigation, these densities can be increased to 120 -130 plants m^{-2} (Anderson and White, 1974; Stoker, 1975).

However, moisture has a deleterious effect on pea seeds during harvest. Seeds harvested after periods of heavy rain appeared to have reduced percentage viability and increased percentage mortality in soil (Flentje, 1964; Matthews, 1973). This effect of rainfall on seed moisture content could have occurred through an increase in the uptake of moisture by the plant from the soil or by the more direct effect of rain on the pods (Matthews, 1973). Aside from these reports, there are as yet no studies concerning the effect of moisture on seed quality in garden peas.

2.9.3. ENVIRONMENT WITHIN THE CROP

Crop responses will largely be dependent on crop canopy environment. Halligan (1986) showed that the maximum daily temperature measured within the canopy of a pea crop can be 3-5°C higher than that measured above the crop canopy. Similarly, Perry and Harrison (1973) demonstrated that peas within the pods experienced temperatures 4-5°C higher than the above canopy. The developing pea seeds therefore, experience temperatures which are several degrees higher than the ambient air temperature.

The effects of seed position on garden pea seed quality has not been well studied. Studies with soybeans have shown that seed quality was improved when seeds were obtained from the top of the plants. Although reasons for enhanced quality of top seeds are not certain Adam *et al.* (1989) suggested three possible reasons: (1) The soybean plant enters senescence at the same time that it begins to mobilise significant reserves of dry matter, especially nitrogen (Sinclair and De Wit, 1976). During this period, competition for

these nutrients from the roots and nodules is greatly reduced as they become physiologically inactive. Thus, the newly developing seeds become the major sink of the assimilates and produced greater seed weight (Adam *et al.*, 1989). (2) Compared to top leaves the bottom leaves of a soybean canopy have reduced photosynthesis levels due to shading which results in a reduced supply of photosynthate to the bottom seeds (Schow *et al.*, 1978) potentially resulting in smaller seeds and lower quality (Adam *et al.*, 1989). (3) Seeds in pods originating from early flowers mature longer in the field than seeds in pods originating from late flowers (Dunphy *et al.*, 1979) and are potentially exposed to more environmental stress factors such as higher temperature and humidity which increase seed deterioration (Adam *et al.*, 1989).

2.10. SEED DETERIORATION DURING SEED MATURATION AND HARVEST

Following maturation the seeds (in "dry fruits") continue to dry down until they reach harvest maturity, i.e. the moisture content at which they can be effectively threshed with mechanical harvesters (TeKrony *et al.*, 1980; Gane, 1985). Climatic conditions during this post maturation pre-harvest period have a great influence on the quality of the seed harvested (Delouche, 1980; TeKrony *et al.*, 1980). Adverse weather conditions during the pre-harvest period cause moderate to severe seed quality problems in many areas every year which is commonly termed weathering (Delouche, 1974).

Weathering is a major problem in seed production. The severity of weathering and the limitations imposed on seed quality by weathering generally increase from cool to warm areas. The worst situation is in the humid subtropics and tropics. The quality of seed produced is generally low and deterioration continues at a rapid rate during storage because of high temperatures and humidities (Delouche, 1980). These situations and problems might also occur in garden peas, but no thorough study has yet been done.

In soybeans, seeds are usually produced in areas where the crop is grown. Delayed harvesting of soybean seed caused by inclement weather results in a reduction in viability and an increase in mechanical damage during harvest (Green *et al.*, 1966). However, in a study on the effect of seed position, planting and harvesting dates on soybean seed quality, Adam *et al.*, (1989) found that early planting (May 1) and early harvest (September 15) also decreased seed quality. Seed deterioration can occur following either early or late harvest if the environment is not favourable for the production of quality seed.

Variation in the environment of seeds at about the time of completion of maturation and harvesting can result in differences in their potential to perform, either in the field or in storage (Bewley and Black, 1986). Seeds exposed to pre-harvest weathering, particularly in warm and humid conditions exhibit reduced germination, reduced field emergence, increase leachate conductivity, reduced respiratory oxygen uptake and deterioration of membranes (Woodstock *et al.*, 1985). Weathered cottonseeds release more potassium, manganese, magnesium and calcium during imbibition than unweathered cottonseeds and the release of potassium and calcium was significantly correlated with measurements of seed quality (Woodstock *et al.*, 1985). Under the electron microscope, weathering deterioration of membranes is manifested by pale cytoplasm and lack of structurally distinguishable ribosomes.

Mechanical damage inflicted during harvesting can severely reduce the viability of some seeds, especially large seeded legumes. Injured or deeply bruised areas may serve as centres for infection and result in accelerated deterioration. Injuries close to vital parts of the embryonic axis or near the point of attachment of cotyledons to the axis usually bring about the most rapid losses of viability. It is therefore of the utmost importance to harvest and thresh seeds very carefully, making sure the drum speed is slow and seeds are harvested at the right time (Matthews, 1973; Gane *et al.*, 1984; Gane, 1985). In the U.K., one method of minimising damage is to harvest seed at a moisture content of around 25%, at which higher vigour seeds and high quality seeds are produced (Gane *et al.*, 1984). High temperatures during drying or drying too quickly or excessively, can also dramatically reduce viability (Bewley and Black, 1986).

2.11. CONCLUSION

Seed development in garden peas is well understood, and this understanding of the growth and development of the crop can serve as a guide in the production of high quality seed. For example correct harvesting at the right time can assist in minimising the problem of poor quality and low vigour seeds. However, garden peas are grown under contrasting environments and a result obtained in one area might not be appropriate in other areas. Further, most seeds used in development studies are grown under controlled condition which at times does not reflect crops grown under field conditions.

Garden pea seed production is affected by factors such as environmental influences associated with crop growth, soil conditions, soil fertility, plant population, row spacing, and time of sowing. These factors have been thoroughly studied and research results have served as the basis for recommendations for crop management for commercial scale seed production. However, differences in seed quality characters resulting from various crop management strategies exist. Production practice effects on seed quality have not generally been taken into consideration in most of the previous studies, and are therefore a major component of this study.

There are few studies on the effects of climatic factors associated with the growth of the mother plant in garden peas. Temperature within the canopy is higher than above the canopy and tends to increase the incidence of hollow heart. Moisture is very important in the growth of peas especially during the onset of flowering, because the roots have ceased to grow, making the plant more vulnerable to water shortage. However, excessive water has deleterious effects on pea seeds during harvest. The environment within the canopy can influence the quality of harvested seeds. Seeds exposed to adverse weather conditions during maturation may have low quality because of seed deterioration resulting from weathering. Time and method of harvest influence production of high quality seeds. Seeds can be damaged during harvesting and processing, which lowers their quality. Such damage can be obvious (i.e. cracked testa) or more subtle (i.e. loss of membrane integrity).

Environmental effects associated with the mother plant in garden peas have not been well studied. The influence of the environment within the canopy under field conditions was therefore investigated in this study, and the influence of time and method of harvest on seed quality in garden peas was also explored.

CHAPTER THREE

MATERIALS AND METHODS

3.1. EXPERIMENTAL FIELD

The experiments were established on the campus plots at the rear of the Seed Technology Centre, Massey University, Palmerston North, New Zealand (40°S, 175°E). The 1988-1989 field experiments were sited on plot No. 8 and the 1989-1990 experiments on plot No. 11. The soil classification is the same as described in Section One.

3.2. LAND PREPARATION

For both 1988-1989 and 1989-1990 seasons the land was cultivated out of a desiccated perennial ryegrass and white clover pasture, and was thoroughly prepared by firstly ploughing and secondly harrowing twice until a good tilth was attained. Before the last harrowing, 250 kg ha^{-1} of superphosphate (0-9-0-12) was applied to the experimental area.

3.3. SEED LOTS

Seed of two cultivars, Pania and Princess was obtained each year from Challenge Seeds Ltd., Palmerston North for use in the study. These were commercial lots with high germination, vigour and expected field emergence (Table II.1). Expected field emergence data (Table II.1) were used in the computation of sowing rates for all the experiments conducted in this Section.

Table II.1. Seed lot quality characters for both the 1988-1989 and 1989-1990 seasons.

SEED QUALITY	CV. PANIA		CV. PRINCESS	
	1988-1989	1989-1990	1988-1989	1989-1990
GERMINATION (%)	98	97	98	99
CONDUCTIVITY (µS g-1 SEED)	12	10	10	10
HOLLOW HEART (%)	3	2	1	0
E.F.E. (%)	92	92	93	94
T.S.W. (g)	230	230	242	240

3.4. TREATMENTS, EXPERIMENTAL DESIGN AND FIELD LAY-OUT

3.4.1. TREATMENTS (1988-1989)

3.4.1.1. Row Width and Plant Population

Both cultivars were sown at 10, 20 and 40 cm row spacings at a sowing rate designed to produce 100 plants m^{-2} (Table II.2) on 22 November 1988, and at a constant row spacing of 20 cm but at sowing rates designed to produce 50, 100 and 200 plants m^{-2} (Figure II.1). The recommended sowing method for garden peas of 20 cm between rows and at a population density of 100 plants m^{-2} was used as a basis in the determination of the other treatments which were achieved by doubling and reducing by half the recommended rate and row width.

3.4.1.2. Time of Sowing

The 20 cm row width at 100 plants m^{-2} plots sown on 22 November 1988 (recommended sowing date) was compared with a further sowing at the same row width and rate on 16 December 1988 (late sowing) (Figure II.1).

3.4.2. TREATMENTS (1989-1990)

3.4.2.1. Row Width and Plant Population

Both cultivars were sown on 3 November 1989 to achieve a population of 100 plants m^{-2} at row widths of 10, 20 and 40 cm, and also at a standard row width (20 cm), but varied population density (50, 100, 200 plants m^{-2}) (Table II.2, Figure II.2).

Table II.2. Description of treatments used in field experiments for population density, row width and time of sowing experiments.

POPULATION DENSITY	ROW WIDTH (cm)	APPROXIMATE INTRA-ROW SPACE (cm)	TIME OF SOWING	WEIGHT OF SEEDS USED+ PER PLOT	PER HECTARE
50 plants m^{-2}*	20	10.0	November	200 g	125 kg
100 plants m^{-2}*	20**	5.0	November***	400 g	250 kg
200 plants m^{-2}*	20	2.5	November	800 g	500 kg
100 plants m^{-2}	10**	10.0	November	400 g	250 kg
100 plants m^{-2}	40**	2.5	November	400 g	250 kg
100 plants m^{-2}	20	5.0	December***	400 g	250 kg

*Treatments for population density experiment
**Treatments for row width experiment
***Treatments for time of sowing experiment
+ Based on EFE data

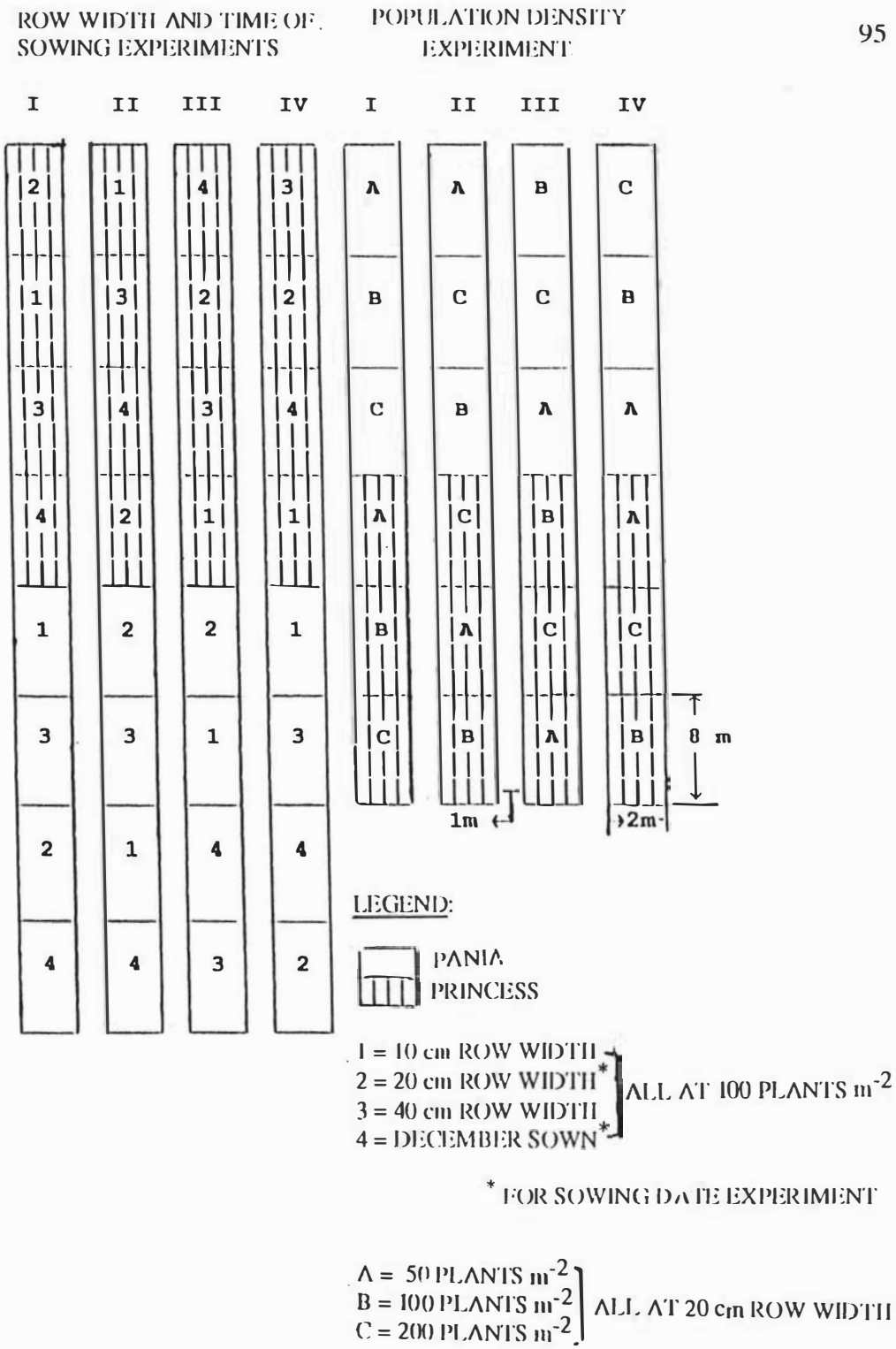


Figure II.1. The field lay-out for experiments conducted in the 1988-1989 cropping season.

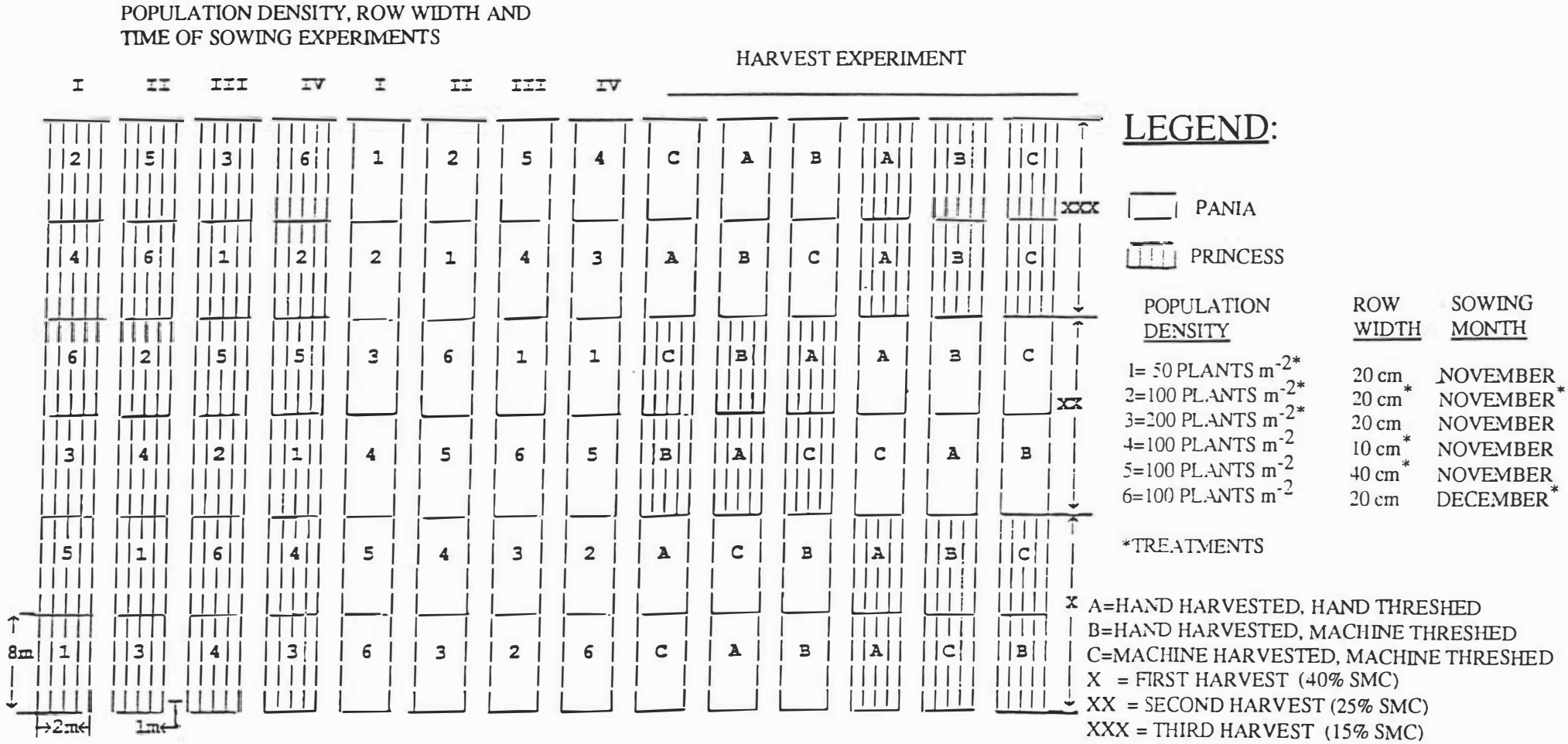


Figure II.2. The field lay-out for experiments conducted in the 1989-1990 cropping season.

3.4.2.2. Time of Sowing

The 20 cm row width at 100 plants m^{-2} plots sown on 3 November 1989 was compared with a further sowing at the same row width and rate on 4 December 1989 (Figure II.2).

3.4.3. EXPERIMENTAL DESIGN AND FIELD LAY OUT

The experiments were arranged in a randomised complete block design for each cultivar with four replications of each treatment. Plot size was 2 m x 8 m, with a one metre border between plots (Figures II.1 and II.2).

3.5. METHOD OF SOWING

Sowing was done using a cone seeder (Elite-Drill-Machine, Seedmatic 6, 'System Weihenstephan', F.Walter and H.Wintersteiger K.G., Austria). The seeder was adjusted to a depth of 3 cm and to sow a distance of 8 meters, equal to the length of the plot. The 10 coulters were set at a distance of 20 cm, the distance between rows for most of the treatments.

For the population density experiments the sowing rates to achieve populations of 50, 100 and 200 plants m^{-2} were respectively 200, 400 and 800 g seed $plot^{-1}$ (125, 250 and 500 kg seed ha^{-1}, Table II.2). This produced approximate intra row widths of 10, 5 and 2.5 cm between seeds respectively.

For the row width experiments, the 20 cm and 40 cm row width treatments were both sown with the coulters set at a 20 cm distance between rows. All row width treatments were sown at a seeding rate of 400 g seed $plot^{-1}$ for both cultivars. To achieve the 40 cm row spacing, plots were sown at 20 cm spacings, and after emergence, every alternate row of seedlings was removed by hand hoeing. Coulters were adjusted to a 10 cm distance, and two passes of the drill made to sow each plot for the 10 cm row distance treatment. At the 10, 20 and 40 cm row spacings, approximate intra row widths of 10, 5 and 2.5 cm respectively were produced between seeds.

All December sowings were sown by a hand sowing machine (Seedalizer Model 1800, Earthway Products Inc., Bristol, Indiana, U.S.A.) adjusted to sow at about 3 cm depth and so that seeds were approximately within row spaced at 5 cm, with a seeding rate of 400 g seed $plot^{-1}$. Row spacing was 20 cm. The seeds were sown on 16 December 1988 and 4 December 1989.

3.6. CROP MANAGEMENT

Fifteen days after sowing (1988-1989 season) and twelve days after sowing (1989-1990 season), MCPB herbicide was applied at the rate of 1.2 kg a.i. ha^{-1} (3 litres in 200 litres of water ha^{-1}) to control broad leaf weeds. The herbicide was applied with the use of a knapsack sprayer. Hand weeding was employed to remove the weeds not controlled by the MCPB herbicide at 25, 35 and 45 days after sowing in both the 1988-1989 and 1989-1990 seasons.

In the 1988-1989 season, nitrile (Bravo) fungicide was sprayed at the rate of 1.0 kg a.i. ha^{-1} 40 days after the November sowing, to prevent an attack of powdery mildew. Mancozeb (Dithane M-45) was then sprayed at the rate of 1.6 kg a.i. ha^{-1} at 55 and 70 days after the November sowing, also to control powdery mildew. In the 1989-1990 season, penconazole (Topas 100 EC) was sprayed at the rate of 0.035 kg a.i. ha^{-1} during the onset of flowering to prevent powdery mildew. Three further applications of penconazole were made at 14 day intervals.

At the pod filling stage in both seasons the peas were sprayed with methiocarb (Mesurol bird repellent) at the rate of 0.075 kg a.i. ha^{-1} (1 kg in 200 litres of water ha^{-1}) to repel birds.

3.7. SEED MOISTURE CONTENT DETERMINATION

Seed development was monitored from 20 days after flowering up to maturity in all experiments conducted in both the 1988-1989 and 1989-1990 seasons. Five plant samples from each treatment were collected at random but excluding border rows every two days up to the last harvest for the determination of seed moisture

content. Seeds from two plants were used for the determination of the seed moisture content for the whole plant. The three other sample plants were used to determine the moisture content in each pod position. For the 1988-1989 season, the pods at the distal end were considered as top pods and all other pods were known as bottom pods. For the 1989-1990 season, the distal pods were top pods, the pods at the first podding truss were bottom pods and the other pods were considered as middle pods. The moisture content was determined using the ISTA method (ISTA, 1985) described in Section One.

Samples for bulk seed quality and vigour assessment were harvested at the appropriate seed moisture content, as described for time and method of harvest (3.8).

3.8. TIME AND METHOD OF HARVEST

For the 1988-1989 sowing, seeds were hand harvested at various stages of growth based on the seed moisture content as described previously. The first harvest was made at 40% SMC (seeds passed the physiological maturity stage) and the second at 15% SMC (recommended in New Zealand). For the 1989-1990 season, the first harvest was done when seeds attained 40% SMC; the second harvest at 25% SMC (recommended in the U. K.); and the third harvest at 15% SMC. For each harvest, an area of 1 m x 2 m chosen at random but excluding the first one metre of each end of a plot was used. Harvesting was done by cutting the base of all the plants and putting them in a paper bag. The seed moisture contents of 40, 25 and 15% for the 50 plants m^{-2} treatment were attained two days later than the other treatments, which also caused a two day adjustment in the harvesting of these plots.

The harvested pods from each plant were divided into top and bottom pods in the 1988-1989 season and into top, middle and bottom pods in the 1989-1990 season as described for the seed moisture determination (3.7). The seeds were hand shelled from each pod position and dried separately using a heated air-system mini drier (Kiwi Mini Drier, Seed Technology Centre, Massey University, New Zealand). Drying was carried out according to Gane *et al.,* (1984) with some

modifications. All seeds harvested at 40% SMC were dried for four days; the first two days at a temperature of 27°C, which was increased to 30°C for the third day and to 35°C on the fourth day. Seeds harvested at 25% SMC were dried for two days; at 27°C for the first day and 35°C for the second day. Seeds harvested at 15% SMC were dried for one day at 35°C. All these drying regimes produced approximately 12% SMC for all the treatments. After drying, all seeds from each treatment were put in paper bags and placed in a 5°C room until the evaluation of seed quality and vigour characteristics.

In the 1989-1990 season, a time and method of harvest experiment was conducted (Figure II.2). For the hand harvested, hand threshed (HHHT) treatment, the pea plants were cut at the base, put inside a paper bag and the seeds obtained by hand podding in the processing hall of the Seed Technology Centre immediately after harvest. For direct harvested treatment (machine harvested and machine threshed, MHMT), a combine harvester (Seedmaster Universal Hydrostatic combine-harvester) with a drum speed of 684 rpm and a rhomboid threshing concave set at 8 cm was used. For the windrow treatment (hand harvested and machine threshed, HHMT), the pea plants were cut at the base and allowed to dry in the field for three days before they were threshed by the same combine harvester used in MHMT.

After harvesting, seeds were immediately dried to 12% SMC as previously described. After the drying of the last harvest, seeds from the HHMT and MHMT treatments were cleaned using an air-screen cleaner (Clipper Inc., Bay City, Michigan, U.S.A.) with a 10 mm round perforation screen. Seed quality and vigour were determined from each treatment as described below (Seed Quality and Vigour Tests 3.9).

3.9. SEED QUALITY AND VIGOUR TESTS

Seed quality characters and vigour were obtained from all treatments in all experiments in both the 1988-1989 and 1989-1990 seasons. The seed quality and vigour tests used were those recommended for garden peas (ISTA, 1985; ISTA, 1987). The quality characteristics of each treatment were determined in the

laboratory using the appropriate ISTA methods (ISTA, 1985) where available. The seed qualities determined were germination, hollow heart, conductivity, thousand seed weight and controlled deterioration. Tests for germination, hollow heart and conductivity used the ISTA methods (ISTA, 1985) as described in Section One (3.2).

3.9.1. THOUSAND SEED WEIGHT

The thousand seed weight (TSW) for each treatment was obtained (ISTA, 1985). For each treatment eight replicates of 100 seeds were counted for the thousand seed weight determination. The mean TSW was calculated from the average of eight weights of 100-seed replicates adjusted to 12% SMC.

3.9.2. CONTROLLED DETERIORATION TEST

The controlled deterioration test was carried out according to Matthews and Powell (1987a) with some modifications. For each treatment, four replicates of 20 g of seeds, with moisture content determined by internationally recommended procedures (ISTA, 1985), were placed in 12 cm x 18 cm aluminium foil packs for the controlled deterioration test. The volume of water required to raise the moisture content of each seed sample to 20% was calculated using the formula:

$$V(cm^3) = \left[\frac{100 - MC_0}{80} \times W\right] - W$$

where MC_0 is the original moisture content of the seeds and W is the weight of seeds (g) in each sample.

The required volume of water was carefully added to the seeds in each foil pack with the use of a pipette, and the packets were heat sealed leaving as small an air gap as possible, using a ribbon sealer. The aluminium foil packets were stored for 24 h in a 5°C room to allow the seeds to equilibrate to 20% seed moisture content.

The packets were then transferred to a germinator set at 40°C and left for the required number of days for controlled deterioration. Three controlled deterioration times were used; 1, 2 and 4 day (24, 48, 96 h). Immediately after removing the samples from the 40°C treatment, seed moisture content and standard germination tests were done as described in Section One.

3.10. DATA ANALYSIS

The 1988-1989 season included three experiments (population density, row width and time of sowing experiment) which at harvest were further divided into time of harvest and pod position effects. These were treated as factorial experiments, rather than a nested split plot design, in order to estimate the second order interaction effects. Thus in the population density experiment, there were two times of harvest, three population densities and two pod positions (a 2 x 3 x 2 factorial experiment) and similarly with the row width experiment. For the time of sowing experiment, the two harvests, with two sowings, and two pod positions were analysed as a 2 x 2 x 2 factorial experiment.

More factors were examined in the 1989-1990 experiments, i.e. there were three harvests and three pod positions. The population density and row width experiments were therefore analysed as 3 x 3 x 3 factorial experiments, i.e. the population density experiment had three harvests, three population densities and three pod positions while the row width experiment had three harvests, three row widths and three pod positions. The time of sowing was a 3 x 2 x 3 factorial experiment with three times of harvest, two times of sowing and three pod positions. The time and method of harvest conducted in 1989-1990 season had three methods of harvest and three times of harvest which was a 3 x 3 factorial experiment. In all experiments the two cultivars (Pania and Princess) used were analysed separately.

Analysis of variance was used to determine the significance of differences between treatments for germination, hollow heart, conductivity, controlled deterioration, and thousand seed weight. Individual effects of population density, pod position and time of harvest were also analysed, including the combined

effects of any two or the three parameters (population density, pod position and time of harvest). Least significant differences (LSD's) was used to compare the means.

Due to the voluminous data obtained from these experiments, only selected analysed data which show the appropriate response of the seeds from a factor and combined factors without hidden interactions have been presented. Complete data are kept at the Seed Technology Centre, Massey University, New Zealand for reference.

3.11. CANOPY ENVIRONMENT EXPERIMENT

3.11.1. FIELD EXPERIMENT CANOPY ENVIRONMENT

The temperature within the canopy of the crop was measured using thermometers (minimum / maximum) for all treatments in both the 1988-1989 and 1989-1990 seasons. In each treatment, the thermometers (two in the 1988-1989 season and three in the 1989-1990 season) were each tied to a bamboo stick which was set beside specific pods at given pod positions described previously (Seed Moisture Content Determination 3.7). Temperature readings were taken between 10:00 a.m. to 4:00 p.m. (high temperatures in the day) at one hour intervals daily from 10 days before the last harvest.

3.11.2. ENVIRONMENT READ FROM DATA LOGGER

Seeds of cv. Princess were hand sown on 5 November 1989 in three 1 m x 2 m plots. Each plot consisted of 100 kg super pack potting mix (Smith Potting Mix, Smith Soil Industries Ltd., Auckland, New Zealand). For each plot, six rows 20 cm apart were sown with seeds at approximately 3 cm depth. Two seeds per position were sown at 10, 5 and 2.5 cm intrarow spacings in separate plots. These were then thinned to one plant per intrarow space upon establishment to obtain a population density of 50, 100 and 200 plants m^{-2} respectively.

Temperature and relative humidity within the canopy of each pea population density were monitored using a data logger (current monitor) with automatic print out system (Current Monitor, Measumeter II, Analogic AN25MOO, Electric Measurement and Control Ltd., Auckland, New Zealand) at one hour intervals from 9:00 a.m. to 5:00 p.m. each day from 20 days after pod setting until maturity. The temperature and relative humidity were monitored from probes tied on bamboo sticks and set beside the third podding truss.

Temperature in different parts of the canopy was monitored using a multipoint recorder (Honeywell Versaprint Single-pen and Multipoint Recorder, Yamatake, Model J153X89C-52). For each plot, three temperature probes tied to a bamboo stick were set beside a pod classified either as a top, middle or bottom pod as described previously (Seed Moisture Content Determination 3.7).

For 1990-1991, a high population density of 200 plants m^{-2} of cv. Pania and cv. Princess were each sown in 1 m x 2 m plots on 29 October 1990 following the methods used in 1989-1990. The temperature and relative humidity within the canopy were monitored from pod development to maturity with the same data logger used in 1989-1990.

CHAPTER FOUR

RESULTS

4.1. FIELD ESTABLISHMENT

The actual field establishments in both seasons were lower than the desired populations (Table II.3). However, there were conspicuous differences between treatments which represent the desired population density differences. For ease of presentation, results are presented as the desired populations (i.e. 50, 100, 200 plants m^{-2}) and not the actual populations.

Table II.3. Population density achieved in field sowings for the 1988-1989 and 1989-1990 seasons.

TREATMENT	1988-1989 SEASON		1989-1990 SEASON	
	cv. PANIA	cv. PRINCESS	cv. PANIA	cv. PRINCESS
50 Plants m^{-2}	40	38	45	40
100 Plants m^{-2}	92	90	95	90
200 Plants m^{-2}	185	180	190	185
December Sown[1]	95	90	95	90
10 cm row width	90	85	93	90
20 cm row width	92	90	95	90
40 cm row width	91	85	95	90

[1] Target 100 plants m^{-2}.

4.2. SEED MOISTURE CONTENT AT HARVEST

The seed moisture content obtained from the whole plant was used as a basis for the harvesting time for all treatments (Table II.4). However at each harvest time, the top pods always had a higher and the bottom pods a lower seed moisture content than the predetermined seed moisture content.

Table II.4. Seed moisture content at harvest.

TARGET SMC	SEED MOISTURE CONTENT AT HARVEST			
	TOP PODS	MIDDLE PODS	BOTTOM PODS	WHOLE PLANT
1988-1989 SEASON				
40% SMC	55	-	35	42
15% SMC	20	-	14	17
1989-1990 SEASON				
40% SMC	54	38	26	40
25% SMC	32	24	18	26
15% SMC	20	16	12	15

4.3. ORGANISATION OF RESULTS PRESENTATION

Although results of population density, row width and time of sowing experiments were obtained from two cultivars (cv. Pania and cv. Princess), the results presented in the text are those of cv. Pania only. The results from cv. Pania showed a more apparent response to the treatments than cv. Princess, although cv. Princess showed similar trends. Factors from seed quality characters

without significant interaction effects are presented in one table for each experiment, i.e. population density (Table II.5), row width (Table II.7) and time of sowing (Table II.11). For the 1988-1989 season, significant interactions between two or three factors are presented in a tabular format. For the 1989-1990 season, the significant interactions between any two factors in the population density and row width experiments are presented in tables while significant interactions between the three factors are presented as figures. For the time of sowing experiment, significant interactions between any two or three factors are presented as tables.

For the harvest experiment, results from both cv. Pania and cv. Princess are presented. The significant interactions between the time and method of harvest are presented as figures. Seed quality characters without significant interaction effects are presented in table form.

Temperature and relative humidity obtained within the canopy of the pea crop from the data logger and thermometer are presented as figures using the data obtained from ten days before harvest.

4.4. POPULATION DENSITY EXPERIMENT

4.4.1. GERMINATION TEST

In 1988-1989, the germination after harvest at 40% SMC was lower than that of the harvest at 15% SMC (Table II.5), but time of harvest did not affect germination in 1989-1990. Germination did not differ with population density or pod position in either season.

4.4.2. THOUSAND SEED WEIGHT

The harvest at 15% SMC in the 1988-1989 season produced lower thousand seed weight than the seeds harvested at 40% SMC (Table II.5). Thousand seed weight declined significantly in both seasons as plant population increased.

Table II.5. The effects of the time of harvest, population density and pod position as a single factor on the seed quality characters of garden pea seeds (cv. Pania) obtained from the population density experiment in two cropping seasons (1988-1989 and 1989-1990).

FACTOR/ TREATMENT	SEED QUALITY CHARACTERS				
	% NORMAL GERMINATION		% H.H.	THOUSAND SEED WEIGHT (g)	
	1988-1989	1989-1990	1988-1989	1988-1989	1989-1990
SMC AT HARVEST					
40 % SMC	88.8	94.0	5.4	234.2	239.0
25 % SMC		96.0			240.7
15 % SMC	96.6	95.4	4.9	225.8	240.2
P-LEVEL	**	N.S.	N.S.	*	N.S.
$LSD_{0.05}$	3.49	3.07	3.77	7.57	3.62
C.V.	6.41	6.88	124.16	5.60	3.21
POPULATION DENSITY					
50 Plants m^{-2}	92.4	94.5	5.3	243.0	245.1
100 Plants m^{-2}	90.3	95.4	3.0	228.7	240.9
200 Plants m^{-2}	95.4	95.2	7.3	218.4	233.9
P-LEVEL	N.S.	N.S.	N.S.	**	**
$LSD_{0.05}$	4.27	3.07	4.61	9.27	3.62
C.V.	6.41	6.88	124.16	5.60	3.21
POD POSITION					
TOP	93.5	96.5	5.0	228.6	229.2
MIDDLE		94.7			241.9
BOTTOM	91.8	93.8	5.3	231.4	248.8
P-LEVEL	N.S.	N.S.	N.S.	N.S.	**
$LSD_{0.05}$	3.49	3.07	3.77	7.77	3.62
C.V.	6.41	6.88	124.16	5.60	3.21

* = Significant at 5% level,

** = Significant at 1.0% level,

NS = Not Significant

SMC = seed moisture content

% H.H. = % hollow heart

Pod position influenced the thousand seed weight in the 1989-1990 season where the bottom pod seeds were significantly heavier and the top pod seeds significantly lighter than middle pod seeds (Table II.5).

4.4.3. HOLLOW HEART TEST

There were no significant differences in the incidence of hollow heart which ranged between 3% to 7.3% in seeds harvested in the 1988-1989 season (Table II.5). However, in the 1989-1990 season, significant differences were obtained between the time of harvest, population density and pod position (Figure II.3). As the time of harvest was delayed, hollow heart incidence increased in all the experiments (Figures II.3 and II.6, Tables II.14d and II.16). As the population density increased, hollow heart incidence tended to increase and was usually highest at the 200 plants m^{-2} population. At 50 and 100 plants m^{-2}, top pods had significantly more hollow heart, but at 200 plants m^{-2}, hollow heart was higher in seeds from bottom pods, particularly at the last two harvests.

4.4.4. CONDUCTIVITY TEST

In 1988-1989 seeds obtained from the second harvest at the 200 plants m^{-2} density gave the highest electroconductivity reading of 14.81 $\mu S\ g^{-1}$ seed (Table II.6). Conductivity did not differ with population density at 40% SMC, or between harvests at 40% and 15% SMC when the population was 50 plants m^{-2}. It was lowest at 15% SMC and 100 plants m^{-2}.

In 1989-1990 the highest electroconductivity reading was obtained from the top pod seeds harvested at 40% SMC from the 50 plants m^{-2} population (Figure II.4). As the density increased to 100 and 200 plants m^{-2}, lower top pod conductivity readings were obtained. At 25% SMC, the top and bottom pod seeds had higher conductivity reading than the middle pod seeds at the highest plant density only. The conductivity of seeds harvested at 15% SMC was higher in top pod seeds than the middle pod seeds at 100 plants m^{-2}.

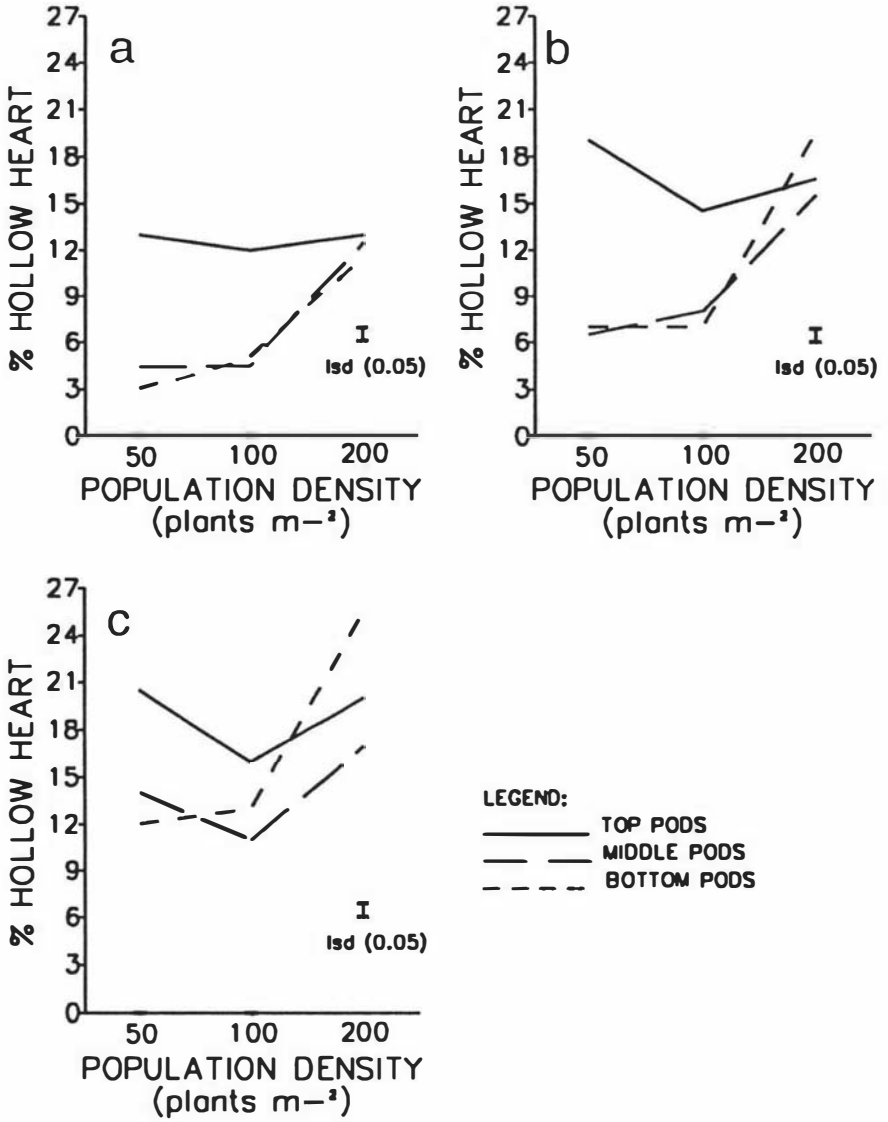


Figure II.3. The incidence of hollow heart in garden pea seeds (cv. Pania) as affected by the interaction of time of harvest, population density and pod position in the 1989-1990 season; (a) 40% SMC harvest, (b) 25% SMC harvest, (c) 15% SMC harvest.

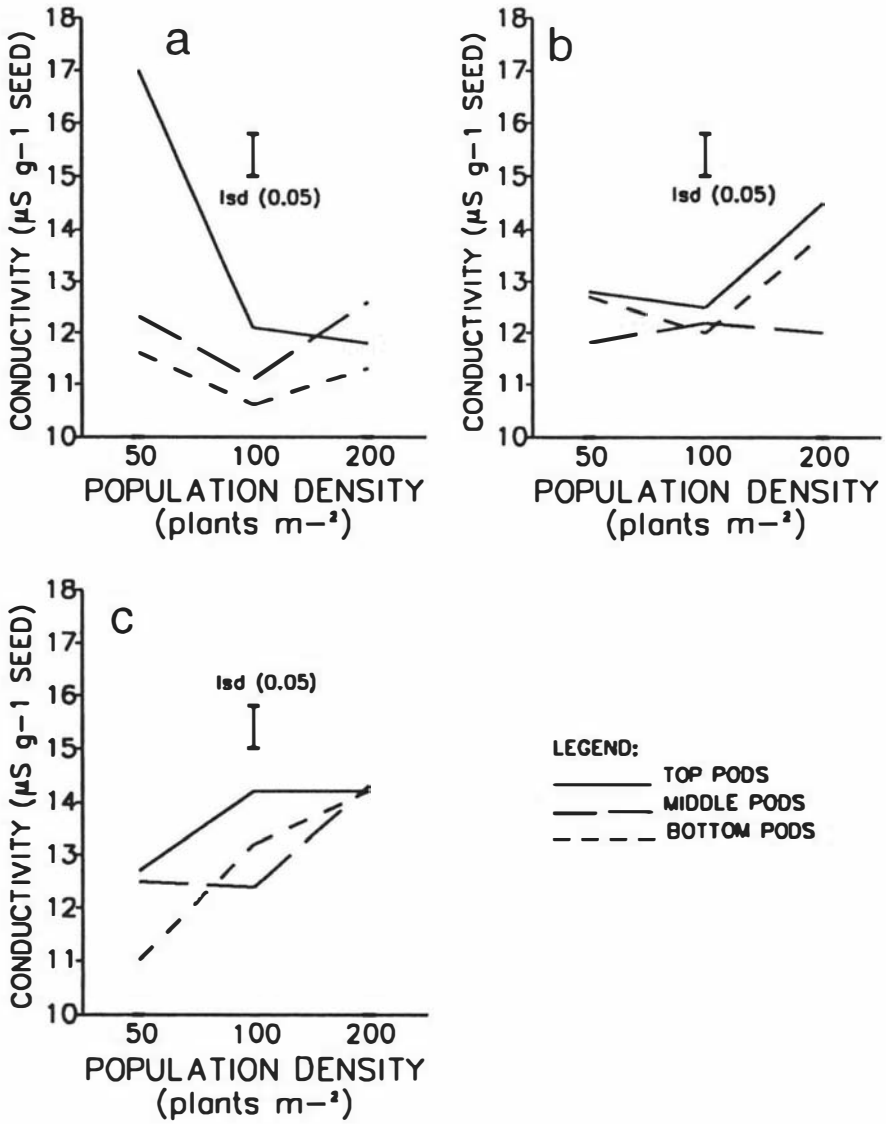


Figure II.4. The electroconductivity readings in garden pea seeds (cv. Pania) as affected by the interaction of time of harvest, population density and pod position in the 1989-1990 season; (a) 40% SMC harvest, (b) 25% SMC harvest, (c) 15% SMC harvest.

Table II.6. The combined effects of time of harvest and population density on the conductivity reading of garden pea seeds (cv. Pania) sown at various population densities in the 1988-1989 cropping season.

SMC AT HARVEST	POPULATION DENSITY (Plants m^{-2}) 50	100	200
40 % SMC	13.25	13.50	12.78
15 % SMC	12.98	11.67	14.81
P-LEVEL = *	$lsd_{(0.05)}$ = 1.50	cv = 4.71	

* Significant at 5% level

SMC = seed moisture content

4.4.5. CONTROLLED DETERIORATION TEST

The controlled deterioration test results are presented using the percent normal germination obtained from the 2 d controlled deterioration test. The 1 d CD treatment did not differentiate between seed lots while the 4 d CD treatment was too severe, reducing germination in all samples. Both the 1 d CD and 4 d CD produced no significant differences between treatments.

The seed samples in all treatments had seed moisture contents between 19.8% and 20.5% after the CD test. Low germination was obtained from seeds harvested at 40% SMC, but as the harvest was delayed, germination increased (Figure II.5).

The bottom pod seeds harvested from 200 plants m^{-2} had a lower germination compared to the top and middle pod seeds when harvested at 40% SMC. In contrast, top pods of 50 plants m^{-2} had the lowest germination at 40% SMC harvest. At 25% SMC harvest, bottom pod seeds in 50 plants m^{-2} had lower germination than the top and middle pod seeds. At 15% SMC, and 200 plants m^{-2}, middle pods seeds had a higher germination than seeds from top and bottom pods.

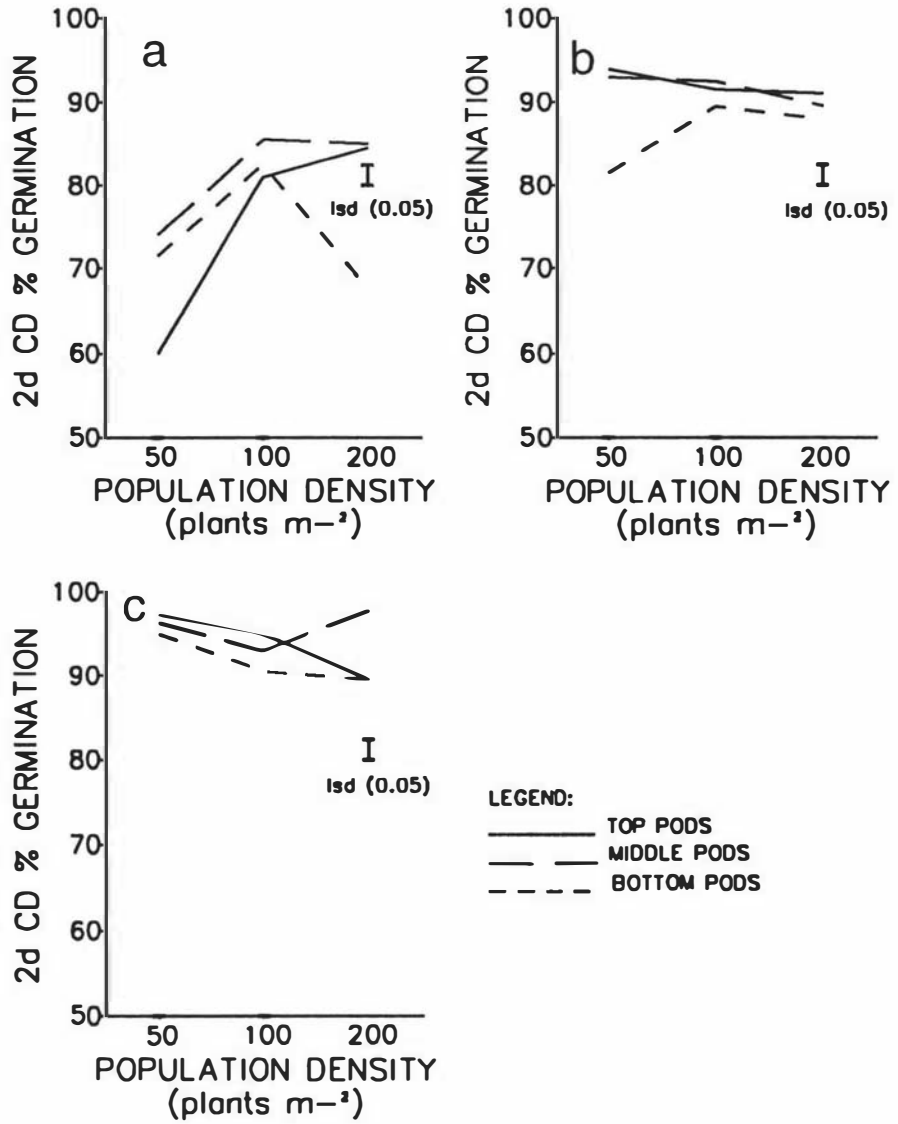


Figure II.5. Percent normal seedlings obtained from the 2d CD test of garden pea seeds (cv. Pania) as affected by the interaction of time of harvest, population density and pod position in the 1989-1990 season; (a) 40% SMC harvest, (b) 25% SMC harvest, (c) 15% SMC harvest.

4.5. ROW WIDTH EXPERIMENT

4.5.1. GERMINATION TEST

The germination of garden peas from the various times of harvest, row width and pod position was high, 88-91% in 1988-1989 and 95-97% in 1989-1990, and no significant differences were observed among treatment means (Table II.7).

4.5.2. CONDUCTIVITY TEST

In 1988-1989, seeds from top pods harvested at 15% SMC, had a higher conductivity reading of 15.57 $\mu S\ g^{-1}$ seed compared to the bottom pod seeds (Table II.8).

For the 1989-1990 season, conductivity reading was higher in the 25% SMC and 15% SMC harvests compared to the seeds harvested at 40% SMC. The top pod seeds had a higher conductivity reading than the bottom pod seeds (Table II.7).

4.5.3. THOUSAND SEED WEIGHT

The bottom pods had higher TSW than the top pods in both cropping seasons (Table II.7). Higher TSW was obtained at 10 cm and 20 cm row widths than at the 40 cm row width in 1988-1989.

4.5.4. HOLLOW HEART TEST

In 1988-1989 the top pod seeds at 15% SMC harvest had the highest hollow heart incidence (Table II.9a). Furthermore, the bottom pod seeds from the 20 cm row width had a higher hollow heart content compared to bottom pod seeds in the 10 cm and 40 cm row width (Table II.9b).

Table II.7. The effects of the time of harvest, row width and pod position as a single factor on the seed quality characters of garden pea seeds (cv. Pania) obtained from the row width experiment in two cropping seasons (1988-1989 and 1989-1990).

FACTOR/ TREATMENT	SEED QUALITY CHARACTERS: % NORMAL GERMINATION 1988-1989	% NORMAL GERMINATION 1989-1990	COND 1989-1990	THOUSAND SEED WEIGHT (g) 1988-1989	THOUSAND SEED WEIGHT (g) 1989-1990
SMC AT HARVEST					
40 % SMC	87.8	96.4	11.46	209.1	241.7
25 % SMC		96.3	13.12		239.5
15 % SMC	91.2	95.2	13.67	209.0	239.4
P-LEVEL	N.S.	N.S.	**	N.S.	N.S.
$LSD_{0.05}$	6.13	2.45	0.81	6.94	3.86
C.V.	11.70	5.45	13.6	5.65	3.42
ROW WIDTH					
10 cm	88.6	96.6	13.14	215.6	238.6
20 cm	90.1	95.4	12.25	210.0	240.9
40 cm	89.6	95.9	13.67	201.5	241.0
P-LEVEL	N.S.	N.S.	N.S.	**	N.S.
$LSD_{0.05}$	7.50	2.54	0.81	8.50	3.86
C.V.	11.70	5.45	13.60	5.65	3.42
POD POSITION					
TOP	89.9	96.9	13.31	202.4	228.4
MIDDLE		95.9	12.61		242.7
BOTTOM	89.0	95.1	12.34	215.6	249.4
P-LEVEL	N.S.	N.S.	*	**	**
$LSD_{0.05}$	6.13	2.45	0.81	6.94	3.86
C.V.	11.70	5.45	13.60	5.65	3.42

* = Significant at 5% level,

** = Significant at 1.0% level,

NS = Not Significant

SMC = seed moisture content

COND = Reading from the conductivity test ($\mu S\ g^{-1}$ seed)

Table II.8. Combined effects of time of harvest and pod position on the electroconductivity reading of garden pea seeds obtained from peas sown at various row widths in the 1988-1989 cropping season.

SMC AT HARVEST	POD POSITION TOP	BOTTOM
40 % SMC	13.91	15.12
15 % SMC	15.57	13.35
P-LEVEL = *	$lsd_{(0.05)} = 1.60$	cv = 18.64

* Significant at 5% level
SMC = seed moisture content

Table II.9a. Combined effects of time of harvest and pod position on the incidence of hollow heart in garden pea seeds obtained from peas sown at various row widths in the 1988-1989 cropping season.

SMC AT HARVEST	POD POSITION TOP	BOTTOM
40 % SMC	5.50	9.17
15 % SMC	13.00	7.00
P-LEVEL = *	$lsd_{(0.05)} = 3.90$	cv = 76.41

* Significant at 5% level SMC = seed moisture content

Table II.9b. The combined effects of row width and pod position on the incidence of hollow heart in garden pea seeds (cv. Pania) sown at various row widths in the 1988-1989 cropping season.

POD POSITION	ROW WIDTH 10 cm	20 cm	40 cm
TOP PODS	7.50	8.50	11.75
BOTTOM PODS	5.00	15.00	4.25
P-LEVEL = *	$lsd_{(0.05)} = 3.90$	cv = 76.41	

* Significant at 5% level

In the 1989-1990 season, significant differences were obtained between the time of harvest, row width and pod position (Figure II.6). At 10 cm row width, bottom pods had the highest hollow heart. However, at 20 cm row width, the top pods had the highest hollow heart at all times of harvest (40%, 25% and 15% SMC harvest). In the 40 cm row width, the top pods at 15% SMC harvest had higher hollow heart than the middle and bottom pods.

4.5.5. CONTROLLED DETERIORATION TEST

The results of the 2 d controlled deterioration test gave significant differences between treatments and were chosen for the presentation of results. The 4 d CD tests produced very low germinations.

For the 1988-1989 season, there was a significant interaction effect of time of harvest, row width and pod position (Table II.10). At the 40% SMC harvest, seeds from the 20 cm row width had higher germination than those in the 10 cm row width. At 10 cm and 40 cm row width, the bottom pods had lower germination than those from the top pods when the seeds were harvested at 40% SMC.

As harvest was delayed to 15% SMC, germination from the bottom pods at the 10 cm row width increased, while those from the 20 cm row width declined (Table II.10).

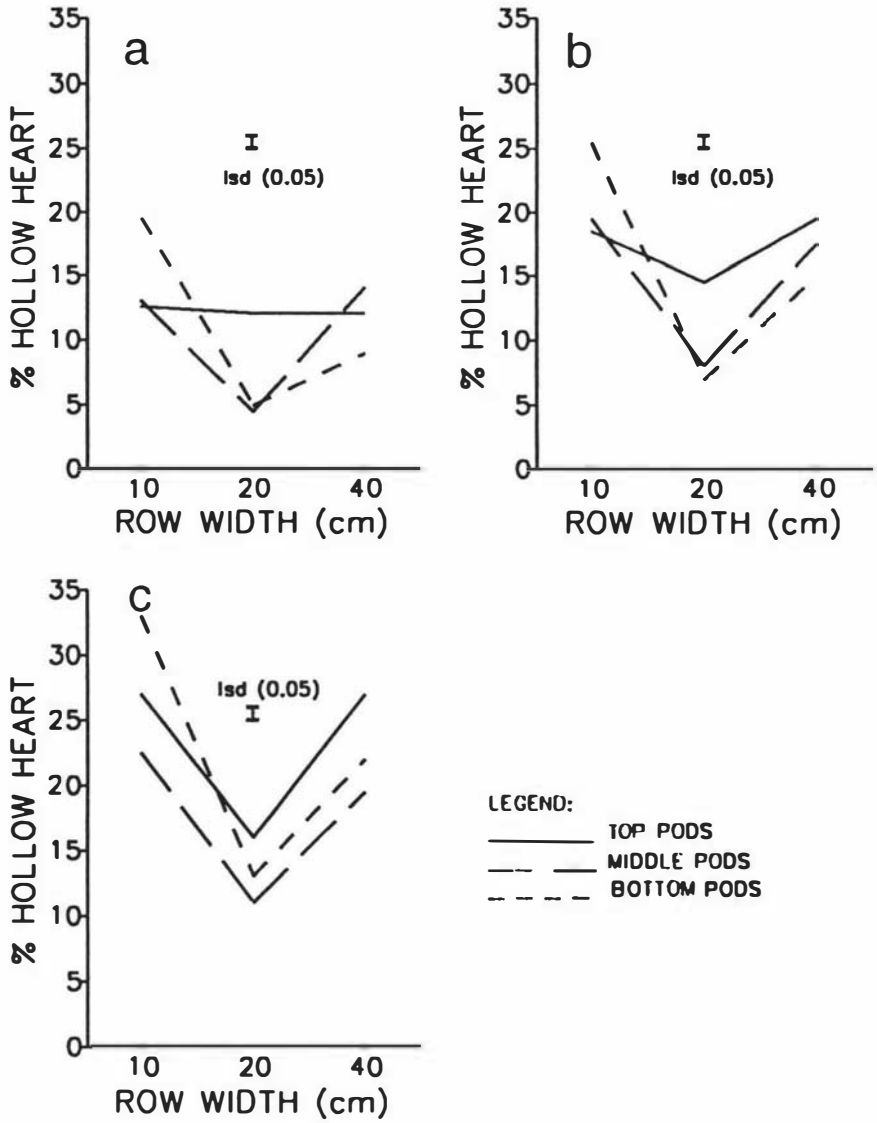


Figure II.6. Percent hollow heart in garden pea seeds (cv. Pania) as affected by the interaction of time of harvest, row width and pod position in the 1989-1990 season; (a) 40% SMC harvest, (b) 25% SMC harvest, (c) 15% SMC harvest.

Table II.10. Percent normal seedlings obtained from 2d CD test on garden pea seeds (cv.Pania) as affected by row width, time of harvest and pod position (1988-1989).

	SMC AT HARVEST					
	40 % SMC			15 % SMC		
POD	ROW WIDTH			ROW WIDTH		
POSITION	10 cm	20 cm	40 cm	10 cm	20 cm	40 cm
TOP	73	78	83	78	82	79
BOTTOM	70	85	74	81	76	75
P-LEVEL = *		$lsd_{(0.05)}$ = 3.89			cv = 7.56	

* Significant at 5% level

SMC = seed moisture content

In 1989-1990 germination from the 2 d CD test increased as harvest was delayed for top and bottom pods at the 10 cm row width (Figure II.7). For the 20 cm row width, the bottom pods had the lowest germination at both the 25% and 15% SMC harvest. At 40 cm row width, the bottom pods had significantly lower germination at 40% and 25% SMC harvest. However, as harvest was delayed to 15% SMC, germination tended to increase at all pod positions, a result which was also found in the time of sowing and harvest experiments.

4.6. TIME OF SOWING EXPERIMENT

4.6.1. GERMINATION TEST

The time of harvest and time of sowing did not cause any significant differences in the germination of seeds in the two cropping seasons (Table II.11). However in the 1989-1990 season, the bottom pod seeds had a slightly lower germination than the top and middle pod seeds (Table II.11).

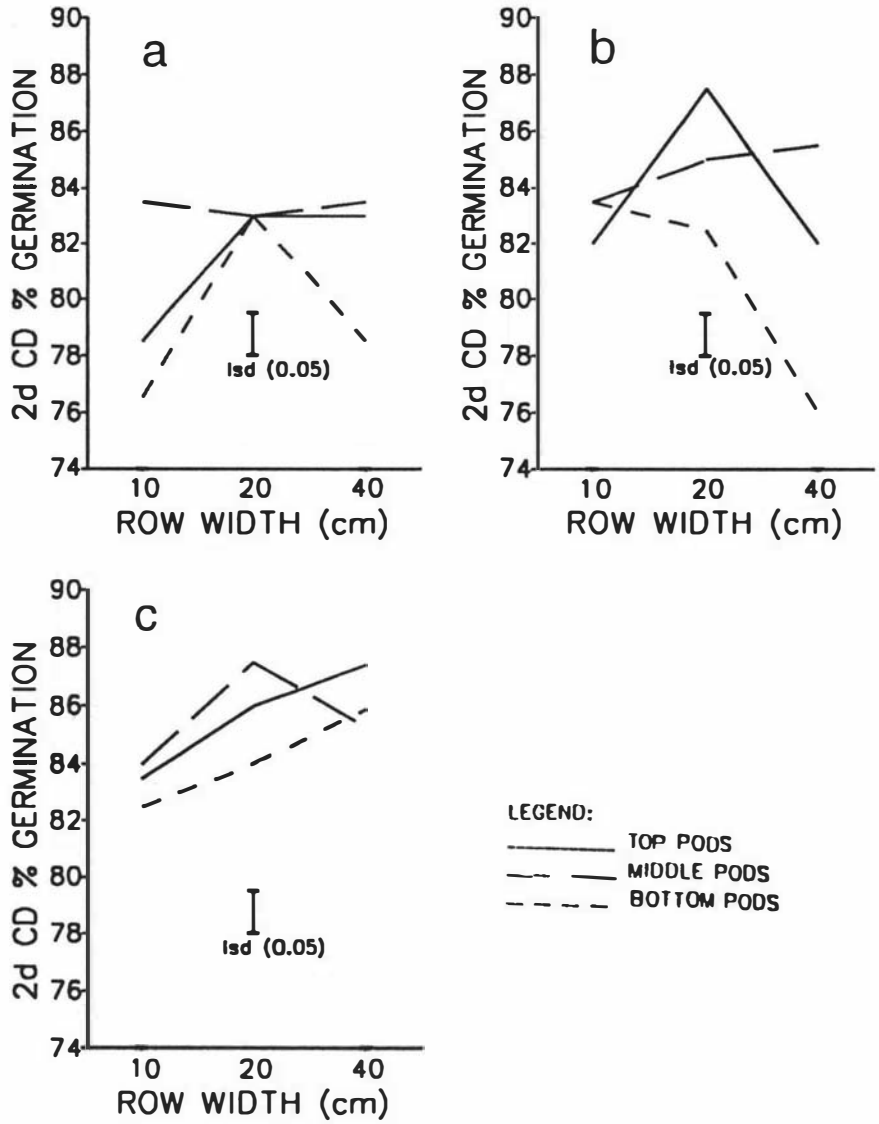


Figure II.7. **Percent normal seedlings obtained from the 2d CD test of garden pea seeds (cv. Pania) as affected by the interaction of the time of harvest, row width and pod position in the 1989-1990 season; (a) 40% SMC harvest, (b) 25% SMC harvest, (c) 15% SMC harvest.**

Table II.11. The effects of the time of harvest, time of sowing and pod position as a single factor on the seed quality characters of garden pea seeds (cv. Pania) obtained from the time of sowing experiment in two cropping seasons (1988-1989 and 1989-1990).

FACTOR/ TREATMENT	SEED QUALITY CHARACTERS			
	% NORMAL GERMINATION		COND	TSW
	1988-1989	1989-1990	1988-1989	1988-1989
SMC AT HARVEST				
40 % SMC	90.5	94.0	13.21	209.4
25 % SMC		95.8		
15 % SMC	95.4	95.7	13.93	206.8
P-LEVEL	N.S.	N.S.	N.S.	N.S.
$LSD_{0.05}$	7.36	4.02	2.09	7.15
C.V.	10.80	7.30	20.90	4.68
TIME OF SOWING				
NOVEMBER	90.1	95.4	15.28	210.0
DECEMBER	95.8	95.0	11.86	206.2
P-LEVEL	N.S.	N.S.	**	N.S.
$LSD_{0.05}$	7.36	3.29	2.09	7.15
C.V.	10.80	7.30	20.90	4.68
POD POSITION				
TOP	95.3	96.4	13.97	200.2
MIDDLE		97.0		
BOTTOM	90.6	92.1	13.17	216.0
P-LEVEL	N.S.	*	N.S.	**
$LSD_{0.05}$	7.36	4.02	2.09	7.15
C.V.	10.80	7.30	20.90	4.68

* = Significant at 5% level,

** = Significant at 1.0% level,

NS = Not Significant

SMC = seed moisture content

COND = Reading from the conductivity test ($\mu S\ g^{-1}$ seed)

TSW = Thousand Seed Weight (g)

4.6.2. THOUSAND SEED WEIGHT

In 1988-1989 the thousand seed weight from the bottom pods was higher than the top pods. However, the time of harvest and time of sowing had no effect on the thousand seed weight. For the 1989-1990 season, significant interaction effects were observed between time of sowing and pod position. Seeds from the November sowing had higher TSW than seeds from the December sowing in all harvests (Table II.12a). The top pods had lower TSW than the middle and bottom pods (Table II.12b) where the top pods in the December sown peas had the lowest TSW of 174.5 g. The TSW decreased as harvest was delayed in November sown peas while the highest TSW was obtained at 15% SMC harvest in December sown peas (Table II.12a).

Table II.12a. Combined effects of time of harvest and time of sowing on the thousand seed weight of garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

SMC AT HARVEST	TIME OF SOWING NOVEMBER	DECEMBER
40 % SMC	243.8	198.2
25 % SMC	241.6	194.0
15 % SMC	237.3	218.8
P-LEVEL = **	$lsd_{(0.05)}$ = 3.44	cv = 2.67

** Significant at 1% level

SMC = seed moisture content

Table II.12b. Combined effects of pod position and time of sowing on the thousand seed weight of garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

POD POSITION	TIME OF SOWING NOVEMBER	DECEMBER
TOP	230.2	174.5
MIDDLE	242.4	208.0
BOTTOM	250.1	228.5
P-LEVEL = **	$lsd_{(0.05)} = 3.44$	cv = 2.67

* Significant at 5% level

4.6.3. CONDUCTIVITY TEST

In 1988-1989 seeds harvested from the November sowing had a significantly higher conductivity reading than seeds obtained from the December sowing (Table II.11).

In 1989-1990 the December sowing had the lowest conductivity readings (Table II.13). As harvest was delayed, leachate conductivity increased in November sowings and was highest at the 15% SMC harvest. However, in December sown peas conductivity decreased as harvest was delayed.

4.6.4. HOLLOW HEART TEST

For the 1988-1989 season, the bottom pod seeds from the November sowing had the highest hollow heart incidence (Table II.14a). In contrast to other studies, however, the incidence of hollow heart did not increase as harvest was delayed (Table II.14b). Furthermore, the incidence of hollow heart did not differ significantly between top and bottom pods. However, the coefficient of variability (cv) is very high, and this result should be treated with caution.

Table II.13. Combined effects of time of harvest and time of sowing on the electroconductivity reading of garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

SMC AT HARVEST	TIME OF SOWING NOVEMBER	DECEMBER
40 % SMC	11.27	10.72
25 % SMC	12.26	8.52
15 % SMC	13.25	7.94
P-LEVEL = **	$lsd_{(0.05)} = 0.84$	cv = 13.57

** Significant at 1% level

SMC = seed moisture content

Table II.14a. Combined effects of pod position and time of sowing on the incidence of hollow heart in garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1988-1989 cropping season.

POD POSITION	TIME OF SOWING NOVEMBER	DECEMBER
TOP	8.50	3.50
BOTTOM	15.00	2.25
P-LEVEL = *	$lsd_{(0.05)} = 3.14$	cv = 58.45

* Significant at 5% level

Table II.14b. Combined effects of pod position and time of harvest on the incidence of hollow heart in garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1988-1989 cropping season.

SMC AT HARVEST	POD POSITION TOP	BOTTOM
40% SMC	5.50	6.50
15% SMC	8.50	8.00
P-LEVEL = ns	$lsd_{(0.05)} = 3.14$	cv = 58.45

ns Not Significant at 5% level

The time of sowing and pod position interacted (1989-1990 season) on the incidence of hollow heart (Table II.14c). Top pods from the November sowing had the highest hollow heart. Very low hollow heart incidence was obtained from the December sowings. When the pod position was categorised into three (top, middle and bottom) in the 1989-1990 season, the top pods had higher hollow heart than the bottom pods in the November sowing (Table II.14c). The top pods at 40% and 25% SMC harvests had higher hollow heart than the middle and bottom pods (Table II.14d). The middle pods had lower hollow heart than the top and bottom pods when harvested at 15% SMC.

Table II.14c. Combined effects of pod position and time of sowing on the incidence of hollow heart in garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

POD POSITION	TIME OF SOWING NOVEMBER	DECEMBER
TOP	14.17	6.00
MIDDLE	7.83	5.33
BOTTOM	8.33	6.33
P-LEVEL = **	$lsd_{(0.05)} = 0.77$	cv = 16.63

** Significant at 1% level SMC = seed moisture content

Table II.14d. The combined effects of time of harvest and pod position on the incidence of hollow heart in garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

SMC AT HARVEST	POD POSITION TOP	MIDDLE	BOTTOM
40 % SMC	7.50	3.25	4.00
25 % SMC	9.75	6.75	6.00
15 % SMC	13.00	9.75	12.00

P-LEVEL = ** $lsd_{(0.05)} = 0.77$ cv = 16.63

** Significant at 1% level

SMC = seed moisture content

4.6.5. CONTROLLED DETERIORATION TEST

In the 1988-1989 season, lower germinations were obtained from seeds from bottom pods in the November sown and top pods of December sown peas at the 15% SMC harvest (Table II.15a). However, there was no increase in germination as harvest was delayed as observed in the 1989-1990 season.

For the 1989-1990 season, the harvest at 40% SMC had the lowest 2 d CD germination at both sowing times (Table II.15b).

Table II.15a. Percent normal seedlings obtained from the 2d CD test of garden pea seeds (cv. Pania) as affected by the interaction of sowing date, time of harvest and pod position in the 1988-1989 cropping season.

	SMC AT HARVEST			
	40 % SMC		15 % SMC	
POD POSITION	SOWING DATE NOV	DEC	SOWING DATE NOV	DEC
TOP	78	82	82	72
BOTTOM	85	84	76	84
P-LEVEL = *	$lsd_{(0.05)} = 1.44$		cv = 6.70	

* Significant at 5% level

SMC = seed moisture content

Table II.15b. Combined effects of time of harvest and time of sowing on the germination from 2d CD test of garden pea seeds (cv. Pania) obtained from the time of sowing experiment in the 1989-1990 cropping season.

SMC AT HARVEST	TIME OF SOWING NOVEMBER	DECEMBER
40 % SMC	83.00	80.17
25 % SMC	85.00	81.00
15 % SMC	85.83	86.75
P-LEVEL = **	$lsd_{(0.05)} = 1.64$	cv = 3.02

** Significant at 1% level

SMC = seed moisture content

4.7. HARVEST EXPERIMENT

4.7.1. GERMINATION TEST

In cv. Pania (Figure II.8) the HHMT and MHMT seeds had a low germination when harvested at 40% SMC. However in MHMT seeds, the germination increased as harvest was delayed with the highest germination at 15% SMC harvest. In the HHHT and HHMT seeds the highest germination was attained at 25% SMC harvests and declined at 15% SMC harvest.

In cv. Princess the MHMT seeds had low germination at 40% SMC harvest, increased at 25% SMC harvest but decreased at 15% SMC harvest (Figure II.9). The HHMT seeds had higher germination than the MHMT seeds at 40% SMC harvest but lower than the HHHT seeds. Germination in HHHT and HHMT was not affected by SMC at harvest. However, HHHT had the highest germination at 40% and 15% SMC harvests.

4.7.2. THOUSAND SEED WEIGHT

The HHHT seeds harvested at 40% SMC had the highest TSW which was significantly higher than the other treatments (Figure II.10). The HHMT seeds had low TSW at the 40% SMC harvest, which increased at the 25% SMC harvest and decreased at the 15% SMC harvest. The MHMT seeds had similar TSW at all harvests.

4.7.3. HOLLOW HEART TEST

In cv. Pania significant differences were obtained depending on the time and method of harvest (Tables II.16 - II.17). In cv. Princess the highest hollow heart was at 25% SMC but no further increase was obtained at 15% SMC (Table II.16). Among the methods of harvest tested, the HHMT seeds were associated with the highest hollow heart incidence (Table II.17).

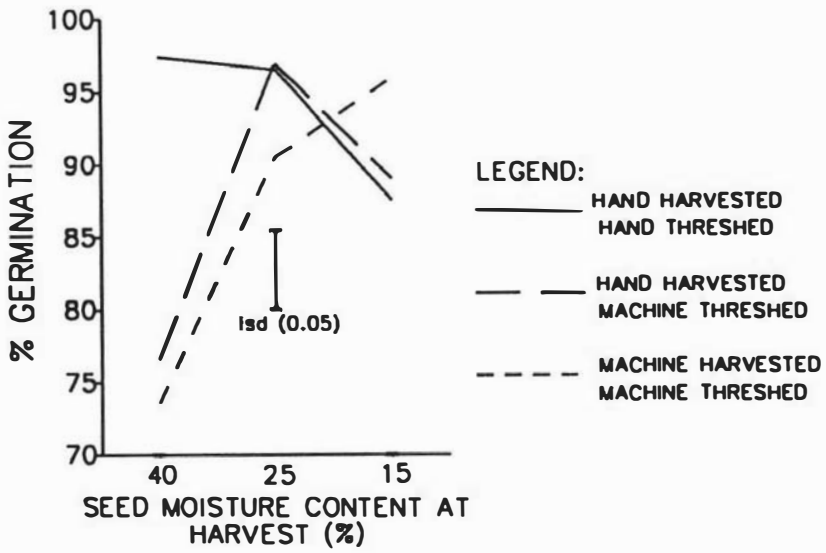


Figure II.8. Percent normal germination of garden pea seeds (cv. Pania) as affected by time and method of harvest.

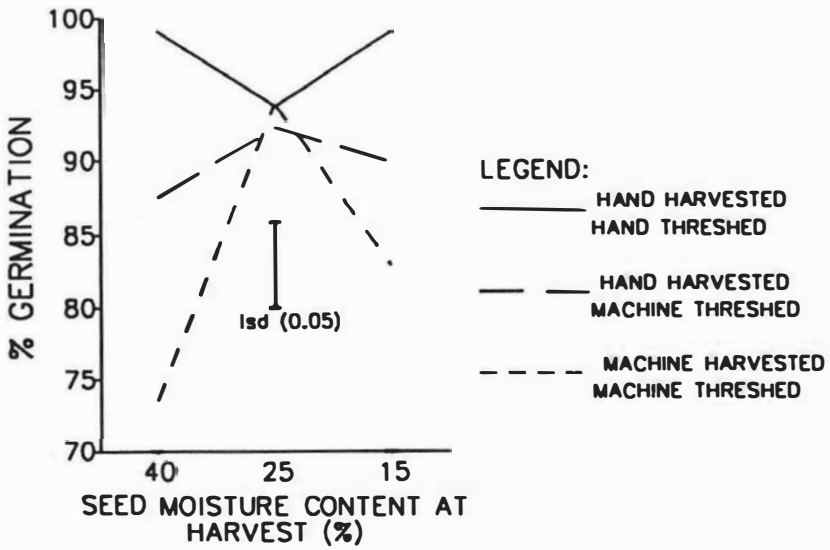


Figure II.9. Percent normal germination of garden pea seeds (cv. Princess) as affected by time and method of harvest.

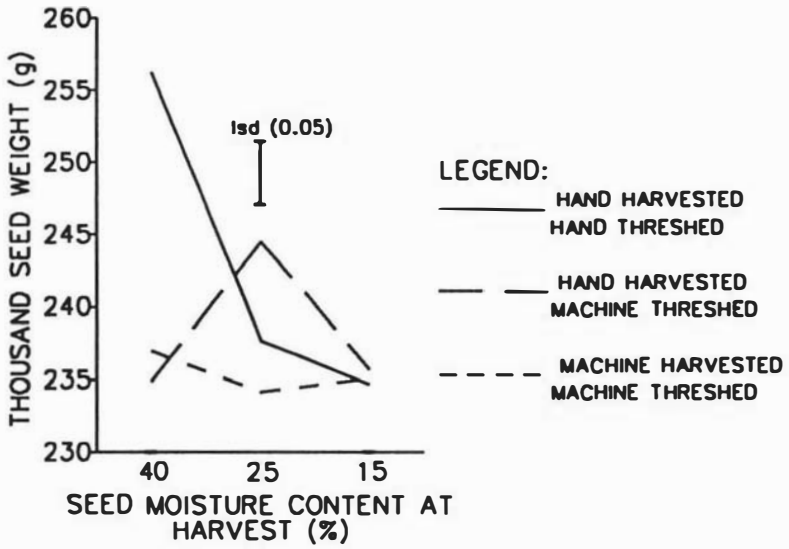


Figure II.10. Mean thousand seed weight of garden pea seeds (cv. Pania) as affected by time and method of harvest.

Table II.16. The effects of time of harvest on the electroconductivity in cv. Pania and hollow heart incidence in cv. Pania and cv. Princess.

SMC AT HARVEST	CONDUCTIVITY cv. Pania	HOLLOW HEART cv. Pania	cv. Princess
40 % SMC	27.1	8.7	3.08
25 % SMC	17.3	11.8	14.83
15% SMC	19.5	21.5	14.50
P-LEVEL	**	**	**
$lsd_{(0.05)}$	2.33	1.64	1.69
cv	13.02	13.88	18.68

SMC = seed moisture content

Table II.17. The effect of method of harvest on the electroconductivity and hollow heart in cv. Pania.

METHOD OF HARVEST	CONDUCTIVITY	HOLLOW HEART
H.H.H.T.	16.3	14.2
H.H.M.T.	24.2	15.2
M.H.M.T.	23.3	12.7
P-LEVEL	**	**
$lsd_{(0.05)}$	2.33	1.64
cv	13.02	13.88

HHHT = hand harvested hand threshed
HHMT = hand harvested machine threshed
MHMT = machine harvested machine threshed

4.7.4. CONDUCTIVITY TEST

In cv. Pania, seeds harvested at 40% SMC had higher conductivity readings compared to seeds harvested at 25% and 15 % SMC (Table II.16). The HHMT and MHMT harvested seeds had a higher conductivity than the HHHT seeds (Table II.17).

For cv. Princess, the MHMT seeds harvested at 40% SMC had the highest solute leakage (Figure II.11). As the SMC decreased at harvest, the conductivity reading decreased regardless of the method of harvest used. However at 15% SMC harvest, HHMT and MHMT seeds had a higher conductivity than HHHT seeds.

4.7.5. CONTROLLED DETERIORATION TEST

In cv. Pania (Figure II.12), seeds from HHMT and MHMT had lower germination than the HHHT seeds when harvested at 40% SMC after the 2 d CD test. The 2 d CD germination between 25% SMC and 15% SMC did not vary significantly among the method of harvest and threshing used. The same pattern of results was obtained from cv. Princess (Figure II.13).

4.8. THE ENVIRONMENT IN THE CROP CANOPY

Seeds obtained from the crop canopy experiment were evaluated for seed quality characters (Appendix II.1). No significant differences in germination were recorded in either year. The germination ranged between 94% and 99%.

The hollow heart in the 1989-1990 season was significantly higher in the bottom pod seeds at 200 plants m^{-2} compared to top and middle pods (Appendix II.1). However at 50 plants m^{-2}, the top pod seeds had higher hollow heart than the middle and bottom pod seeds. In the 1990-1991 season, the bottom pod seeds in cv. Pania had significantly higher hollow heart than the middle and top pod seeds. In cv. Princess the bottom pod seeds had significantly higher hollow heart than the middle pod seeds.

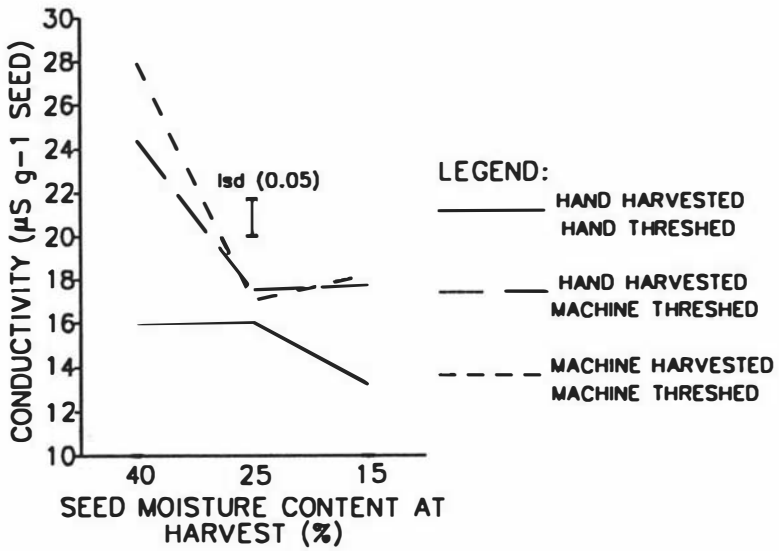


Figure II.11. The electroconductivity reading obtained from garden pea seeds (cv. Princess) as affected by time and method of harvest.

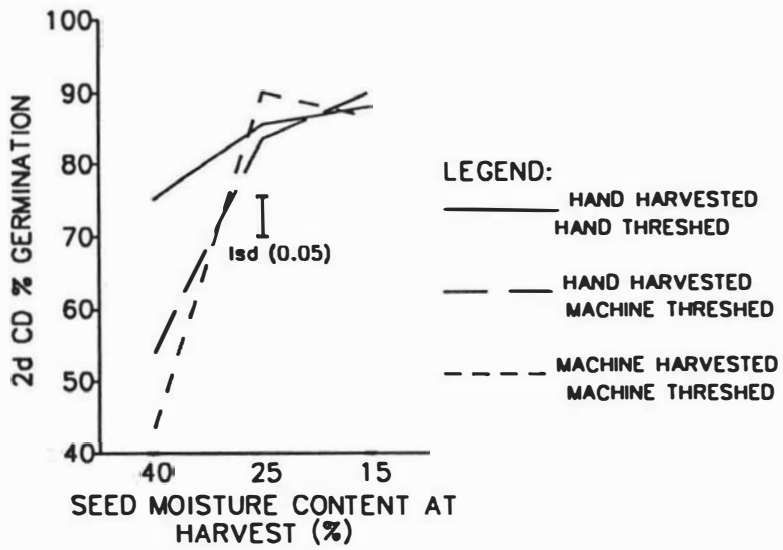


Figure II.12. Percent normal seedlings obtained from the 2d CD test of garden pea seeds (cv. Pania) as affected by time and method of harvest.

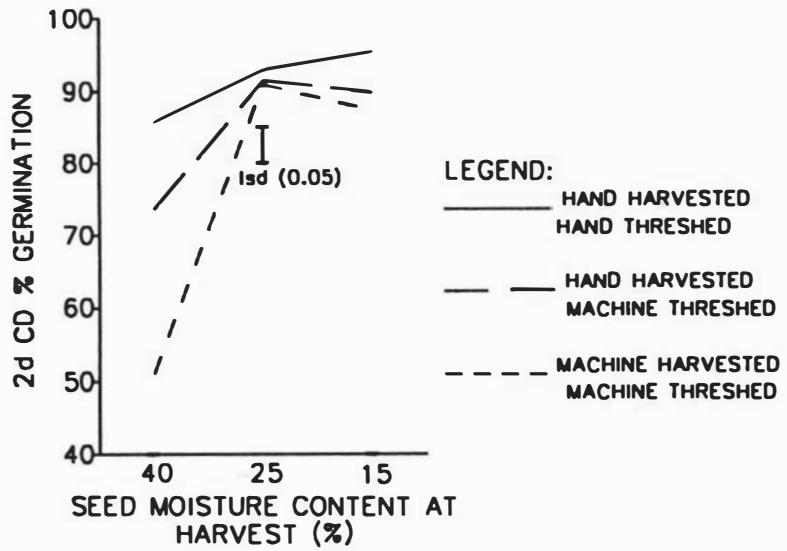


Figure II.13. Percent normal seedlings obtained from the 2d CD test of garden pea seeds (cv. Princess) as affected by time and method of harvest.

4.8.1. TEMPERATURE IN THE CROP CANOPY

The temperature within the canopy of the pea crop was usually higher than the air temperature (Figures II.14, II.15 and II.16). Within the canopy of the 200 plants m^{-2} population density, temperature was 1°C - 5°C higher and reached a maximum of 34°C in cv. Princess (Figure II.14a) at 4 days before harvest while 1°C - 4°C increases were recorded at 100 plants m^{-2} (Figure II.14b).

In cv. Pania, the temperature in the canopy was consistently highest at the 200 plants m^{-2} population density (Figure II.14b). Although both cultivars had higher canopy temperature than air temperature, cv. Pania had higher canopy temperatures than cv. Princess (Figure II.15).

On a clear sunny day the bottom canopy of cv. Princess in all population densities (50, 100, 200 plants m^{-2}) had higher temperatures than the air temperature (Figure II.16). The middle canopy had higher temperature than the air temperature at 100 and 200 plants m^{-2} but the top canopy did not differ.

4.8.2. RELATIVE HUMIDITY IN THE CROP CANOPY

The relative humidity within the crop canopy was higher than the air relative humidity in the 1989-1990 season (Figure II.17) and for most of the 1990-1991 season (Figure II.18). The relative humidity reached up to 100% in the 200 plants m^{-2} population density in both cultivars in both seasons (Figures II.17 and II.18), and in 1989-1990 relative humidity within the canopy increased as population density increased.

The canopy structure of cv. Princess enabled the cultivar to hold more moisture than the canopy of cv. Pania (Figure II.18). However, the relative humidity within the canopy of cv. Pania had a greater fluctuation than in cv. Princess.

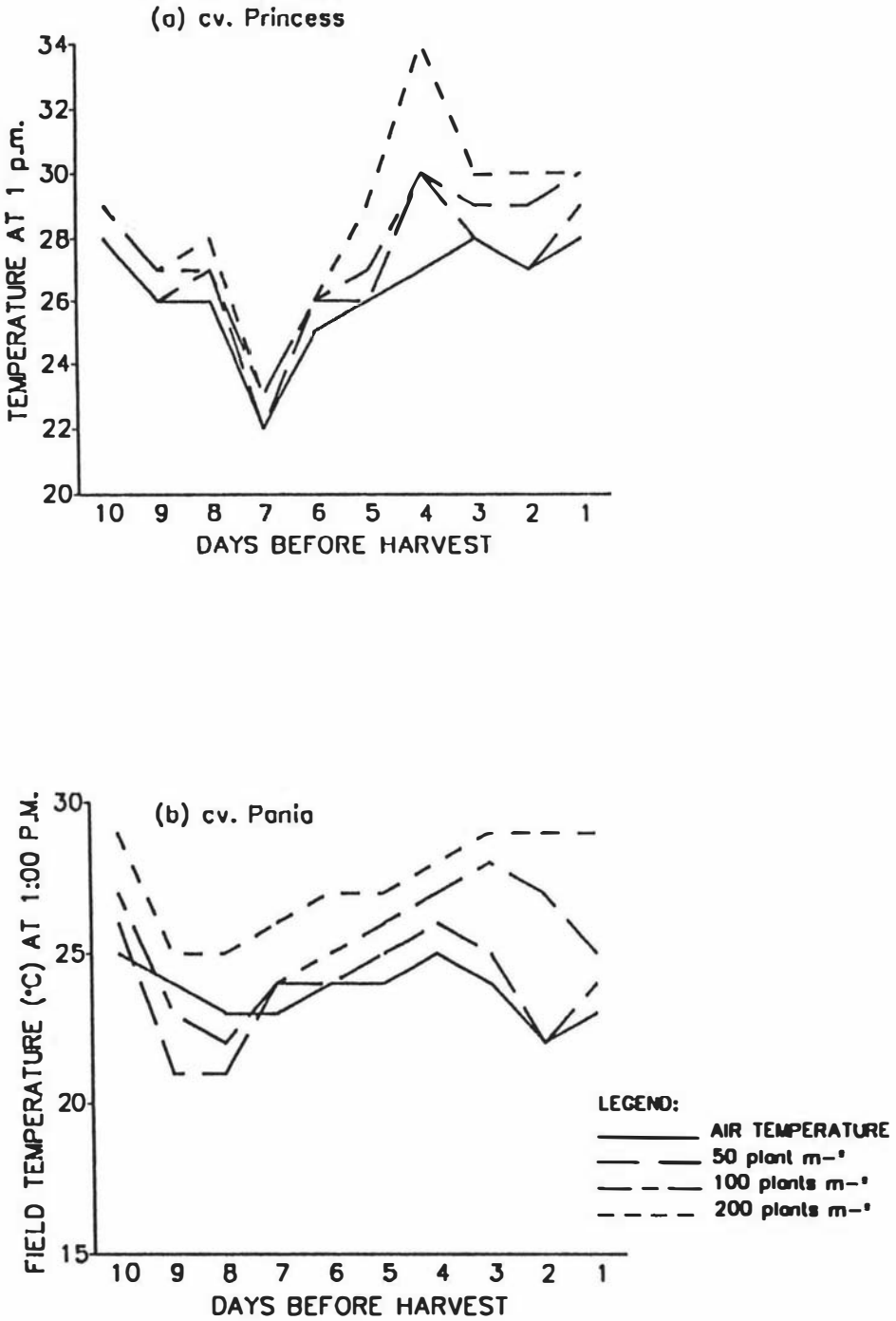


Figure II.14. The temperature (°C) within the canopy obtained at 1:00 p.m. from the different population densities, and air temperature in (a) cv. Princess (b) cv. Pania.

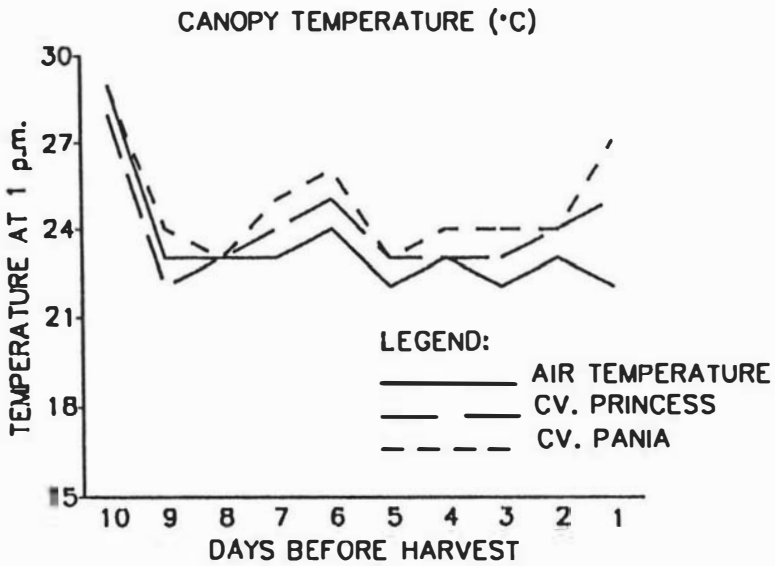


Figure II.15. The temperature (°C) within the canopy of cv. Pania and cv. Princess sown 200 plants m^{-2} and air temperature obtained at 1:00 p.m. in a ten day period before the 15% SMC harvest.

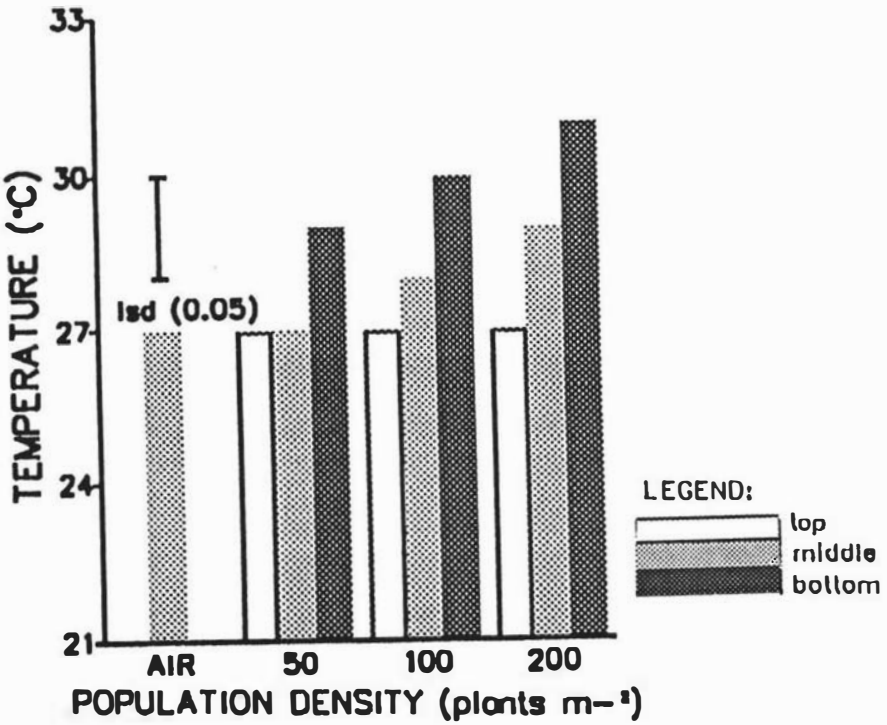


Figure II.16. Example of temperatures (°C) of the top, middle and bottom of the canopy obtained at 1:00 p.m. from the different population densities compared with the air temperature in cv. Princess.

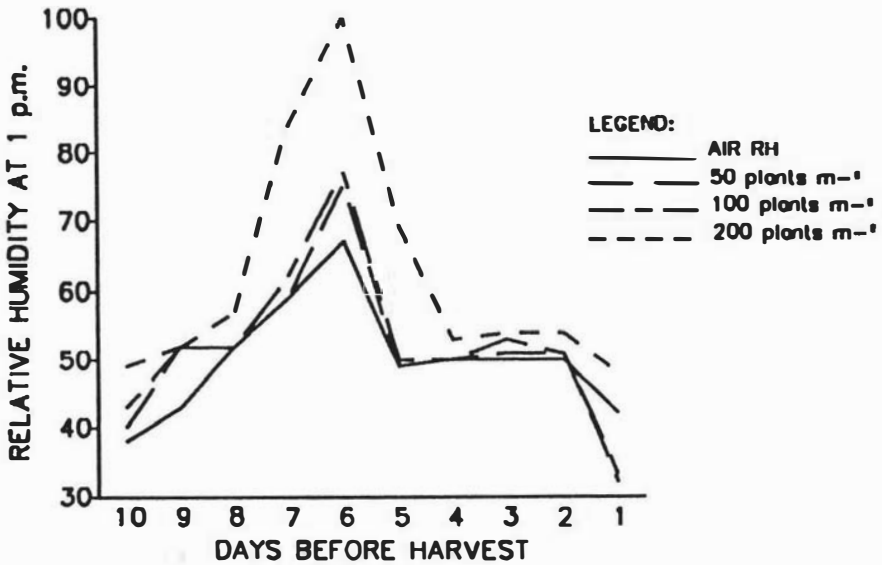


Figure II.17. The percent relative humidity within the canopy of garden pea (cv. Princess) grown at different population densities obtained at 1:00 p.m. in a ten day period before 15% SMC harvest in the 1989-1990 season.

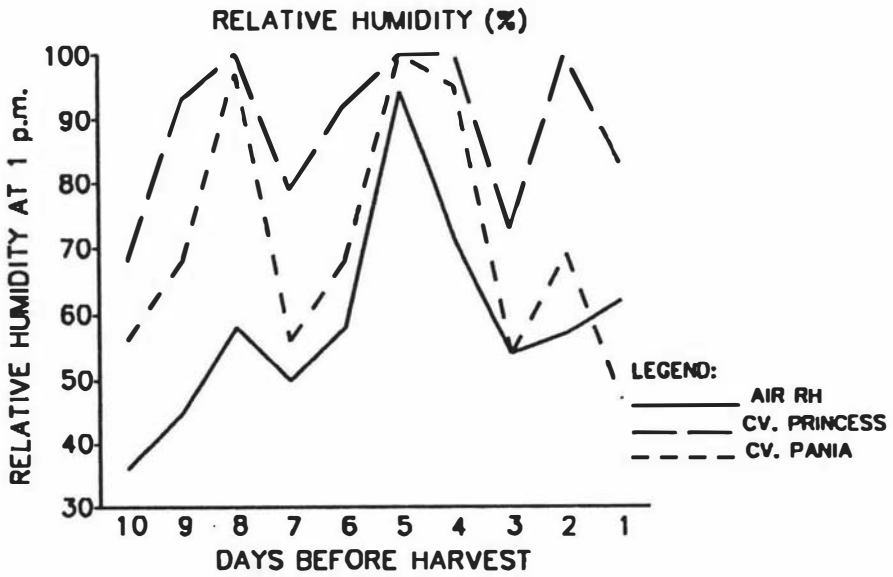


Figure II.18. The percent relative humidity within the canopy of cv. Pania and cv. Princess sown at 200 plants m^{-2} and air relative humidity obtained at 1:00 p.m. in a ten day period before the 15% SMC harvest in 1990-1991 season.

CHAPTER FIVE

DISCUSSION

This study examined three factors which may influence garden pea seed quality: population density, row width and time of sowing. In addition, the influences of time and method of harvest and pod position on seed quality were established. Interactions between these factors were also evaluated.

Seed vigour is a concept describing several seed performance associated characteristics (ISTA, 1987). It can encompass potential seed performance both in the field and in storage (Hampton and Coolbear, 1990). Seed vigour can be considered a reciprocal of the deterioration processes involved with seed ageing, both pre- and post-harvest, in that vigour decreases as the level of deterioration increases. Seed deterioration begins from the time seeds attain physiological maturity, and its time course may range from a few days to many years depending upon factors such as genetic constitution, the environment, seed moisture content and physical damage (Hampton and Hill, 1990). Biological changes occur, following a generalised sequence, and involving changes in solute leakage, enzyme activity, respiration and ATP content, protein and DNA synthesis, the chemical content of the seed, and genetic changes (Powell, 1988).

The consequences of seed deterioration are a progressive reduction in performance capabilities, such as reduced germination rate, lowered germination, and consequently increases in abnormal seedlings and dead seed (Hampton and Hill, 1990). Loss of vigour often precedes loss of germination (AOSA, 1983; ISTA, 1987; Wang and Hampton, 1991), so that although two seed lots may have similarly high germination values, one seed lot can be physiologically older than the other (i.e. more deterioration has occurred); thus its vigour is lower, and it cannot perform as well as the high vigour lot.

Garden peas are grown in various environments that greatly influence seed vigour. High temperature can depress yield (Pumphrey and Ramig, 1990) and increase hollow heart incidence (Halligan, 1986). Although spring and summer temperatures are suitable for pea growing, the temperature within the canopy of the crop can increase,

which can cause stress conditions during seed development and maturation (Perry and Harrison, 1973; Halligan, 1986). Irrigating peas at flowering increases yield (Gane *et al.*, 1984), but excessive moisture during maturation and harvest is detrimental because moisture encourages seed deterioration through weathering (Matthews, 1973; Delouche, 1980).

Plant density affects the yield potential (Anderson and White, 1974; White and Anderson, 1974; Stoker, 1975) and growth characteristics of the pea crop (Gane, 1985). Peas are grown in rows for ease of cultivation, weed control and harvest (Gane, 1985). Population density and row width effects on yield have been well studied in garden peas (White and Anderson, 1974; Stoker, 1975; Gane *et al.*, 1984; Gane, 1985). However, few studies have considered the relationship between population density and/or row width and seed quality. This study attempted to document the effects of pod position and time of harvest as influenced by population density, row width and time of sowing on seed quality and vigour in garden peas grown under field conditions. The influences of type and method of harvesting on the vigour of garden peas were also studied. Furthermore, interaction effects between these factors were also evaluated.

5.1. EFFECTS ON GERMINABILITY

The recommended plant population of 80-100 plants m^{-2} with a 20 cm row width (White and Anderson, 1974; Stoker, 1975; Gane *et al.*, 1984) in garden peas is aimed to maximise yield. In this study, seeds produced from 100 plants m^{-2} at 20 cm row width had high germination (Tables II.5 and II.7). Reducing the population to 50 plants m^{-2} or increasing it to 200 plant m^{-2} did not affect the germinability of seed produced. Altering the row width to 10 cm or 40 cm also did not significantly affect germination. High germinating seeds were also obtained from both the November and December sowings at the recommended density and row width.

Furthermore, seeds hand harvested at 40% SMC (1989-1990) had high germination, comparable to the seeds harvested at 25% SMC and 15% SMC. Although the seeds were still considered immature for harvest at 40% SMC, they had the capacity to germinate when placed under suitable conditions (ISTA, 1985; Le Deunff, 1989).

However, the use of machinery in either harvesting and or threshing of seeds at high SMC (40%) resulted in low germination (Figure II.8) in HHMT and MHMT treatments. The seeds were prone to damage due to the high moisture content of the seed. This result supports the findings of Mashauri (1991) who showed that maize (*Zea mays* L.) seeds threshed at high SMC suffered a high level of bruising and internal damage. Furthermore, Escasinas (1986) reported that harvest damage to maize seeds caused reductions in seed quality and low germination because of cracks at or near the embryo axes. As the pea seeds dried out, i.e. reduced their SMC to 25%, germination increased. This agrees with the findings of Moreira *et al.* (1981) who reported that at optimal seed moisture content, seeds are dry enough to prevent rupture of cells and release of destructive hydrolytic enzymes upon impaction, but not dry and brittle enough to promote fracturing and mechanical damage.

5.2. EFFECTS ON THOUSAND SEED WEIGHT

Seeds produced at the top of the plant at the 200 plant m^{-2} density and seeds from the December sowing harvested at 40% SMC (Table II.12a) had low thousand seed weight. The top seeds were not fully mature either when the plants were at the senescence stage (Table II.5) or when harvested at 40% SMC. The low TSW could be attributed to the limitations of source reserve nutrients (Flinn and Pate, 1968, Pate and Flinn, 1977) or in the case of seeds from the December sowing, plants were senescing before physiological maturity had been attained .

The December sowings in 1989-1990 had lower TSW than the November sowings (Tables II.12a-b). However, they possessed high germination and TSW was not related to the results obtained for hollow heart, conductivity and controlled deterioration. These results confirm that TSW can be a poor vigour determinant and seed size or weight often has little relationship to vigour (Wang, 1989). Therefore the low TSW from the December sowings does not mean low seed quality. This is in contrast with the findings of Smith and Camper (1975) for soybean but supports the findings of Eua-Umpon (1991) for soybean and Wang (1989) for red clover.

Lower TSW was also exhibited by the seeds harvested at 40% SMC from the HHMT and MHMT than from the HHHT treatment. In HHMT, harvested pea plants were dried in the field for three days before threshing. The lower TSW at the 40% SMC harvest for HHMT is therefore likely to have resulted from the drying in the swath after harvest. For MHMT, seeds were damaged at the 40% SMC harvest as leakage of solutes was high. Loss of cell contents through damaged membranes and cracked seed coats may therefore have contributed to lower TSW for this treatment.

5.3. EFFECTS ON HOLLOW HEART INCIDENCE

The increasing incidence of hollow heart as harvest was delayed (Figures II.3 and II.6) can be related to the exposure of the seeds to higher temperature (Figures II.14, II.15 and II.16) especially for the bottom pods at the 200 plants m^{-2} density. This supports the results of Halligan (1986) who showed that hollow heart increased with the length of exposure to high temperature. Although the air temperature was favourable for pea production, the canopy temperature was 2 or 3°C higher, which can result in an increase in hollow heart (Perry and Harrison, 1973; Halligan, 1986). Temperature can also increase inside the pod above the already high canopy temperature (Perry and Harrison, 1973) which may also have triggered the increase in hollow heart in the bottom pod seeds.

Reducing the row width to 10 cm at 100 plants m^{-2} produced a high incidence of hollow heart from the bottom pods. Altering the row width to 40 cm resulted in a higher incidence of hollow heart in seeds from the top of the plants (Figure II.6). These results suggest that wider spacings either between rows or within the row increase hollow heart incidence in garden peas.

The high hollow heart in HHMT seeds could be associated with drying of the seeds in the swath. The seeds obtained from HHHT and MHMT were brought to the laboratory immediately after harvest and were not exposed to field conditions after harvest. During the three day exposure in the field, hollow heart incidence increased as seeds were exposed to high temperature (Figure II.14). Adverse

weather in the field (Figures II.14 - II.18) can cause severe seed quality problems (Delouche, 1980) and high temperature increases the incidence of hollow heart (Perry and Harrison, 1973; Halligan, 1986).

Although the hollow heart incidence during development was higher in seed from top pods than middle and bottom pods at 50 and 100 plants m^{-2}, it did not increase as harvest was delayed. This could be attributed to lower temperatures within the top canopy of the 50 and 100 plants m^{-2} populations than in the 200 plant m^{-2} population density (Figure II.16) and a shorter period of exposure to high temperature (Figure II.14).

5.4. EFFECTS ON SEED VIGOUR

There were high leachate conductivity readings and low CD germination in seeds harvested at 40% SMC. This was related to the harvest immaturity of the seeds and damage at harvest (Gane *et al.*, 1984). Seed moisture content varied within the crop, i.e. although the SMC averaged 40% for the whole crop, the top pod seeds were at 54% SMC while the bottom pods were at 20% SMC in the 1989-1990 season (Table II.4). Seeds which have high SMC at harvest can have a high level of damage (Mashauri, 1991), and this is likely to have triggered the high solute leakage obtained in this study.

However, when seeds were harvested at 25% and 15% SMC the leachate conductivity decreased. A fall in the leachate conductivity during seed maturation is usually observed in peas (Bedford and Matthews, 1975), and a sharp fall in the conductivity of pea seeds occurs as seeds develop the ability to withstand post-harvest drying without loss of viability (Bedford and Matthews, 1975; Powell, 1988).

The seeds harvested at 15% SMC at the 200 plants m^{-2} density had high leachate conductivity but 2 d CD germination were above 85% in all pod positions (Figures II.4 and II.5). At 100 plants m^{-2} population density the top pods had high leachate conductivity while in the 50 plants m^{-2} population density the top and middle pod seeds had higher leachate conductivity than the bottom pod seeds.

These results suggest that the canopy environment (high temperature and RH) at the 200 plants m^{-2} population density was associated with the high leachate conductivity regardless of the pod position when seeds were harvested at 15% SMC. At lower population densities (50 and 100 plants m^{-2}) and for seeds harvested at 15% SMC, the top pod seeds had been exposed to more adverse environmental conditions for a longer period of time, which resulted in higher leachate conductivity than that obtained from the bottom pod seeds.

Seeds from the December sowing had low conductivity and high germination in the controlled deterioration test (Tables II.13a-b and II.15a-b). The higher conductivity readings from seeds harvested from the November sowing (Tables II.13a-b) were due to the exposure of the seeds to greater stress conditions during development on the mother plant compared to seeds harvested from the December sowings. November sown peas produced seeds during January where the maximum temperatures were higher and with a wider daily range (Figures II.19 and II.20) than February, when seeds from the December sowing were developing. Furthermore, more rainfall and a wider range of relative humidities occurred in January than February. These results suggest that the recommended sowing date for garden peas could result in lower seed quality. The major factors influencing the extent of ageing on the plants are seed moisture content and temperature (Hampton, 1990). In this study, the high temperature in January influenced the ageing of seeds from the November sowing and this was likely to be further damaged by the wider range of RH. However, a crop can be managed to avoid prolonged exposure to an adverse environment during seed development and maturation, and produce high vigour seed (Hampton, 1990) shown by the December sowing where temperature was lower during seed development and maturation (February). Furthermore, the 60 year average maximum temperature in Palmerston North for January is 29°C while that of February is 22°C (DSIR, 1990) which supports the findings in this study that seeds from a late sowing (December) produced higher vigour seeds than those from a November sowing, because the seeds were grown in a more favourable environment during seed development.

There are many changes in the organisation of cells during the development of seeds to physiological maturity (Abdul-Baki, 1980; Delouche, 1980) and the main components of the cell organisation are the cell membranes (Powell, 1988). The

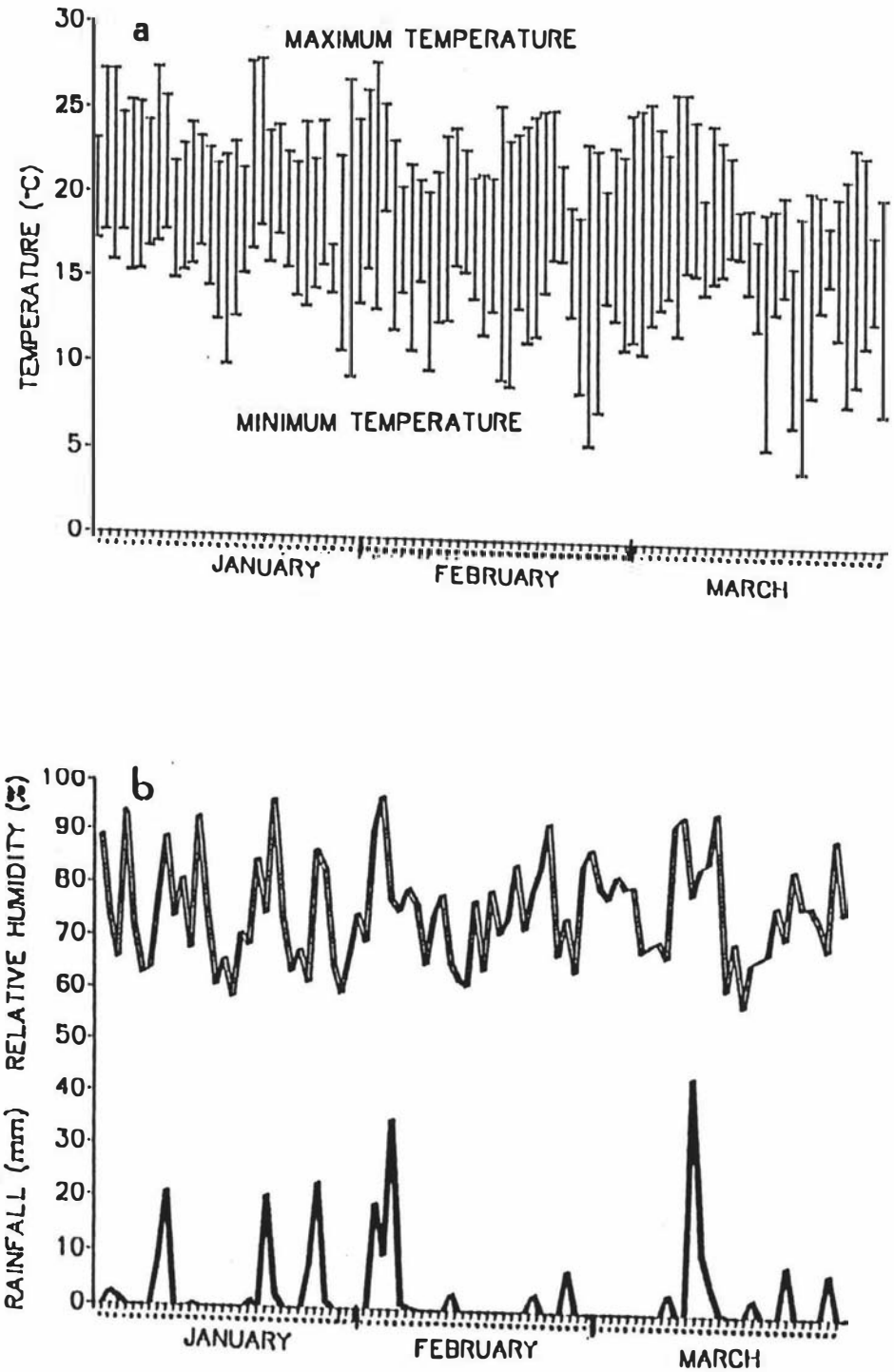


Figure II.19. The weather data in January - March 1989 obtained at DSIR, Palmerston North, New Zealand; (a) minimum and maximum temperatures (b) rainfall and relative humidity.

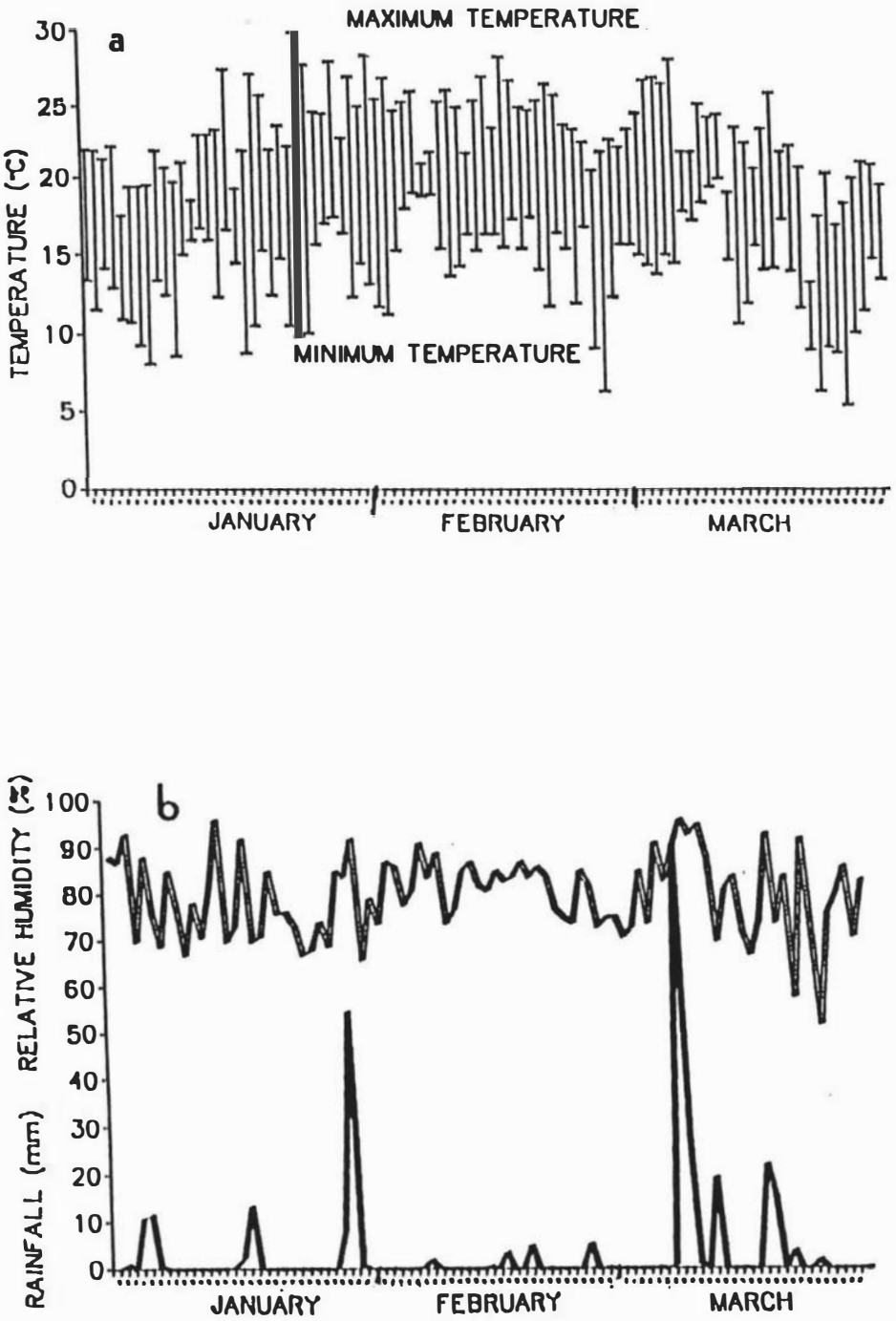


Figure II.20. The weather data in January - March 1990 obtained from DSIR, Palmerston North, New Zealand; (a) minimum and maximum temperatures (b) rainfall and relative humidity.

importance of cell membrane integrity in the successful germination and establishment of seeds has been emphasised by their association with the causes of differences in seed vigour (Powell, 1988; Hampton, 1990). It seems therefore, that high temperature within the canopy of peas can damage potential membrane integrity on subsequent germination even when seeds are still attached to the mother plant.

Seeds harvested at 40% SMC using HHMT and MHMT had lower vigour than seeds obtained from HHHT as revealed by the controlled deterioration test (Figure II.12). However when harvest was delayed to 25% and 15% SMC, germination after the CD test was comparable in all treatments (Figures II.12 and II.13). This result would imply that machine harvested peas at 25% SMC are not damaged and can withstand the impact of machine harvesting. The seed vigour was comparable to the hand harvested peas, even though machinery was used in harvesting. However, peas machine harvested at 15% SMC had higher leachate conductivity (Figure II.11) and high hollow heart incidence in cv. Pania (Table II.16). This supports the findings of Gane *et al.* (1984) that damage can occur in seeds when harvested at 15% SMC because the seeds are brittle and easily crack during harvest. Direct machine harvesting should be employed when seeds attain a SMC of 25% to avoid bruising damage and thus reduce the likelihood of cell membrane damage resulting in low vigour seeds (Matthews, 1973; Gane *et al.*, 1984).

5.5. CONCLUSION

Seed quality and vigour were affected by population density, row width, time of sowing and method and time of harvest in various ways. Machine harvesting peas at 40% SMC increased the risk of producing low quality seed because of a high incidence of damaged seeds, and seed immaturity, which lowered germination and TSW. As a result seeds had high leachate conductivity and low CD germination and therefore low vigour. Delaying the harvest to 15% SMC increased hollow heart incidence and leachate conductivity suggesting that the seeds were of lower quality. These unwanted seed quality characters were not

manifested on seeds harvested at 25% SMC and this SMC is therefore recommended as the stage for harvesting peas, providing of course that quality is not lost during the drying necessary for safe storage.

Increasing the population density to 200 plants m^{-2} or reducing the row width to 10 cm lowered seed vigour due to the stress conditions brought about by increased temperature and RH within the canopy. This environment caused an increase in hollow heart incidence, especially when seeds were harvested at 15% SMC. The bottom seeds were inferior in quality because the bottom canopy temperature and RH were higher than the middle and top canopy, which caused deterioration, as revealed by the conductivity and controlled deterioration tests, and an increase in hollow heart incidence. This study therefore has demonstrated that a 200 plants m^{-2} population density and/or 10 cm row width is unwise for the production of high quality garden pea seeds.

Seeds exposed to high temperature in the field after harvest are prone to deterioration and an increase in the incidence of hollow heart which consequently increases the risk of producing low vigour pea seeds. This study therefore firmly suggests that windrowing should not be employed in garden pea seed production.

Higher seed quality and vigour was obtained from the December sowing than in the November sowing. This can be attributed to the more favourable environmental conditions during the production and maturity of seeds sown in December. Sowing therefore should be altered and timed in such a way that seeds develop and mature when the environment causes less deterioration of seeds (e.g. in the December sowings in Manawatu, seeds developed and matured during February or March when the temperature and RH were more mild). From this study and at this site, December sowing is recommended for the sowing of garden peas for high quality seed production.

Sowing seeds at 100 plants m^{-2} in 20 cm rows in December and harvesting at 25% SMC are therefore recommended for the production of high quality garden pea seeds. Although significant factors in the production of high vigour garden pea seeds were identified in this study, there are also areas for further investigation. Further studies should be conducted on other environmental factors

associated with the mother plant, as in this study they were limited only to temperature and relative humidity, and such data should also be accumulated for other sites. It is also suggested that further study should be conducted using other cultivars, i.e. semi-leafless and leafless garden peas. Similar studies should also be conducted in other leguminous crops where seed vigour is a quality problem.

SECTION THREE

LABORATORY METHODS FOR THE PREDICTION OF STORAGE LIFE IN GARDEN PEAS (*Pisum sativum* L.)

CHAPTER ONE

INTRODUCTION

Most of the world's agriculture depends upon the principle that once seeds are harvested and dried they can retain their viability for varying periods of time, depending upon the storage conditions (Roos, 1986). However, seeds undergo deterioration in storage which can be caused by many factors before harvest, during harvesting and during processing (Justice and Bass, 1978; Roberts, 1986; Roos, 1986). Furthermore, seed vigour is normally at its greatest level when the seed reaches physiological maturity. After this point seed may become less and less vigorous as ageing proceeds (Moore, 1963; Roberts, 1986; Roos, 1986).

The life span of seeds is associated with loss of vigour and subsequently of viability, which could be slow or rapid, and depends upon the kind of seed, extent of mechanical damage, and environment during seed development, harvest and storage. Based on these factors, seeds therefore could be physiologically still young after long storage, or old and/or dead after few days of storage (Justice and Bass, 1978).

Seeds are divided into two major categories with respect to seed deterioration (Roberts, 1986):

1. Orthodox seeds are those which desiccate naturally on the mother plant and can be dried to low moisture contents without harm. The lower the moisture content and temperature the longer they survive (although exceedingly low moisture contents may cause damage). The relationship between moisture content, temperature, time, and percentage viability can be described quantitatively by simple rules (Roberts, 1986).

2. Recalcitrant seeds, on the other hand, are killed by desiccation and, even under moist conditions, survival is typically limited to a few weeks or months. These seeds are difficult to store and are mainly large fleshy seeds of woody species (Roberts, 1986).

Seeds of economic plants are stored in order to preserve the planting stocks from one season until the next which starts at seed maturity on the plant and ends upon sowing. Types of seed storage were categorised by Harrington (1972) into: (1) Short term in bulk storage, where seeds are held for few months until the next sowing, i.e. most crop seeds; (2) Medium term in bulk or small sample storage, used as reserves which are held for 2 or 3 seasons and used during disasters, or storage for expensive or exotic seeds which are not produced every season, i.e. many vegetable seeds, and (3) Long term small-scale storage of seeds in as near optimum conditions as possible, i.e. for germplasm collection.

Peas can be stored safely at a maximum SMC of 14% without ventilation at 10°C with little loss of viability for one year (Abdalla and Roberts, 1969; Perry, 1969; Gane *et al.,* 1984). However, in unfavourable conditions, i.e. high temperature and moisture, differences in pea longevities between cultivars and harvest years become more apparent (James *et al.,* 1967). The loss of viability for garden peas occurs in a relatively short time (24-45 days) at 35°C or higher (Abdalla and Roberts, 1969). Unfavourable storage conditions may also be manifested in storage during transit, especially between countries, which can take a long time and the use of appropriate storage containers becomes critical (Perry, 1969). Storage containers which are water impermeable and have the ability to maintain low seed moisture content irrespective of ambient RH can protect seeds from deterioration (Southwick, 1974; Justice and Bass, 1978). The use of appropriate storage containers could be important in pea storage and transport where seed quality deterioration is a major problem (Gane *et al.*, 1984).

Before seeds are stored it is common practice to assess their quality. The germination test remains the principal and internationally accepted criterion for seed viability (ISTA, 1985). A germination test result less than an accepted standard indicates that quality of the seed lot is suspect, and that there may be future problems with storage (Hampton and Coolbear, 1990). However, performance differences may also occur between seed lots which the germination test indicates are of similar quality (Wang and Hampton, 1989). Further, seeds which germinate after long storage show reduced growth rates in the seedling stages (Abdalla and Roberts, 1969). Thus, reduced performance in viable pea seeds can result from deterioration in storage and problems may arise before any significant loss in viability has occurred (Matthews, 1977). The performance difference between high quality seed lots is attributed to seed vigour and

in this circumstance, vigour becomes important and vigour testing necessary (Hampton and Coolbear, 1990). Results from vigour tests can be utilised for the determination of the relative storage potential of seed lots and prediction of storage life (Justice and Bass, 1978; ISTA, 1987), but there have been no studies done for garden peas. The role of seed vigour in seed storage has not been well studied and an improved knowledge of this could contribute to better seed store management for peas.

The improved viability equation formulated by Ellis and Roberts (1980a) has greatly facilitated the prediction of seed survival in storage. However, species-specific constants are needed in using the equation, which are available for some crops, i.e. barley and onion, but not for many others including garden peas.

This study was therefore formulated with the following objectives:

1. To determine the interactions between garden pea seed lots of different vigour and different storage conditions with respect to changes in both viability and vigour.
2. To determine whether the relative storability of different pea seed lots with high initial percentage of germination, but differing vigour can be predicted by pre-storage vigour tests.
3. To evaluate the appropriateness for garden peas of the improved viability equation formulated by Ellis and Roberts (1980a).

CHAPTER TWO

REVIEW OF LITERATURE

Prediction of seed storage life with a high degree of precision is important especially in long term seed storage. This serves as a guide on the planting value of a seed lot or production of new set of samples for genetic conservation. Survival curves are now available for some crop species based on the normal distribution of the decline in germination from long term storage experiments and will be discussed in this review.

Seeds are stored from maturity to sowing and during this time are subject to deterioration. The problem of seed deterioration in storage is affected by several factors, i.e. production practices and storage conditions. Seed vigour is affected by deterioration before and during storage and may be used in evaluating the storage potential of a seed lot. These factors can affect the quality of seed in storage and have been well studied in many crops. When data for peas are wanting, discussions in this review were based from other crops especially legume species.

High relative humidity in storage can increase the seed moisture content which eventually cause seed deterioration. This bring about the importance of using appropriate seed container in storage. Seed containers are also critical during transport especially between countries.

This review therefore gives insights on some established findings and developments in the methods for predicting storage life, factors that affect storage life and seed packaging for seed longevity.

2.1. METHODS FOR PREDICTING STORAGE LIFE

Loss of storage potential is one of the specific consequences of seed deterioration, just as is a decrease in germination rate, and an increase in the incidence of seedling abnormalities (Delouche, 1980). Loss of the capacity to germinate is about the last thing that happens as a seed dies (Bewley, 1986). No seedsman

knowingly stores weak or non-germinable seed. However, all too often the seeds he stores have good germination but poor storage potential (Delouche and Baskin, 1973). Thus it is very important to determine storage life and to predict the storability of seeds, especially in long term genetic conservation of crops or in gene banks (Roberts, 1986; Roos, 1986).

2.1.1. SEED SURVIVAL CURVES

The work of Roberts and his associates (Roberts, 1960; Roberts, 1972; Ellis and Roberts, 1980a; Ellis, 1984; Roberts and Ellis, 1984) has led to detailed descriptions of the effects of temperature, humidity and moisture content on the loss of viability in a number of species. These data are based on the behaviour of hermetically stored seeds at combinations of constant temperatures and moisture contents.

The decline of seed viability as SMC and storage temperature increase follows a normal distribution of deaths in time. This suggested that loss of viability could be predicted in orthodox seed and led to the development of the basic viability equations (Roberts, 1972). The basic viability equations can predict the expected percentage viability after a given period of storage under any combination of temperature and seed moisture content during medium-term storage (2 - 3 years) with a high level of accuracy (Ellis and Roberts, 1980a). However, the basic viability equations had limitations. Variations between seed lots (i.e. seed vigour) before storage are not taken into consideration in the prediction of storage life. The linear relationship between storage conditions (temperature and SMC) and viability period are accurate only within a narrow range, i.e. barley 6% - 12% SMC and 10°C - 25°C (Ellis and Roberts, 1980b). At wider ranges of storage environments, the relationship between either temperature or SMC and the viability period is not linear, especially under the very low temperature and SMC conditions needed for long term storage.

The results of research on barley lead to the modification of the basic viability equation to account for the inter- and intracultivar variations of initial seed quality within species which affect subsequent longevity in

storage (Ellis and Roberts, 1980a; Ellis *et al.,* 1982). This new viability equation improves the accuracy of prediction over a very wide range of storage conditions (Roberts, 1986).

The first equation describes the viability (v, probit percentage viability) expected after a given storage period (p, days)

$$v = K_i - p/\sigma$$

where K_i (initial germination in probits) is a constant for the seed lot and σ is the standard deviation of the frequency distribution of seed deaths. The differences between seed lots do not affect the value of σ, and are accounted for simply by differences in the value of K_i.

The storage environment affects σ according to the equation:

$$\log \sigma = K_E - C_W \log m - C_H t - C_Q t^2$$

This equation estimates the value of σ expected in an environment with a seed moisture content of m(percent, fresh weight) and temperature t(°C). The K_E, C_W, C_H, and C_Q are constants whose values are common to all seed lots of a species.

The seed survival curve derived from the two equations can then be presented as:

$$V = K_i - p/10^{K_E - C_W \log m - C_H t - C_Q t^2}$$

Thus, according to this model, seed storage conditions inevitably affect the slope ($1/\sigma$) of the survival curve but not the initial viability (K_i) before the seeds are stored, whereas genotype and pre-storage environment affect the value of K_i but not the slope ($1/\sigma$).

Ellis and Roberts (1980a) proposed that it is quite evident that different species lose viability at markedly different rates under the same storage conditions, but the pattern of deterioration in each case can be described by means of the same general equation. Roberts and Ellis (1984) have supplied species-specific constants that can be used in the deterioration equation for barley and onion but not on many other crops. Seed viability at a later point in time can be predicted from the improved viability equation by using data for the initial germination of the seed lot, seed

moisture content and the temperature during storage (Ellis and Roberts, 1980a). Predictions can be accurately obtained from -20°C to 90°C and from 5% to 18% SMC (Ellis and Roberts, 1980a; Roberts and Ellis, 1984). However, because of freezing damage, seed deterioration under combinations of high SMC and low temperature (below 0°C) storage can be greater than that predicted by the equation (Priestley, 1986). There are some species, e.g. lettuce, where the decline in germination does not follow the normal distribution pattern at higher seed moisture content (above about 15%-20%), which is attributed to the metabolic repair processes that inhibit the decline in viability (Ibrahim and Roberts, 1983).

When germination data are transformed from percentages to probits, the decline in germination become linear, and assessment of the storage life of the seed is facilitated (Priestley, 1986). The half viability period (P50), the time taken for germination to drop to the 50% level is accurately quantified in a probit analysis under constant controlled conditions (Roberts, 1984; Priestley, 1986). However, in exceptionally unfavourable storage conditions, the decline in germination is abrupt at the later stages of storage and does not show the expected "tailing off" in germination decline usual under controlled storage (Priestley, 1986). Further, survival curves for seed lots in ambient conditions, where temperatures and humidity fluctuate, does not follow the ideal deteriorative curve and when subjected to probit analysis, significant non normal distributions are evident (Finney, 1971; Priestley, 1986).

Seed vigour effects are not accounted for in the seed survival curve, although seeds surviving at the P50 level are low in vigour and cannot withstand the rigours of field environments (Priestley, 1986). Seed survival under stress conditions (i.e. field emergence) is always lower than those surviving under favourable conditions (i.e. laboratory germination) (Delouche, 1981) and this becomes more conspicuous in aged seeds (Laughland and Laughland, 1939). So, seed lots which have attained the half viability period (P50) are old and useless for sowing (Priestley, 1986).

2.1.2. ACCELERATED AGEING TECHNIQUES

Accelerated ageing techniques were developed for assaying the relative storage potential of seed lots. These techniques involve exposure of small samples from all lots under test to adverse levels of temperature and relative humidity for two to eight days (40-45°C and 100% RH) or two to twenty four weeks (30°C and 75% RH) followed by regular germination tests (Baskin, 1987). Seed lots that maintain germination well after accelerated ageing also maintain germination well in storage under more normal conditions. Conversely, those that are severely reduced in germination by accelerated ageing decline rapidly in viability during storage (Delouche and Baskin, 1973; AOSA, 1983; ISTA, 1985). The accelerated ageing techniques are effective in evaluating seed vigour and plant performance (Delouche and Baskin, 1973; Baskin, 1987).

The accelerated ageing test can be used in the prediction of field emergence. Delouche and Baskin (1973) found that germination responses after appropriate periods of storage at 30°C and 75% RH were closely associated with those after open storage of 6-12 months in water melon and onion seed lots. The more severe accelerated ageing (40-45°C and 100% RH) tended to correlate more closely with longer term storage responses beyond 12 months (Baskin, 1987).

However, accelerated ageing and storage responses were closely associated in some seed lots of most crops studied (Delouche and Baskin, 1973). They have attributed this to varietal differences and/or mechanical damage. For using accelerated ageing tests to predict storability for a specific period (6-8, 18-20, 30-32 months and so on), the severity of the test conditions should be adjusted to obtain the best information for the storage period desired. Further, since longevity of seed lots in uncontrolled storage is also related to the ambient conditions of the storage site, these too will influence the choice of accelerated ageing required. The time factor must also be taken into consideration in selecting an accelerated ageing regime for use. In many situations the more rapid development of information with severe accelerated ageing conditions will compensate for their somewhat lower efficiency.

To date, accelerated ageing is as yet only recommended as a vigour test for some specific crops. References on the effectiveness of accelerated ageing in many crops, including garden peas, are lacking.

2.1.3. CONTROLLED DETERIORATION

In controlled deterioration, the seeds are taken to a required moisture content before holding in moisture-tight containers at adverse temperatures. Seed lots that have high germination after the controlled deterioration have a potential to maintain high germination in storage (Matthews, 1980; Powell and Matthews, 1984).

The controlled deterioration test has predicted the storage potential of onions and Brussels sprouts under commercial storage conditions (Powell and Matthews, 1984). Seed lots with poor germination after CD showed rapid decline in germination during storage, whereas those with high CD germination retained viability for a longer period (Powell, 1988). However, the CD test resulted in a poor prediction for lettuce, and for this species the repeatability of the test was found to be poor both within and between laboratories (Powell *et al.*, 1984).

The controlled deterioration test is considered to have potential for small-seeded crops, for example vegetables and ornamentals (Matthews and Powell, 1987a). There are no studies on its use in a wide range of other crops, including garden peas.

Controlled deterioration incorporates better control of seed moisture content and temperature during the period of ageing than accelerated ageing (Matthews, 1980). In controlled deterioration, the equilibration of SMC before ageing causes seeds to undergo constant deterioration under stress conditions (Powell and Matthews, 1981). In accelerated ageing, the SMC gradually increases until it reaches equilibrium with the relative humidity (Delouche and Baskin, 1973; Baskin, 1987). Seed lots differ in the rate of

increase in SMC which suggests that the control of the ageing condition is not accurate and the extent of deterioration among seed lots therefore varies (Matthews, 1980).

The controlled deterioration test can be used in the determination of the potential storability of seed lots for short term (one season) or long term storage (Powell and Matthews, 1984). Although the test has potential for predicting the decline in pea germination after various times of ageing, no studies have been conducted.

2.1.4. OTHER TECHNIQUES FOR EVALUATING STORABILITY

Many other tests and measurements were evaluated by Delouche and Baskin (1973) as to their efficiency in predicting the relative storage potential of seed lots: rate of respiration during early stages of imbibition and germination, seedling growth rate, cold tests, glutamic acid decarboxylase activity, electrical resistance of seed leachate and tetrazolium reactions. Results of all of these tests and determinations have been reported to correlate with storability of different lots of some kinds of seeds (Delouche and Baskin, 1973). None of them, however, were as generally applicable and effective as accelerated ageing (Delouche and Baskin, 1973) and controlled deterioration (Matthews and Powell, 1987a).

2.2. FACTORS THAT AFFECT STORAGE LIFE

The factors that control the deterioration of the seed in store are: seed factors, storage factors, and effects of pests and chemicals (Justice and Bass, 1978). The effects of pests and chemicals were not evaluated in the study and are not discussed in this review.

Seed characters affecting storage life include: genetic effects, seed structure and composition, seed dormancy and hard seededness, moisture content, mechanical damage and seed vigour. Mechanical damage, which is associated with membrane damage, and seed vigour factors were discussed in Section One (2.2 and 2.3) and are not further discussed in this section.

Storage factors, i.e. temperature and RH, play vital roles in seed deterioration. The influence of storage environments is discussed as a separate component of the factors that affect storage life.

2.2.1. GENETIC EFFECTS

Seeds of some species can survive a given set of storage conditions longer than others. Essentially all known cases of seeds surviving for a century or more belong to species with hard impermeable seed coats (Roos, 1986). Among the species listed by Harrington (1972) as having a longevity of 10 or more years are legumes which are known to produce hard seeds.

Variation has also been observed among cultivars within a species. Roos (1986) reported that eight cultivars of beans deteriorated at different rates, even though they were produced under the same conditions and stored identically. In *Phaseolus vulgaris* the white seeded cultivar Tenderette had more extensive damage during imbibition than the brown seeded cv. Provider (Powell *et al.*, 1986). These show that cultivars within the species can differ in morphological structures important in the maintenance of high vigour, i.e. seed coat (Delouche, 1980).

Not all seed species, cultivars, or individual seeds within a genetic group are destined to survive for the same period of time under a specified set of conditions. A lot or sample of seeds does not die at one time, but follows the normal distribution of death over time as discussed previously (2.1. Methods of Predicting Storage life).

2.2.2. SEED STRUCTURE AND COMPOSITION

The presence or absence of glumes (lemma or palea) in grasses is a well known example of a seed structure that influences life span. Many crops retain viability better when hulls are retained than seeds of the same harvest that have been threshed and stored (Justice and Bass, 1978). The hull

protects the seed from pest damage in store (Harrington, 1972) and its removal could cause subtle damage which eventually lowers seed vigour (Hampton, 1990).

Generally small seeds escape injury during harvesting and processing, whereas large seeds are more likely to be extensively damaged (Roberts, 1972; Wang, 1989; Eua-Umpon, 1991). Bean and Lima bean are susceptible because the large cotyledons and the location of the embryo axis represent a structure that will tolerate only low levels of impact (Justice and Bass, 1978). Spherical shaped seeds give more protection than flat or irregularly shaped seeds, but this is mediated by exposure of vital parts, seed coat thickness, and its strength or brittleness during impact (Roberts, 1972).

2.2.3. SEED DORMANCY AND HARD SEEDEDNESS

Any healthy seed which fails to germinate when conditions are favourable for growth is dormant (ISTA, 1985). Dormancy is part of the survival strategy of many plants, a means of temporal dispersal. Dormancy differs from species to species, i.e. hard seededness in legumes where the seed coat is impermeable to water, to immature embryos in cereals. During the growing state of the seed one or more dormancy mechanisms may gradually take effect, and depending on the intensity of environmental stimuli received by the parent plant during the seed ripening stage, the seed will exhibit primary dormancy (Duffus and Slaughter, 1980; Bewley and Black, 1982). Seeds undergo gradual release from dormancy which can be a response to specific environmental factors or simply due to the passage of time. Seeds become non-dormant but there is no growth because one or more of the basic environmental factors for growth is absent, this is known as the quiescent state. When all environmental conditions are favourable for germination, dormancy is broken and the seed germinates. In other cases, primary dormancy may be broken many months or even years before conditions become suitable for germination. The seeds may remain

quiescent or may, usually in response to unsuitable environmental stimuli, move into a new and often deeper type of dormancy, secondary dormancy (Villiers, 1975).

Dormant seeds undergo changes, some of which lead to breaking of dormancy and others inducing dormancy which can be affected by storage conditions (Justice and Bass, 1978; Duffus and Slaughter, 1980). Dormancy in immature seeds of barley, oats, rye and wheat persists longer than in mature seeds when stored at 0°C to -35°C, where the duration of dormancy is increased by lowering the temperature (Koller, 1972). But dormancy can be overcome within 1 to 6 months when seeds are stored at 40°C (Justice and Bass, 1978). Dormancy in peanut was overcome when seeds were stored at 20-25°C and 40°C, but dormancy persisted for 2 years under low temperature storage conditions (Justice and Bass, 1978). Storage conditions which reduced the SMC of peas to 7%, i.e. low RH, increased the incidence of hard seeds which subsequently increased seed longevity under hermetic storage (Ellis and Roberts, 1982).

2.2.4. SEED MOISTURE CONTENT

High seed moisture content coupled with high temperature in storage will kill seed rapidly or cause the invasion of microorganisms and insects (Harrington, 1978; Halloin, 1986). However, in practice, most orthodox seeds are stored at low SMC. Moisture removal leads to reduced cell activity because water is a solvent for most biological reactions (Leopold and Vertucci, 1989) and reduced deterioration of seed in storage. At very low SMC the metabolic activities of the seed ceases and there is a little sign of life; but a small increase in SMC will start metabolic processes and cause growth (Priestley, 1986). Most orthodox seeds are usually stored between these two conditions.

Increased SMC in storage causes seed deterioration and shortens storage life. One of the signs of deterioration in stored seeds is changes in the structural components of cells in the seed. In an unimbibed pea seed, the

coalescence of lipid bodies and withdrawal of plasmalemma from the cell wall are signs of deterioration (Harman and Granett, 1972). Evidence of deterioration becomes more obvious upon germination. Deteriorated seed have slow development and in severe cases of deterioration, necrosis and autolysis occur (Priestley, 1986).

Damaged membranes can be detected during imbibition when solute leakage occurs. During imbibition, the transition of membrane phospholipids from the gel phase to liquid-crystalline phase occurs at different times which causes leakage of solutes. However, more leakage occurs in deteriorated seed because of increased damage and slow repair of membranes. The measurement of leakage conductivity is now widely used in the determination of pea seed vigour and has been extensively discussed in Section One.

Deterioration in seeds with low moisture contents is caused by peroxidation either through atmospheric autoxidation on lipids or through the agency of lipoxygenase (an enzyme present in many seeds) (Priestley, 1986). Enzyme activity has been suspected of indirectly generating off-flavours in raw peanuts attributable to lipid breakdown products (St. Angelo *et al.*, 1979). Soybean lipoxygenase has also been shown to function in model systems at a very low level of moisture (Priestley, 1986).

Peroxidation starts by an abstraction of hydrogen (H^*) from a methylene group ($-CH_2-$) adjacent to a double bond (Priestley, 1986). Although it is not clear how this process normally occurs in desiccated seeds, studies in isolated oil suggest that the reaction of metal ion with oxygen to form the superoxide anion (O_2^-) starts the process (Priestley, 1986). Once started, lipid peroxidation can continue as a chain reaction (Justice and Bass, 1978; Bewley and Black, 1986; Priestley, 1986). If enough cells in the meristematic regions are dead the seed can no longer germinate (Harrington, 1972; Cherry and Skadsen, 1986).

However, seeds contain natural antioxidants, the tocopherols (Duffus and Slaughter, 1980; Priestley, 1986) which are effective in reducing the oxidative properties of free radicals causing seed deterioration (Leibovitz

and Siegel, 1980). But there are contrasting research results on the presence of or deterioration induced changes in antioxidants in seeds. Loss of germinability was associated with a decline in tocopherols for wheat, maize, oil seeds and desert plants (Sharma, 1977; Priestley, 1986). But no change in tocopherols were found in soybean when seeds were subjected to 40°C and 100% RH and even when the seeds lost viability (Priestley *et al.*, 1980). These studies show that the role of antioxidants in seed ageing is unclear and needs further investigation.

2.2.5. STORAGE ENVIRONMENT

Storage temperature is a major factor affecting seed longevity. The cooler the temperature the more slowly seed viability declines (Harrington, 1972). High temperatures are also conducive to the activity of microorganisms. At 5°C and below, insects become inactive.

A common problem in large seed stores is movement of water vapour from a warm area to a cool area. For example, along outside walls in cold climates, where cooling is appreciable, the dew point is reached and water condenses on the walls and adjacent seeds. Such accumulations of moisture are prevented by proper construction and proper ventilation of storage facilities (Duffus and Slaughter, 1980).

The moisture of a seed normally comes into equilibrium with the ambient RH, a process known as hysteresis (Harrington, 1972; Justice and Bass, 1978). For most species each seed has its own moisture equilibrium value for a given RH because the molecules in seed vary in the amount of water they absorb. Proteins absorb most water, starch and cellulose less, but still a considerable quantity, while lipids adsorb no water (Harrington, 1972). The hysteresis effect occurs because, on rehydration, dried macromolecules do not completely unfold at intermediate levels and thus do not have as many sites available for adsorption of water molecules. However, at lower storage temperature, the SMC in equilibrium with a given RH is slightly higher because the energy of the water molecules is less at lower

temperature and fewer escape the attractive forces of the macromolecules (Harrington, 1972). It is therefore evident that the SMC in equilibrium with a given relative humidity may have two values, one when the seed is adsorbing moisture (which forms a rehydration curve), and another when it is drying out (which forms the dehydration curve) (Harrington, 1972; Hunt and Pixton, 1974). The SMC in equilibrium with a given RH is higher in the dehydration curve than in the rehydration curve.

The storage atmosphere can affect the deterioration of seed in store. In long term storage experiments, under low temperature and seed moisture content there was little effect on germination by substituting nitrogen, carbon dioxide, argon, etc. for air in the storage container (can) (Bass, 1973; Justice and Bass, 1978). But in a related study on lettuce, carbon dioxide and argon increased the incidence of chromosomal aberrations in root tips of aged seeds (Justice and Bass, 1978).

High respiration of seeds in store is detrimental to seed storage life. Respiration in storage is also affected by pests (bacteria, fungi, insects, mites) associated in or on the seed. Respiration increases as temperature increases until it becomes limited or terminated by inactivation of enzymes or enzyme systems, exhaustion of substrate or oxygen, and accumulation of carbon dioxide to inhibitory levels (Roberts, 1973b; Justice and Bass, 1978; Priestley, 1986). The most effective method of keeping the respiration of stored seed to a minimum is to keep the seed dry, stored at low temperature and at an RH that will maintain a safe moisture content throughout storage.

2.3. SEED PACKAGING FOR SEED LONGEVITY

Where seed storage conditions are less than ideal, packaging can be used effectively to protect seed and, in certain cases where the chosen packaging material is water impermeable, maintain their moisture content irrespective of the ambient relative humidity of the seed store. The package is a storage container. It must protect the seed from physical damage, from losses or deterioration during storage, be useful for display and must be convenient to use (Southwick, 1974).

Common packaging materials are cotton, jute, paper, aluminium foil, tinplate, plastic films, laminates, etc. The hazards incurred by packages in the tropics are more severe compared to temperate zones, because of poorer transport systems, increased risk of infection and, most important, climate (Warham, 1986). Often the choice of packaging materials is based on cost effectiveness and availability of local materials. However, conditions under which the seeds are to be produced, processed and stored are also crucial. It is not a good policy to assume that temperate-high-technology packing methods can be transferred directly to tropical situations.

Decisions about appropriate packaging are important components of seed store management and subsequent distribution. Choice should be viewed against the conditions under which the seeds are to be produced and stored, i.e. it would be inappropriate to store high moisture content seed in effectively moisture-proof packages. Storage requirements are also crucial, varying from tropical short-term bulk storage to low-temperature small scale long-term storage such as might be found in germplasm centres.

Seed survival in packages largely depends on the ability of the packages to maintain low seed moisture content (Justice and Bass, 1978). The moisture resistance of the packaging materials is based on the water vapour transmission rate (WVTR) measured in $g/m^2/d$ and is the rate at which water vapour passes through a unit area of material per day at 37.8°C from 100% RH on one side to 0% on other. WVTR is a good physical criterion for the comparison of moisture protection by seed packaging materials of any combination (Ching and Abushakra, 1965). Further moisture absorbance by packaging materials is also crucial to prevent rotting.

2.4. CONCLUSION

The importance of determining the relative storability and prediction of storage life of seeds is inescapable, especially in long term storage. The improved viability equation of Ellis and Roberts (1980a) has made it possible to predict storage life under a wide range of constant environments. However, species-specific constants are not as yet available for all crops.

Seed longevity in storage is affected by factors inherent to the seed and the storage conditions. These factors influence the deterioration of seeds in storage. Seed deterioration causes a decline in vigour before any decline in viability. Differences in the performance of high germinating seed lots after storage can therefore be attributed to differences in vigour. Further, seed vigour can be influenced by the environment before and during storage. It is therefore apparent that seed lots come into store at various levels of vigour and may be expected to decline in vigour and viability at different rates in storage. These relationships are not well understood in garden peas, and hence this study was conducted.

Seed vigour in garden peas is primarily used in the determination of the planting value of a seed lot, but vigour tests can also be used in determining the storage potential of a seed lot. The controlled deterioration test has been used as a predictor of storage potential in some vegetable crops, i.e. onion and brussel sprouts. However, the potential of vigour tests in the prediction of storage life for garden peas has not been investigated. This study therefore explored the potential of vigour tests for the prediction of the relative storability of garden peas.

CHAPTER THREE

MATERIALS AND METHODS

3.1. SEED LOTS

Five seed lots from two cultivars, Pania (2 seed lots) and Princess (3 seed lots) obtained from Challenge Seeds Ltd., Palmerston North, New Zealand were used in this study. The Pania seed lots were designated as Pania 1 (12 months old) and Pania 2 (1 month old). The Princess cultivars were: Princess 1 (1 month old), Princess 2 (12 months old) and Princess 3 (12 months old). These were commercial seed lots with high but varying seed quality characters (Table III.2a).

3.2. STORAGE EXPERIMENTS

Each seed lot was divided into four sublots before experiments were conducted. These sublots became the four replications. In each evaluation, before and after storage, samples in replication I were from sublot 1, replication II from sublot 2, replication III from sublot 3 and replication IV from sublot 4 in every seed lot.

Two storage materials were used; laminated packets (12 cm x 18 cm Corson laminated package composed of 12/20/50 micron polyester / aluminium foil / polythene) and cloth bags (20 cm x 30 cm muslin cloth bag) (Table III.1a). The laminated packets were used for 'sealed' storage while the cloth bags were used as the 'open' storage condition. Pea seeds in sealed and open bags were stored at 5°C, 25°C and ambient (Table III.1a).

In sealed storage, 100 g pea seeds were placed in a laminated packet and heat sealed (Ribbon Sealer, Smith Manufacturing Co. Ltd. Auckland, New Zealand) for 2 seconds. For each storage temperature, 36 packets (nine from each sublot) of each seed lot were prepared for the evaluation of seed quality during the 24 months of storage. Four packets (one from each sublot) were withdrawn at each evaluation time.

Table III.1a. Description of the storage conditions.

STORAGE MATERIAL	TEMPERATURE	RELATIVE HUMIDITY
A. SEALED CONDITIONS (laminated packet composed of 12/20/50 micron polyester / aluminium foil / polythene)	5°C	determined by seed moisture content
	25°C	
	AMBIENT	
B. OPEN CONDITIONS (muslin cloth bag)	5°C	45 %
	5°C	95 %
	25°C	45 %
	25°C	95 %
	AMBIENT	AMBIENT

In open storage, 3 kg pea seeds were placed in a cloth bag and tied with a rubber band at the open end. For each open storage condition, four cloth bags (one from each sublot which represented a replicate) from each seed lot were prepared for the 24 month storage duration. Upon evaluation, sub samples were obtained from each sublot to represent a replicate.

At 5°C and 25°C open storage, relative humidities of 45% and 95% were used and obtained by using glycerine (Glycerine W.I., 98% glycerol; Lever N.Z. Ltd., Petone, New Zealand) and water mixtures in various proportions (Table III.1b) in a lidded 40 cm x 60 cm x 20 cm plastic container. Six litres of glycerine solution were placed in each plastic container. Two 30 cm x 40 cm x 7 cm seed trays (Hygiene tray Horticultural Merchants Ltd., Auckland, New Zealand) were placed one inverted and another placed over it inside the plastic container to prevent the seeds from coming into contact with the glycerine solution. The cloth bagged seeds of each seed lot were placed on top of the upper seed tray

Table III.1b. Amount of glycerine and water to produce 45% RH and 95% RH obtained from the actual measurements of relative humidity at 5°C and 25°C storage conditions.

STORAGE CONDITION	GLYCERINE (%)	WATER (%)
5°C, 45% RH	100	0
5°C, 95% RH	20	80
25°C, 45% RH	95	5
25°C, 95% RH	10	90

within each plastic container. The rims of the plastic containers were greased (Petrolatum extra light white, Mobil Oil New Zealand Ltd., Wellington, New Zealand) to seal the containers. Each container represented a replicate which contained five bags (one sublot from each seed lot) used for the duration of the study.

In ambient open storage, four cloth bags (one from each sublot) from each seed lot were prepared for the whole 24 months storage duration. In ambient sealed storage, 36 packets (nine from each sublot) were prepared for the 24 months of storage. The cloth bags in open storage and packets in sealed bags were randomly arranged in an open cabinet exposed to uncontrolled temperature and RH of a seed store. Sampling was done similarly to 5°C and 25°C storage as discussed previously. The temperature and relative humidity for ambient storage were measured with a thermohygrograph (Casella, London, England) set on the open storage cabinet. The temperature and relative humidity were recorded daily for 24 months.

The eight storage conditions were treated as separate experiments. In each experiment a completely randomised design with five treatments (seed lots) with four replications was used.

3.3. SEED QUALITY AND VIGOUR TESTS

3.3.1. BEFORE STORAGE

Before storage, seed quality characters and vigour were determined for all the seed lots used. The tests conducted were: seed moisture content, standard germination, hollow heart, conductivity, accelerated ageing, controlled deterioration, expected field emergence and field emergence. All but the accelerated ageing test method were as described in Section One and Section Two. However, for the controlled deterioration test four deterioration times were used, i.e. 1, 2, 4, 6 days (24, 48, 96, 144 h). Field emergence without irrigation was assessed from a sowing on 15 August 1988 as described in Section One.

3.3.2. ACCELERATED AGEING TEST

The accelerated ageing test was carried out according to Baskin (1987) with some modifications. For each seed lot, four replicates of 20 g of seeds were placed in a 10 cm x 10 cm muslin cloth and tied with a rubber band. The muslin cloth bags were placed on top of a mesh wire in air tight glass jars containing 100 ml of water.

The glass jars were placed in a germinator set at 40°C and left for the required number of days for accelerated ageing. Four accelerated ageing times, were used; 1, 2, 4 and 6 days (24, 48, 96, 144 h). Immediately after removing the samples from the 40°C treatment, seed moisture content and standard germination tests were done as described in Section One.

3.3.3. STORED SEEDS

From sealed storage four packets from each seed lot for each storage condition were withdrawn at each sampling time for the determination of seed quality. From open storage, each bag was gently shaken three times

by hand to randomly mix the seeds before sampling. A 100 ml beaker was used to scoop approximately 70 g of seed from each cloth bag for the evaluation of seed quality.

Seed moisture content and standard germination were determined after three months storage and every three months thereafter up to 24 months of storage. Conductivity was evaluated after 6, 12, 15, 18, 21 and 24 months of storage. Field emergence without irrigation was determined after 12 and 18 months storage as described in Section One. The 12 month evaluation was sown on 20 August 1989, and a sowing was made on 6 February 1990 for the 18 month's storage.

3.4. DATA ANALYSIS

Analysis of variance was used to determine the differences between seed lots for each storage condition and evaluation time. Least significant differences (LSD) were used to compare the means. Correlation analysis was used to determine the relationship between stored and pre-storage seed quality characters.

Probit analysis was used in an attempt to model the storage life of the seed using the standard germination test results. The normal distribution of percent germination over time was linearised using the probit analysis. This was used as the basis in the formulation of a regression line for the prediction of storage life. The normal germination percentages were transformed to probits to produce linear relationship between germination and time of storage which were used in the estimation of probit line (Finney, 1971). The germination at time zero (before storage) was specified as a starting estimation of the decline in germination rate (Finney, 1971). The probit initial germination (K_i) and the slope of the probit line were calculated by the SAS probit procedure (SAS, 1988). The chi square test of the discrepancy between the observations and predictions (Finney, 1971) as calculated by the SAS probit procedure (SAS, 1988) and were used to evaluate the normality of the seed death distribution over time.

CHAPTER FOUR

RESULTS

4.1. SEED QUALITY BEFORE STORAGE

High germination was exhibited by all seed lots of both cultivars (Table III.2). All seed lots had a germination of above 90% but the Pania 2 seed lot had a significantly higher germination than Princess 2 (98.5% versus 91.0%, respectively). The seed moisture contents were not significantly different, ranging between 12.9% and 13.2%.

Pania 2 had the lowest conductivity result of 18.2 $\mu S\ g^{-1}$ seed while Princess 2 had the highest reading of 30.2 $\mu S\ g^{-1}$ seed (Table III.2). Pania 1 seed lot had the highest hollow heart of 26.5% while Princess 2 and Princess 3 seed lots had a lower hollow heart incidence of 9.0% and 11.5%, respectively (Table III.2).

The field emergence of the Pania 2 seed lot was significantly higher than the other seed lots (Table III.2). Pania 1 had significantly higher field emergence than Princess 2 and Princess 3 seed lots while Princess 1 had significantly higher field emergence than the Princess 3 seed lot.

Germination following controlled deterioration (CD) decreased as the deterioration time increased in all seed lots (Figure III.1a). Irrespective of time of ageing the Pania 2 seed lot always had the highest germination and Princess 3 seed lot always had a significantly lower germination than Pania 2 seed lot. At 6 day CD, differences between seed lots were more prominent where Pania 2 seed lot had the highest CD germination, and Princess 2 and Princess 3 seed lots the lowest. The Pania 1 and Princess 1 seed lots had lower CD germination than Pania 2 seed lot but higher than Princess 2 and Princess 3 seed lots and were considered intermediate. The seed moisture contents during controlled deterioration were very close to 20% (Appendix III.1).

Table III.2. Germination, seed moisture content, conductivity, hollow heart and field emergence of the various seed lots before storage.

SEED LOT	GERM. (%)	S.M.C. (%)	COND. (µS/g)	HOLLOW HEART(%)	% FIELD EMERGENCE
PANIA 1	97.0	13.0	25.4	26.5	91.5
PANIA 2	98.5	12.9	18.2	15.0	96.5
PRINCESS 1	94.0	13.0	28.4	17.0	89.5
PRINCESS 2	91.0	13.2	30.2	9.0	87.5
PRINCESS 3	95.0	13.2	26.8	11.5	85.0
P-VALUE	**	ns	**	**	**
$LSD_{0.05}$	4.36	0.37	2.61	9.26	2.76
$LSD_{0.01}$	6.11	0.48	3.66	12.98	3.86
C.V.	2.97	1.33	6.57	38.03	1.99

GERM. = Percent normal seedlings from the standard germination test.

S.M.C. = Seed moisture content

COND. = Electroconductivity reading in $\mu S\ g^{-1}$ seed

ns = not significant

** = significant at 0.01 level

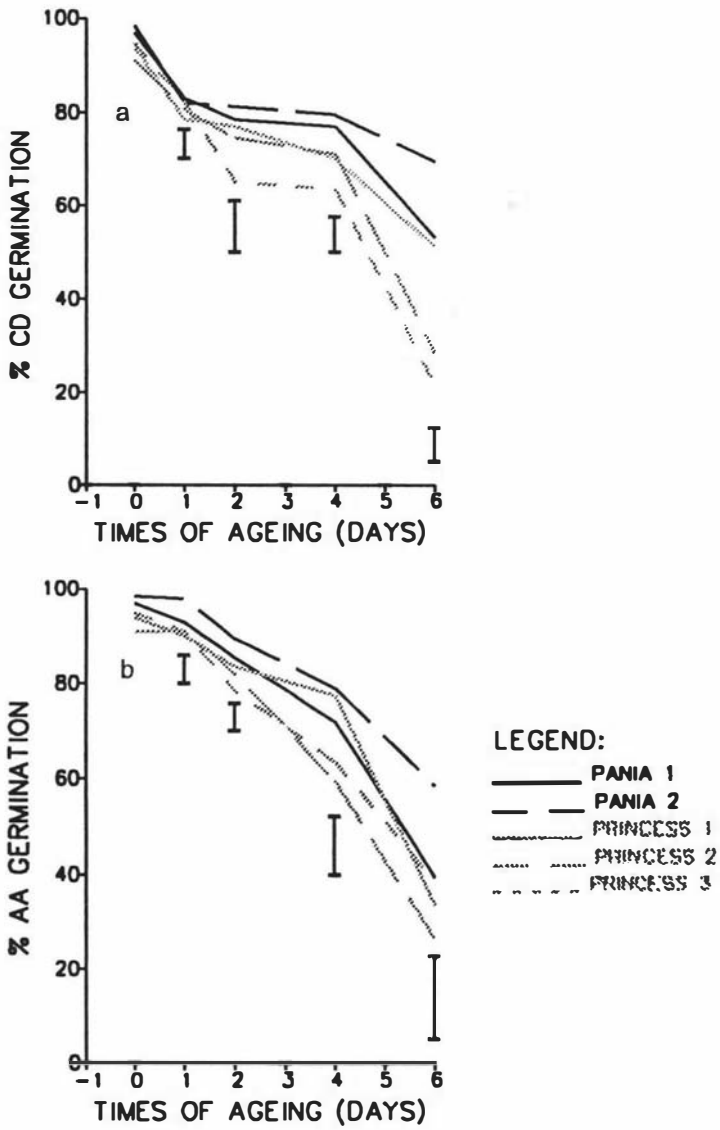


Figure III.1. Percent germination of seed lots exposed to different times of (a) controlled deterioration and (b) accelerated ageing before storage. The least significant differences (lsd) at the 5% level between means are represented by vertical bars.

Germination differences between seed lots after accelerated ageing were not as distinct as in the controlled deterioration test (Figure III.1b). However, Pania 2 seed lot had always the highest AA germination which was very evident at 6 day AA. The seed moisture content increased as the time of accelerated ageing increased (Appendix III.2).

4.2. AMBIENT STORAGE CONDITIONS

The ambient temperature within the seed store varied during the duration of storage (Figure III.2). Minimum temperatures were lowest during the months of June, July and August (7°C - 10°C), maximum temperatures were highest during the months of January and February (29°C - 32°C) and the mean temperature range was from 13.6°C to 25.4°C. The maximum relative humidity (RH) was highest in May and July 1990 (98%) but the lowest minimum RH was obtained in May 1989 (44%). The mean relative humidity ranged from 65% to 75%.

4.3. SEED QUALITY AFTER STORAGE

4.3.1. GERMINATION

The decline in germination increased as the storage temperature and relative humidity increased (Figure III.3). However, differences in the germination between seed lots exists in all storage conditions.

In all storage conditions, Pania 2 seed lot had the highest germination and its superiority was more apparent in storage conditions where the decline of germination was high (Figure III.3). At storage conditions where the decline in germination was high, i.e. 5°C / 95% RH, 25°C / 95% RH, 25°C sealed and ambient in sealed storage conditions, Princess 2 and Princess 3 seed lots had consistently lower germination than the Pania 2 seed lot. Pania 1 and Princess 1 seed lots had higher germination than Princess 2 and Princess 3 seed lots when stored in sealed bags at 25°C and ambient conditions.

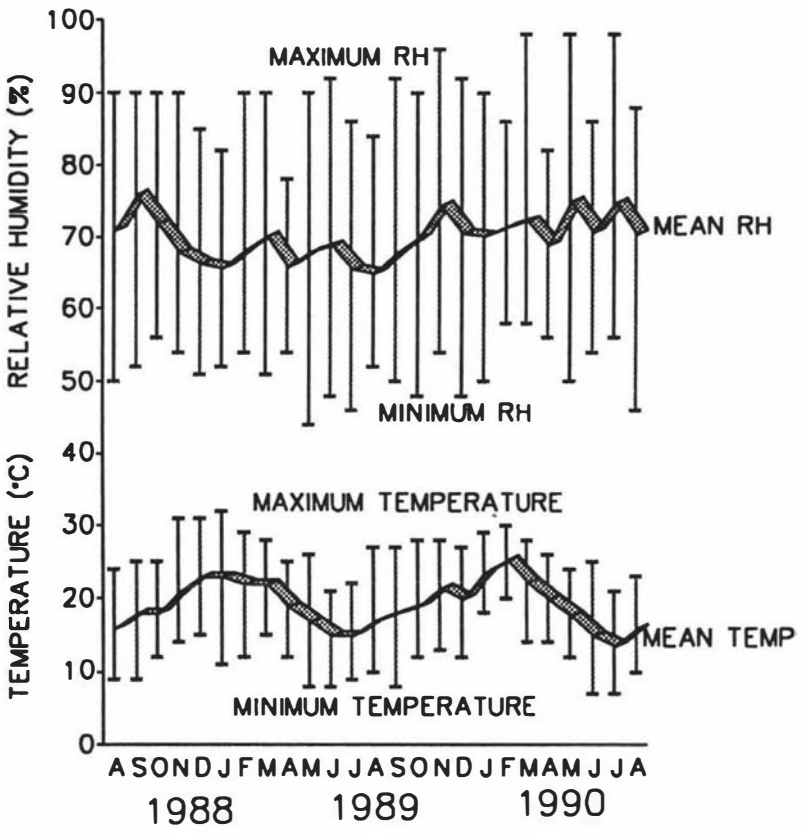


Figure III.2. The mean monthly temperature and relative humidity in ambient storage. The minimum and maximum temperature and relative humidity are presented in vertical bars and the means by the horizontal graphs.

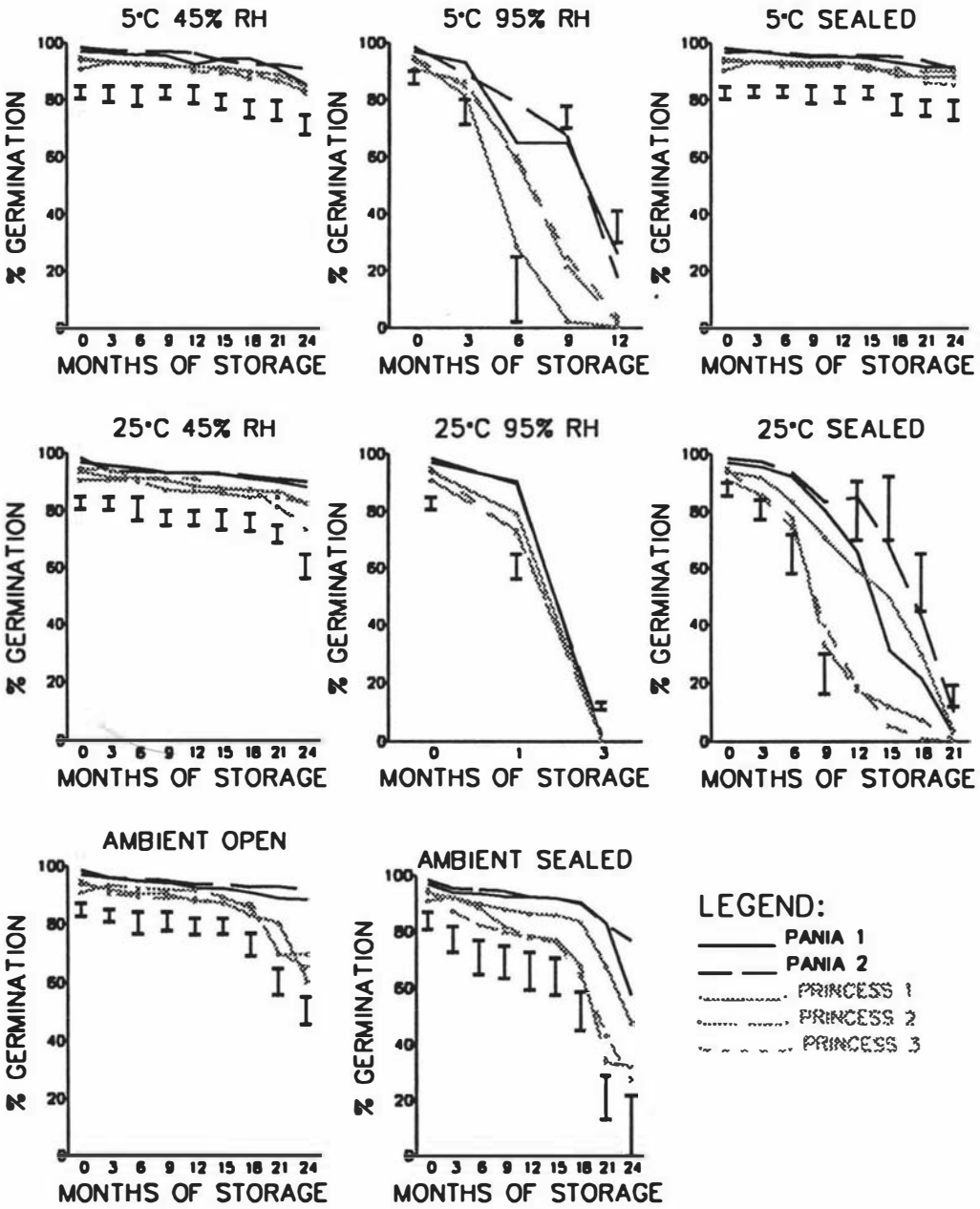


Figure III.3. Percent germination of seed lots after storage in various conditions and for various times. The least significant differences (lsd) at the 5% level between means are represented by vertical bars.

In storage condition where the decline in germination was low (i.e. 5°C / 45% RH, 25°C / 45% RH and ambient open storage), differences in germination between seed lots was obtained at 21 and 24 months after storage (Figure III.3). Princess 2 and Princess 3 seed lots had always lower germination than the Pania 2 seed lot.

4.3.2. SEED MOISTURE CONTENT (SMC)

No significant differences among seed lots and cultivars were recorded for SMC (Figure III.4). However, the SMC for all the seed lots changed as storage time increased in open storage conditions (Figure III.4).

At 5°C and 45% RH storage, SMC equilibrated to around 8% within the first three months and was maintained at this level for the duration of the experiment (Figure III.4). At 95% RH storage, the SMC increased to 22% after three months of storage and continued to increase to 30% after twelve months of storage for all seed lots. The SMC before storage was maintained in the sealed bags for 24 months of storage.

In 25°C storage, the SMC of seed lots stored at 45% RH equilibrated to 7% during the first three months of storage, and this was maintained for the next 21 months. At 95% RH SMC increased to 26% after one month of storage and had further increased up to 28% after three months of storage. In sealed storage, the SMC before storage for all seed lots was maintained.

4.3.3. CONDUCTIVITY

Although there was increased solute leakage as storage was prolonged in all storage conditions for all seed lots, differences between seed lots were evident (Figure III.5).

The leachate conductivity in Pania 2 seed lot was lowest in all the storage conditions and in all evaluations (Figure III.5). The Pania 1 seed lot had lower leachate conductivity than Princess 2 and Princess 3 seed lots in all

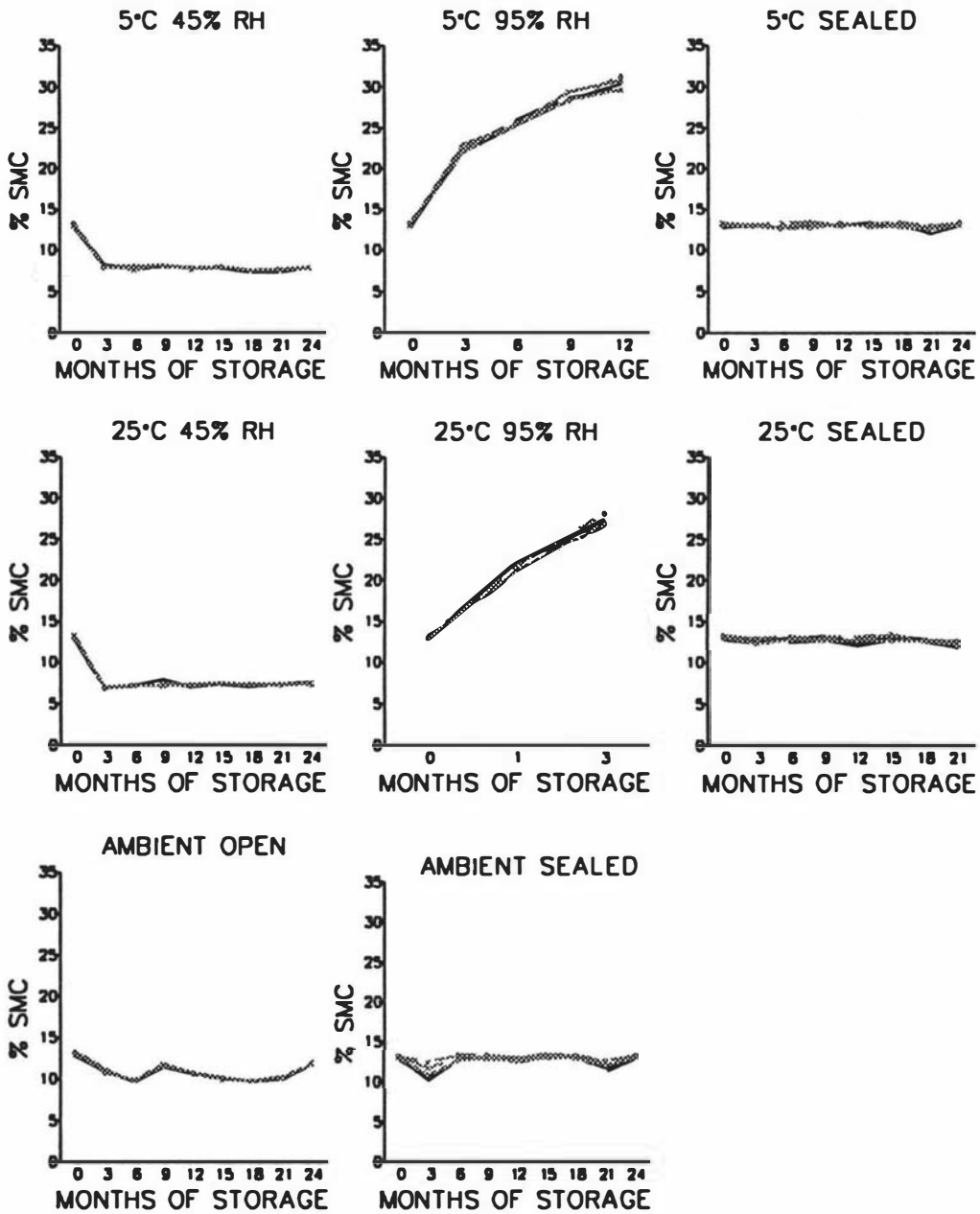


Figure III.4. Percent seed moisture content of seed lots stored in various conditions for up to 24 months.

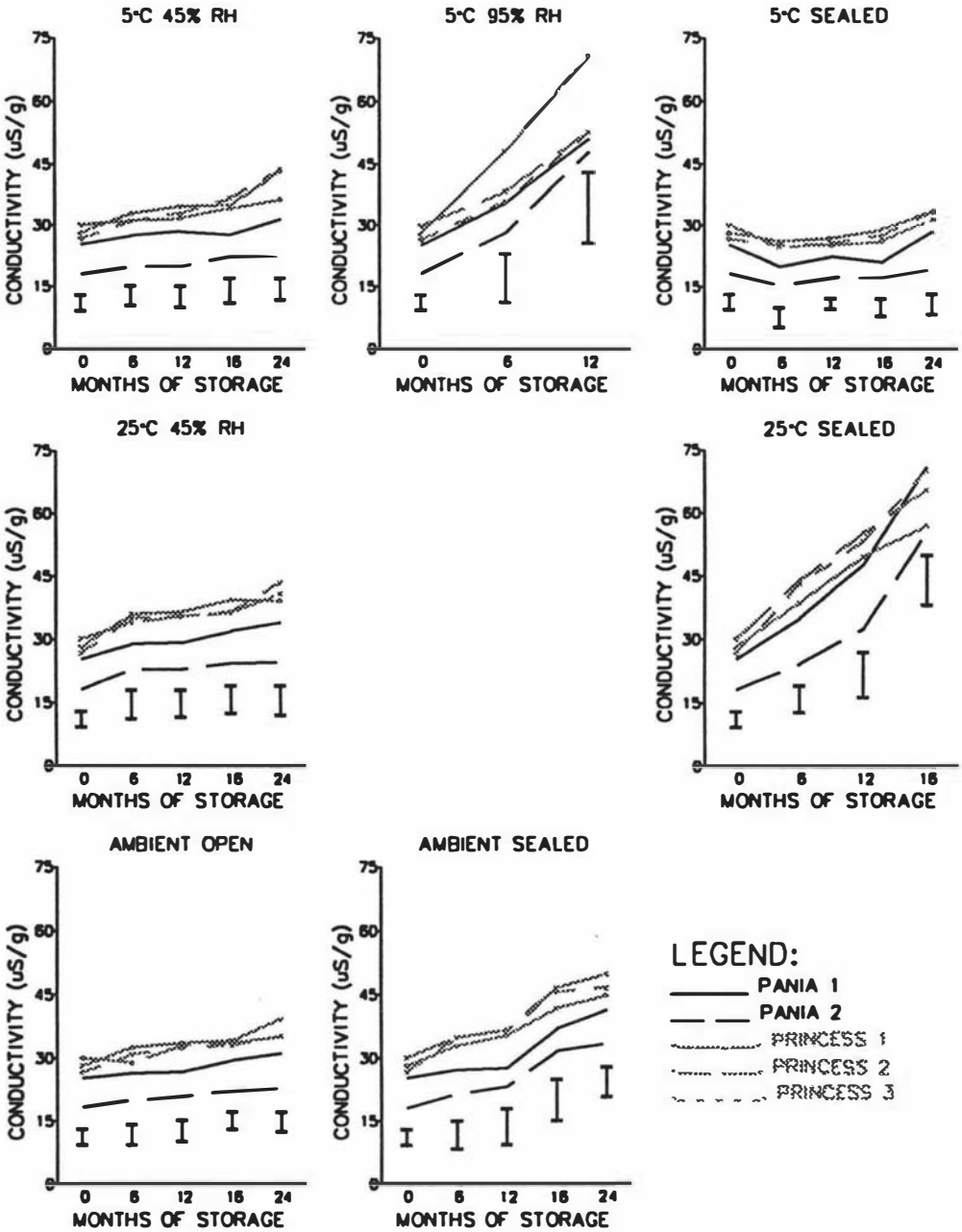


Figure III.5. The electroconductivity reading ($\mu S\ g^{-1}$ seed) of seed lots after storage in various conditions and for various times. The least significant differences (lsd) at the 5% level between means are represented by vertical bars.

conditions except at 5°C / 95% RH and in 25°C sealed storage. All cv. Princess seed lots had similar high leachate conductivity in all storage conditions.

4.3.4. FIELD EMERGENCE

Differences between seed lots were more apparent after 18 months storage than after 12 months storage (Figure III.6). After 12 months storage, Pania 2 seed lot had the highest field emergence, although the differences from that of the other seed lots was not always significant for all storage conditions. However, the Princess 2 and Princess 3 seed lots always had a lower field emergence than the Pania 2 seed lot.

After 18 months storage, Pania 2 seed lot had the highest field emergence in all the storage conditions. The Princess 2 and Princess 3 seed lots had significantly lower field emergence than the Pania 2 seed lot. The Pania 1 and Princess 1 seed lots did not differ from the other seed lots in most of the storage conditions. However, for some storage conditions (i.e. 5°C sealed, 25°C 45% RH, ambient sealed), the Pania 1 and Princess 1 seed lots had higher field emergence than Princess 2 and Princess 3 seed lots.

4.4. PREDICTION OF STORAGE LIFE

4.4.1. SEED QUALITY CHARACTERS

The seed quality characters obtained before storage were correlated with germination after storage for various times and in various conditions for the prediction of seed storage life (Appendix III.3 - III.11). However, due to the volume of data produced, only those relationships with reasonably consistent and high predictability are described here.

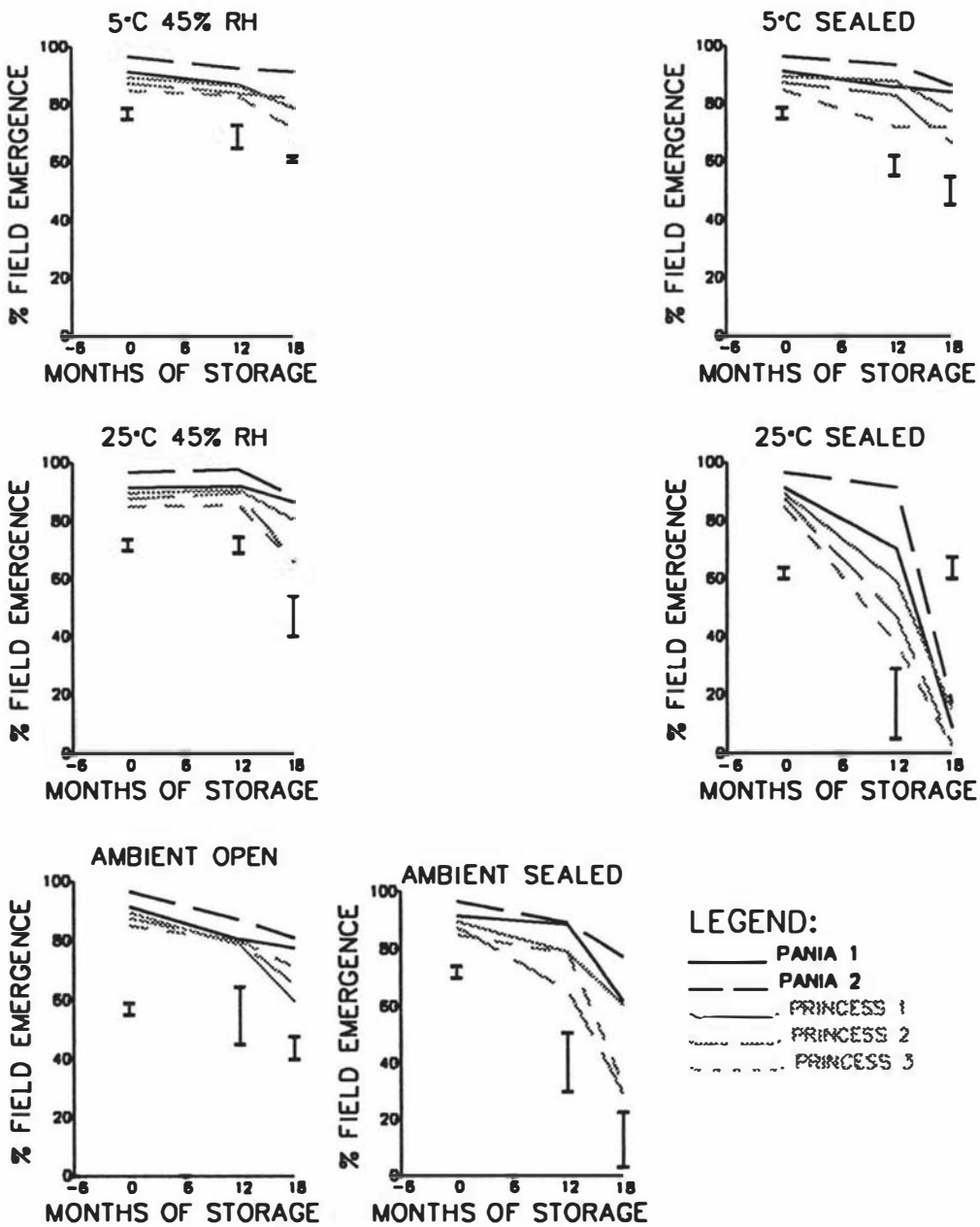


Figure III.6. Percent field emergence of seed lots after storage in various conditions and for various times. The least significant differences (lsd) at the 5% level between means are represented by vertical bars.

When seed lot performance was assessed through field emergence, the 6 day CD and conductivity tests was strongly correlated with field emergence, while significant but weaker relationships were also recorded from standard germination, 1, 2 and 4 day CD and 1, 4 and 6 day AA tests (Table III.3a).

The six day CD test was correlated with germination after storage for all storage treatments except 25°C and 45% RH, although these relationships were not always significant for each month (Table III.3b). The six day CD was most strongly related to germination after storage at 25°C in sealed containers, and in ambient sealed storage. Conductivity was also frequently correlated with germination after storage under all conditions except ambient open storage (Table III.3b).

The 4 day and 6 day controlled deterioration tests were highly correlated to the field emergence obtained after 12 and 18 months of storage in controlled temperatures and/or sealed storage, but not in ambient open storage (Table III.3c). The 4 day AA and 6 day AA tests were significantly correlated with field emergence after 18 months of storage in sealed conditions (Table III.3c).

Conductivity was significantly correlated with field emergence after both 12 and 18 months of storage for all conditions except ambient open storage (Table III.3c). The germination test before storage correlations with field emergence were inconsistent.

However, although significant correlation coefficients (r) were obtained between germination and field emergence after storage and seed quality characters, most were below 0.60, (Tables III.3b and III.3c), and caused the coefficient of determination to be very low (r^2 = below 0.36). The low coefficient of determination suggests that only a small portion of the variation was accounted for, which makes the relationship unreliable.

Table III.3a. Relationships of seed quality characters obtained before storage to field emergence and germination before storage.

SEED QUALITY TEST	FIELD EMERGENCE BEFORE STORAGE	GERMINATION BEFORE STORAGE
1 day CONTROLLED DETERIORATION	0.45*	0.47*
2 day CONTROLLED DETERIORATION	0.59**	0.35
4 day CONTROLLED DETERIORATION	0.49*	0.29
6 day CONTROLLED DETERIORATION	0.84**	0.58**
1 day ACCELERATED AGEING	0.48*	0.31
2 day ACCELERATED AGEING	0.37	-0.20
4 day ACCELERATED AGEING	0.62**	0.39
6 day ACCELERATED AGEING	0.54*	0.53*
CONDUCTIVITY	-0.75**	-0.68**
GERMINATION	0.55*	-

* = Significant at 0.05 level

** = Significant at 0.01 level

Table III.3b. Relationship between germination after various times and conditions of storage and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY[1] BEFORE STORAGE						
	3	6	9	12	15	18	24
5°C 45% RH STORE							
6 day CD	0.44*	0.42	0.54*	0.46*	0.54*	0.31	0.55*
COND.	-0.47*	-0.36	-0.53*	-0.43	-0.47*	-0.29	-0.53*
5 °C SEALED STORE							
6 day CD	0.49*	0.57**	0.34	0.33	0.46*	0.24	0.28
COND.	-0.40	-0.53*	-0.40	-0.25	-0.60**	-0.43	-0.16
25°C 45% RH STORE							
GERM.	0.32	0.23	0.39	0.73**	0.59**	0.68**	0.21
COND.	-0.23	-0.34	-0.34	-0.50*	-0.50*	-0.52*	-0.40
25°C SEALED STORE							
2 day CD	0.62**	0.49*	0.54*	0.39	0.57**	0.55*	0.44*
4 day CD	0.44*	0.52*	0.48*	0.60**	0.37	0.69**	0.49*
6 day CD	0.82**	0.59**	0.82**	0.89**	0.80**	0.83**	0.64**
4 day AA	0.56*	0.18	0.64**	0.76**	0.67**	0.62**	0.45*
COND.	-0.64**	-0.54*	-0.61**	-0.62**	-0.57**	-0.57**	-0.59**
AMBIENT OPEN STORE							
6 day CD	0.53*	0.25	0.42	0.54*	0.51*	0.42	0.58**
AMBIENT SEALED STORE							
6 day CD	0.56*	0.46*	0.11	0.51*	0.77**	0.54*	0.79**
COND.	-0.47*	-0.46*	-0.47*	-0.50*	-0.50*	-0.51*	-0.69**

[1] As assessed by the following tests:

CD = Controlled deterioration

AA = Accelerated ageing

GERM. = % Normal seedlings from germination test

COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)

* = Significant at 0.05 level

** = Significant at 0.01 level

Table III.3c. Relationship between field emergence after storage in various conditions for 12 and 18 months and various initial seed quality tests.

SEED QUALITY TEST	STORAGE CONDITION AND MONTHS OF STORAGE											
	5°C 45% RH		5°C SEALED		25°C 45% RH		25°C SEALED		AMBIENT OPEN		AMBIENT SEALED	
	12	18	12	18	12	18	12	18	12	18	12	18
1 day CD	0.48*	0.39	0.39	0.57**	0.50*	0.45*	0.36	0.17	0.54*	0.21	0.03	0.34
2 day CD	0.31	0.46	0.60**	0.46*	0.56*	0.47*	0.61**	0.40	0.13	0.32	0.42	0.52*
4 day CD	0.55*	0.42	0.60**	0.52*	0.57**	0.47*	0.42	0.54*	0.21	0.32	0.10	0.59**
6 day CD	0.60**	0.49*	0.82**	0.80**	0.71**	0.81**	0.81**	0.83**	0.27	0.36	0.42	0.88**
1 day AA	0.49*	0.49*	0.41	0.49*	0.49*	0.42	0.50*	0.28	0.35	0.54*	0.19	0.29
4 day AA	0.41	0.30	0.56*	0.50*	0.39	0.59**	0.47*	0.67**	0.01	0.18	0.42	0.72**
6 day AA	0.53*	0.42	0.36	0.53*	0.32	0.20	0.45*	0.45*	0.26	0.52*	0.51*	0.58**
GERM.	0.49*	-0.03	0.25	0.68**	0.35	0.52*	0.45*	0.42	0.30	0.34	0.55*	0.60**
COND.	-0.59**	-0.42	-0.48*	-0.72**	-0.58**	-0.52*	-0.64**	-0.59**	-0.35	-0.63**	-0.53*	-0.68**

CD= Controlled deterioration
AA = Accelerated ageing
GERM= % Normal seedlings from the germination test
COND= Conductivity ($\mu S\ g^{-1}$ seed)

*=significant at 0.05 level
**= significant at 0.01 level

4.4.2. PROBIT ANALYSIS

The losses in germination at 5°C and either 45% RH or constant 13% SMC (sealed conditions), 25°C / 45% RH and ambient open storage were low and not sufficient to compute the estimate of seed longevity in storage (Appendices III.12 - III.16). Under controlled storage conditions with high decline in germination, the data are expected to be normally distributed and, if this is the case, prediction of storage life can be accurately quantified (Ellis and Roberts, 1980a). It was thus expected that prediction of storage life could be obtained in the controlled storage conditions (i.e. 25°C / constant 13% SMC) of this study, where the decline in germination was high. But at 25°C / constant 13% SMC storage, the data points in all seed lots lie in a curve rather than follow the straight probit line (Appendices III.12 - III.16).

The goodness of fit test expressed in chi square values reveals the relationship between the germination data and the predicted probit germination in a probit analysis. A significant chi square value signifies deviation from the relationship between the observed data and the expected germination which the probit analysis predicts. When the decline in germination was high, i.e. 5°C 95% RH, 25°C 95% RH, 25°C constant 13% SMC storage conditions (Appendices III.12 - III.16), all seed lots had highly significant chi square values (Tables III.4 and III.5). This suggests that the probit analysis is not entirely appropriate for the prediction of storage life in garden peas. Although the chi square values were not significant in some controlled storage conditions, i.e. 45% RH in both 5°C and 25°C (Tables III.4 - III.6), the decline in germination was low and insufficient to determine the estimate of seed longevity in storage (Appendices III.12 - III.16).

The best estimates of intercepts and slopes of the probit lines are presented to quantify the effects of seed vigour and storage environment on the deterioration of garden pea seeds in storage. Further, the results are compared to the known effects of the new viability model of Ellis and Roberts (1980a). The K_i's (intercept of the probit line) of a seed lot were

Table III.4. The effects of storage at 5°C and at various relative humidities on the germination decline pattern of different garden pea seed lots.

STORAGE CONDITION	INTERCEPT (K_i)	SLOPE ($1/\sigma$)	GOODNESS-OF-FIT TEST (CHI-SQUARE
5°C 45% RH			
PANIA 1	1.86 ±0.085[a]	-0.03 ±0.006[a]	7.06[ns]
PANIA 2	2.09 ±0.100[a]	-0.03 ±0.006[a]	1.56[ns]
PRINCESS 1	1.59 ±0.073[b]	-0.02 ±0.005[a]	1.90[ns]
PRINCESS 2	1.59 ±0.072[b]	-0.02 ±0.005[a]	8.95[ns]
PRINCESS 3	1.60 ±0.073[b]	-0.02 ±0.005[a]	1.34[ns]
5°C 95% RH			
PANIA 1	1.88 ±0.232[a]	-0.20 ±0.029[b]	25.70[**]
PANIA 2	2.07 ±0.282[a]	-0.22 ±0.035[b]	33.48[**]
PRINCESS 1	1.85 ±0.166[a]	-0.40 ±0.033[a]	12.19[**]
PRINCESS 2	1.74 ±0.198[a]	-0.28 ±0.030[b]	21.27[**]
PRINCESS 3	1.74 ±0.122[a]	-0.27 ±0.018[b]	8.72[*]
5°C SEALED			
PANIA 1	1.99 ±0.095[a]	-0.03 ±0.006[a]	7.32[ns]
PANIA 2	2.10 ±0.103[a]	-0.03 ±0.007[a]	1.93[ns]
PRINCESS 1	1.70 ±0.078[b]	-0.02 ±0.005[a]	5.06[ns]
PRINCESS 2	1.48 ±0.068[b]	-0.02 ±0.005[a]	4.35[ns]
PRINCESS 3	1.66 ±0.075[b]	-0.02 ±0.005[a]	3.35[ns]

Note:

** - Highly significant at 1% level.

* - Significant at 5% level.

ns - Not Significant.

k_i - the intercept value of survival curve of the seed lot expressed in probit percentage of germination at the beginning of the storage period and also referred to as the seed lot constant.

1 - values with the same letter are not significantly different at 5% level.

Table III.5. The effects of storage at 25°C and at various relative humidities on the germination decline pattern of different garden pea seed lots.

STORAGE CONDITION	INTERCEPT (K_i)	SLOPE ($1/\sigma$)	GOODNESS-OF-FIT TEST (CHI-SQUARE)
25°C 45% RH			
PANIA 1	1.85 ± 0.085^{a}	-0.03 ± 0.006^{a}	1.96^{ns}
PANIA 2	1.78 ± 0.083^{a}	-0.02 ± 0.006^{a}	6.07^{ns}
PRINCESS 1	1.58 ± 0.071^{bc}	-0.03 ± 0.005^{a}	2.68^{ns}
PRINCESS 2	1.36 ± 0.065^{c}	-0.02 ± 0.005^{a}	0.76^{ns}
PRINCESS 3	1.71 ± 0.075^{ab}	-0.04 ± 0.005^{a}	8.06^{ns}
25°C 95% RH			
PANIA 1	2.56 ± 0.901^{a}	-1.54 ± 0.590^{a}	20.33^{**}
PANIA 2	2.62 ± 0.421^{a}	-1.49 ± 0.239^{a}	14.59^{**}
PRINCESS 1	1.90 ± 0.436^{ab}	-1.28 ± 0.308^{a}	12.23^{**}
PRINCESS 2	1.63 ± 0.401^{b}	-1.22 ± 0.309^{a}	13.94^{**}
PRINCESS 3	1.82 ± 0.207^{ab}	-1.31 ± 0.158^{a}	12.90^{**}
25°C SEALED			
PANIA 1	2.33 ± 0.200^{ab}	-0.18 ± 0.015^{a}	32.00^{**}
PANIA 2	2.62 ± 0.293^{a}	-0.16 ± 0.020^{a}	51.00^{**}
PRINCESS 1	1.76 ± 0.161^{bc}	-0.13 ± 0.013^{a}	41.98^{**}
PRINCESS 2	1.54 ± 0.168^{c}	-0.19 ± 0.017^{a}	41.44^{**}
PRINCESS 3	1.66 ± 0.102^{c}	-0.21 ± 0.011^{a}	13.43^{**}

Note:

** - Highly significant at 1% level.

* - Significant at 5% level.

ns - Not Significant.

k_i - the intercept value of survival curve of the seed lot expressed in probit percentage of germination at the beginning of the storage period and also referred to as the seed lot constant.

1 - values with the same letter are not significantly different at 5% level.

Table III.6. The effects of ambient storage conditions on the germination decline pattern of different garden pea seed lots.

STORAGE CONDITION	INTERCEPT[1] (K_i)	SLOPE[1] ($1/\sigma$)	GOODNESS-OF-FIT TEST (CHI-SQUARE)
AMBIENT OPEN			
PANIA 1	1.84 ± 0.084^{a}	-0.03 ± 0.005^{a}	1.93^{ns}
PANIA 2	1.85 ± 0.087^{a}	-0.02 ± 0.006^{a}	3.06^{ns}
PRINCESS 1	1.70 ± 0.115^{ab}	-0.05 ± 0.007^{a}	19.18^{**}
PRINCESS 2	1.71 ± 0.139^{ab}	-0.05 ± 0.009^{a}	28.01^{**}
PRINCESS 3	1.57 ± 0.102^{b}	-0.04 ± 0.007^{a}	18.22^{**}
AMBIENT SEALED			
PANIA 1	1.96 ± 0.199^{a}	-0.06 ± 0.012^{a}	46.10^{**}
PANIA 2	2.07 ± 0.092^{a}	-0.05 ± 0.006^{a}	16.33^{**}
PRINCESS 1	1.75 ± 0.146^{ab}	-0.06 ± 0.009^{a}	33.31^{**}
PRINCESS 2	1.63 ± 0.132^{b}	-0.08 ± 0.009^{a}	31.46^{**}
PRINCESS 3	1.56 ± 0.135^{b}	-0.08 ± 0.009^{a}	36.44^{**}

Note:

** - Highly significant at 1% level.

* - Significant at 5% level.

ns - Not Significant.

k_i - the intercept value of survival curve of the seed lot expressed in probit percentage of germination at the beginning of the storage period and also referred to as the seed lot constant.

1 - values with the same letter are not significantly different at 5% level.

similar under different storage conditions (Tables III.4 - III.6), and the Pania 2 (high vigour) seed lot always had a higher K_i than Princess 2 and Princess 3 (low vigour) seed lots.

The slopes of the calculated probit lines at each storage condition did not differ between seed lots except at 5°C / 95% RH (Tables III.4 - III.6). The decline in germination, manifested by the slope was higher in a harsh environment (95% RH) than in a mild environment (45% RH) in both 5°C and 25°C storage.

CHAPTER FIVE

DISCUSSION

The vigour of the different seed lots varied before storage, as shown by the results from the conductivity test, hollow heart test (Table III.2) and controlled deterioration test (Figure III.1). Seed lot Pania 2 was considered to be of high vigour, Pania 1 and Princess 1 of intermediate vigour, and Princess 2 and Princess 3 of low vigour.

The rate of seed deterioration under different storage conditions varied according to the temperature and relative humidity used. As the RH increased there was an increase in seed moisture content and eventually a decreased storage life (Figures III.3 and III.4). As discussed in 2.2.4., increased SMC leads to the availability of water as a solvent for biochemical reactions in the seed which cause increased deterioration (Bewley and Black, 1986; Priestley, 1986; Leopold and Vertucci, 1989). High temperature and RH (25°C, 95% RH) caused rapid deterioration which reduced the germination of seeds to a very low level after just one month of storage. This result agrees with the general notion that these kinds of conditions will kill seeds rapidly (Harrington, 1978).

As the temperature for storage was decreased, storage life as manifested by the germination test was longer. When the RH for storage was reduced to 45%, seed deterioration was low, even when the storage temperature was 25°C. Under constant 13% SMC storage (sealed bags), the low temperature of 5°C allowed a longer storage life than at 25°C and under ambient conditions. However, the reduction of SMC to 7% for all seed lots (Figure III.4) at 25°C / 45% RH storage allowed a reduction of the rate of seed deterioration and longer storage life compared to seeds stored at 25°C / constant 13% SMC.

5.1. EFFECT OF VIGOUR ON SEED STORAGE LIFE

The conductivity and controlled deterioration tests before storage differentiated the seed lots into various vigour groups, i.e. Pania 2 seed lot was of high vigour and had a long storage life while Princess 2 and Princess 3 seed lots were of low

vigour and stored poorly (Table III.2 and Figure III.1a). Although the decline in germination and field emergence and the increase in conductivity varied at different storage conditions, seed lot differences did not change. The Pania 2 seed lot always had the highest germination and field emergence and lowest conductivity in all storage conditions. Princess 2 and/or Princess 3 seed lots had consistently low germination and field emergence and high conductivity in all storage conditions.

Seed deterioration rates, as determined from the various seed quality characters, differed between seed lots. Based on the germination test, Pania 2, a high vigour seed lot, maintained high germination up to 24 months of storage with low temperature and/or low RH (5°C 45% RH, 5°C sealed, 25°C 45% RH), and also under ambient open conditions. In low vigour lots (Princess 2 and Princess 3) germination was less than 70% after 24 months storage in ambient open conditions, and even in storage environments with low temperature and low RH, germination was significantly reduced. These results suggest that high vigour garden pea seed lots have better storage potential than low vigour seed lots, a result also shown by Delouche and Baskin (1973) for many crops. Further, when pea seeds were stored at about 13% SMC, which was lower than the maximum SMC for safe storage of 14% (recommended by Gane *et al.*, 1984), low vigour seed lots (Princess 2 and Princess 3) showed reduced germination. This implies that seed moisture contents traditionally regarded as being "safe" for different species (Harrington, 1972) may not be so for low vigour seed lots. This result is similar to that reported for *Trifolium pratense* by Wang and Hampton (1991).

Leachate conductivity increased as storage time increased, indicating deterioration, although the seed lots differed in the rate of increase of leaching. In low vigour seed lots, more solute leakage during imbibition (Matthews and Powell, 1987b; Wang and Hampton, 1991) and damage of cell membranes (Powell, 1986) occurred. Membrane damage can be related to the formation of free radicals by peroxidation and/or changes in the amount of membrane phospholipids due to hydrolysis when SMC's are high in a high RH storage environment (Powell, 1986), and is regarded as the first sign of seed deterioration (Powell, 1986; Matthews and Powell, 1987b).

The high conductivity reading after 18 months of storage at 45% RH at both 5°C and 25°C would imply that there was a change in vigour in all seed lots, although germination was still high. This agrees with the general notion that seed vigour changes before viability begins to decline (Priestley, 1986).

The conductivity test before storage showed that Princess 2 (a low vigour seed lot) had the highest leachate conductivity and Pania 2 (a high vigour seed lot), the lowest leachate conductivity (Table III.2). Further, Princess 3 (a low vigour seed lot) always had lower germination than the Pania 2 seed lot at all times of ageing in the controlled deterioration test (Figure III.1a). These results support the suggestion that seed vigour should be employed in determining storage potential of a seed lot, i.e. decisions on the length of time a seed lot can be stored safely should be based on a vigour test, and not solely on the germination test result (Delouche and Baskin, 1973; Wang and Hampton, 1991). However, what needs to be determined is which vigour test or tests can more clearly differentiate the potential of seed lots to be stored, particularly in ambient conditions which can vary markedly within a seed store, and between seed stores. This is explored in the following section.

5.2. PREDICTION OF SEED STORAGE LIFE

Relationships between initial seed quality parameters and germination after storage varied depending upon storage conditions. Germination after 24 months ambient open storage was significantly correlated with initial germination ($r=0.62^{**}$, Appendix III.9), and only conductivity ($r=-0.72^{**}$) was more strongly related. However, 24 months was the only time when initial germination was related to germination after storage, and although not always significant, the relationship between firstly conductivity and secondly 6 day CD with germination after storage was stronger than that of initial germination.

In conditioned storage (controlled temperature, RH; open or sealed), both the 6 day CD and conductivity tests (Table III.3b; Appendices III.3 - III.8) were reasonably good predictors of storage life. Conductivity testing seems to have a better relationship with germination after storage than any of the other laboratory

tests. However, the 6 day CD and conductivity did not have a significant relationship with germination after storage in all storage conditions. Significant relationships between 6 day CD and germination after storage were obtained mostly in controlled storage because the decline in germination was uniform. This suggests that a more accurate prediction of storage life can be achieved in controlled storage conditions than in uncontrolled conditions. The low germination after storage can be attributed to the damage of membranes as manifested by the high leachate conductivity (Figure III.5). Further, damage of membranes can be associated with faster seed deterioration under harsh environments, i.e. high temperature and high RH storage (25°C / 95% RH) than in a milder environment of 5°C / 45% RH storage (Figure III.5).

Higher correlation coefficients were obtained between 6 day CD and field emergence than EFE and field emergence (Section One). At 6 day CD the seeds were exposed to very stressful conditions (high temperature and RH for a long time) which differentiated the vigour status of seed lots sufficiently well to predict field emergence. This result might suggest that prediction of field emergence can be better attained using the 6 day CD rather than the EFE currently used. These data agree with the findings of Matthews and Powell (1987a) that the CD test can differentiate vigour among seed lots and, in their work, CD test results were highly correlated to field emergence in brussel sprouts and onion. However, the results here must be treated with some caution because of the low coefficient of determination in most correlations. Although the correlation coefficients were significant, mostly they were low (r = below 0.60, Tables III.3b and III.3c), and thus the r^2's below 0.36. A low coefficient of determination shows that only a small portion of the variation was taken into account which therefore suggests incomplete relationships - i.e. other factors are involved.

The low relationships between accelerated ageing test results and germination and field emergence after storage suggest that the accelerated ageing test is a poor predictor of storage life. At 1 d AA little stress can have been inflicted on the seeds as the germination was comparable to the germination before ageing. The stress conditions at 4 day AA and 6 day AA were probably too severe and caused a rapid decline of germination (which might be related to a longer time of storage). Further the SMC increased very rapidly which caused severe

deterioration (Appendix III.2). These factors are likely to have caused the poor relationships between AA germination and germination and field emergence. This leads to the suggestion of Baskin (1987) that the severity of the test conditions should be adjusted to the desired time of storage. Shorter times of ageing should be suited for short term storage, and severe ageing for long term storage. However, the wide range of ageing times tested in this study generated poor relationships between AA and germination or between AA and field emergence before storage (Table III.3a). Furthermore, poor relationships were also generated between AA and germination or field emergence after storage, under the wide range of storage conditions used in this study (Tables III.3b and III.3c). These results suggest that the accelerated ageing test is not appropriate for the prediction of germination and field emergence for garden peas. The sudden increase of SMC under the high temperature and RH of the accelerated ageing test might have caused severe seed deterioration which did not occur under any of the storage and field conditions used in this study, and hence the poor relationships.

5.3. PROBIT ANALYSIS

Under controlled storage with a high decline in germination, germination data of a deteriorating seed population are expected to follow the negative cumulative normal distribution in time, and probit transformation would thus linearise this relationship (Roberts, 1972). In this study, among the controlled storage conditions tested, the decline in germination was high at 25°C. However, the chi square values were high and significant (Tables III.4 - III.5). The reliability and precision of the probit analysis in the prediction of storage life is measured by the chi square test (goodness of fit test) (Finney, 1971; SAS, 1988). Low and non significant chi square values were obtained only in storage conditions where the decline in germination was low and not sufficient to compute the estimate of seed longevity in storage.

A significant chi square in probit analysis is evidence of two potential problems (Wilson *et al.*, 1989). Either individual subjects (seeds) in a sample do not react independently, or the underlying mathematical model is not appropriate. In storage conditions where the decline in germination is expected to follow a

normal distribution in time, the probit-transformed data points follow a curve rather than the straight probit line, and this is shown by all the seed lots (Appendices III.12 - III.16). The growth habit of garden peas might have contributed to the poor prediction of storage life using the probit model. The indeterminate character of peas causes differences in maturity of seed at harvest which can affect seed quality. Further, seeds within different parts of the canopy developed at different temperatures and RH, some of which were stressful and caused low vigour in seeds from the bottom pods (Section Two). These factors all contribute to the production of heterogeneous seed lots in garden peas.

Heterogeneity interferes with probit analysis because of low initial germination and the decline in germination is non-linear (Wilson *et al.,* 1989). Modelling the decline in germination of heterogeneous seed lots has produced contrasting results in previous studies. The probit analysis showed good fit in modelling the decline in viability of chickpea, cowpea and soybean (Ellis *et al.,* 1982) but did not prove a good model for field beans (Wilson *et al.,* 1989). These two studies differed on the evaluation of germination percentage. Ellis *et al.* (1982) used radicle protrusion as the criterion for germination while Wilson *et al.* (1989) evaluated normal seedling production from the germination test, an approach which was also used in this study. A probit analysis functions well when seed lots of very high initial germination are used (Ellis and Roberts, 1980a; Wilson *et al.,* 1989) while the use of lower initial germination percentages and abrupt decline in germination in garden peas (Appendices III.12 - III.16) and field beans data (Wilson *et al.,* 1989) made the probit model inappropriate. Heterogeneous seed lots can have an abrupt decline in germination in storage because a proportion of seeds have undergone some degree of deterioration within the crop canopy during growth brought about by high temperature and RH (Section Two). Wilson *et al.,* (1989) thus argued that data based on radicle protrusion are an over-estimate of the germination percentage due to the inclusion of abnormal seedlings which have no chance of survival in field conditions. Further, the decline in germination of a heterogeneous seed lot, e.g. garden peas (Appendices III.12 - III.16) and field bean, was non linear and to fit it to a linear model is not appropriate (Wilson *et al.,* 1989). It is therefore likely that the probit analysis is less relevant in heterogeneous seed lots. Further studies should be done on the development or improvement of a mathematical model which might be appropriate for the prediction of storage life of heterogeneous seeds.

Despite the limitations of the probit analysis in modelling storage life in garden peas, a semi-quantification of seed lot characters can be obtained based from the calculated K_i and slope values of the best fit probit line. Accordingly, and in order to compare the influence of environment and seed lot vigour on storability of garden peas to the "Improved Viability Model" of Ellis and Roberts (1980a), the estimated K_i and slope values for the probit lines are discussed.

Seed lots vary in the conditions with which they come into store, and this can be quantified by the K_i in a probit analysis (Ellis and Roberts, 1980a). The seed lots in this study differed in their K_i's in most storage conditions, e.g. the K_i of Pania 2 seed lot was higher than the K_i of Princess 3 seed lot at 25°C sealed storage (Tables III.4 - III.6). However, the K_i's of any one seed lot under various storage conditions were similar. These results confirm the findings of Ellis and Roberts (1980a) that the storage environment does not affect the K_i, but that it is affected by factors before storage and is specific for the seed lot.

The decline in germination during storage can be caused by the extent of seed deterioration largely influenced by the storage environment (Roberts and Ellis, 1984). In the probit analysis, this is quantified by the slope of the probit line (Finney, 1971; Ellis and Roberts, 1980a). The slopes were similar in all seed lots in most of the storage conditions (Table III.4 - III.6) which supports the findings of Ellis and Roberts (1980a) that the slope is species specific. This result suggests that the storage environment affects the decline in germination during storage but does not explain the effects of seed vigour during storage. The slopes in a more harsh environment (i.e. 25°C / 95% RH) were higher than in a mild environment (i.e. 25°C / 45% RH), thereby indicating a shorter storage life of seeds under harsh environments.

5.4. CONCLUSION

The results of this study strengthened the general notion that seed vigour is a better determinant of the potential storability of a seed lot than the germination test. High vigour seed lots had a lower decline in germination compared with low

vigour seed in all storage conditions studied. It is therefore concluded that high vigour seed lots have better storability than low vigour lots. Further, recommendations on the storability of a seed lot should be based on seed vigour characters.

However, none of the laboratory test methods for seed quality showed significant relationships to germination and field emergence in all storage conditions. Conductivity and 6 day CD tests produced the best relationships in most of the storage conditions and thus could be considered for prediction of germination and field emergence after storage. Better prediction of storage life was obtained in controlled storage conditions due to the uniformity of the decline of germination. This study therefore suggests that conductivity and 6 day CD tests be further explored for predicting the relative storability of garden peas, especially under controlled storage conditions.

The probit analysis is not entirely appropriate in the prediction of storage life of garden peas. The indeterminate character of peas leads to heterogeneity of seed lots caused by a variable environment associated with the crop canopy during seed development and maturation. This is thought to contribute to the inappropriateness of the probit analysis for garden peas. Further study should be conducted in the prediction of storage life in garden peas using other methods of data transformation and regression models.

CONCLUSIONS AND SCOPE FOR FURTHER STUDY

CONCLUSIONS

One potential problem in the production of garden peas is poor field emergence, which is usually associated with low seed vigour. Differences in vigour among seed lots can be attributed to physical and physiological damage resulting from both environmental conditions during seed development, maturation and harvesting, and also that incurred during seed harvesting, processing and storage. Most research with garden peas has been concerned with increasing seed yield, not seed quality. The purpose of this study was therefore to evaluate the role of garden pea seed vigour on seed lot performance in the field and in storage, and to examine how seed production factors influence seed vigour.

Although the time of sowing for garden peas is relatively short (spring to early summer) field conditions can vary considerably, ranging from favourable (good rainfall and temperatures) to stressful (extremely dry or very wet) (Section One). The germination and field emergence of garden peas is helped by a fine moist soil with good structure and good drainage, which can provide the water, oxygen and suitable temperature necessary for germination (Crawford, 1977; Gane, 1985; Matthews and Powell, 1986). Germination can be limited during dry spells which result in low soil moisture content, or by heavy rain and/or poor drainage which result in excessive soil moisture content (Chopra and Chaudhary, 1981; Fausey and McDonald, 1985).

Climatic conditions in 1988 provided good rainfall and favourable temperature for good germination and establishment (Table I.1). However, 1989 sowings were affected by water availability (Table I.8). Low rainfall during November 1989 caused a significant reduction in field emergence in unirrigated sowings. On the other hand, because of rain, the irrigated sowings of 30 October and 20 December 1989 ended up under excessive water, which caused a significant reduction in field emergence.

Vigour differences among seed lots became apparent in the conductivity test, and these results were strongly related to field emergence (Tables I.5 and I.10, Figures I.3 and I.6). Seed lots with high conductivity tended to have lower field emergence compared to seed lots with low conductivity under both favourable and unfavourable conditions. The conductivity test is well established for garden peas and an increase in conductivity tends to be associated with decreased field emergence (Matthews and Bradnock, 1965; Perry, 1970; Carver and Matthews, 1975; Ladonne, 1989). The conductivity test was the best predictor of field emergence under all the different sowing conditions used, being significantly correlated with field emergence in the 1988 sowings, and in most irrigated and unirrigated sowings in the 1989 season. These results therefore suggest that at this site the conductivity test was the best available for determining the planting value of a garden pea seed lot under all sowing conditions.

Any advantages of using combined factors for predicting field emergence over a single quality factor (Scott and Close, 1976; Hampton and Scott, 1982) were not shown in this study. The EFE was comparable to the conductivity test in the prediction of field emergence under stress conditions, but was not as good under more favourable conditions as it could not always predict field emergence for all cultivars (Table I.5). Removing the correction factor for hollow heart from the EFE equation under favourable conditions increased the relationship between EFE and field emergence, but reduced it under stress conditions. EFE should therefore be used under stress conditions in order to include the effect of hollow heart. Further the EFE can be used to determine the amount of seed for sowing to achieve a specific population, which the conductivity test result alone can not do. When data obtained from this study were used to derive the best multiple regression equation for the prediction of field emergence, significant results were obtained in both the 1988 and 1989 sowings (Tables I.6, I.7, I.13, I.14 and I.15). However, no results resembled the EFE equation currently commercially used. It is apparent that equations differ between cultivars and various soil and stress conditions. Further work should be done to improve the EFE equation, perhaps through the development of a series of equations for specific cultivars and sowing conditions.

Under favourable environmental conditions, germination test results alone were significantly correlated with field emergence (e.g. 1988 sowings, Table I.5). However, the germination range was wide because of the inclusion of low germinating seed lots

(Table I.2). The relationship between field emergence and germination data was low and unreliable when low germinating seed lots were not included in the analysis of the 1988 sowings (Table I.5). Including low germinating lots in the correlation analysis can distort results, and their removal allows the effects of seed lot vigour differences to be more accurately evaluated (Scott and Close, 1976). It is therefore suggested that low germinating seed lots should not be included in seed vigour studies.

Differences in vigour were obtained in seeds harvested from various population densities and row widths, different times of sowing and following different methods of harvest (Section Two). Population density and row width effects on yield have been well studied in garden peas (Anderson and White, 1974; White and Anderson, 1974; Stoker, 1975; Gane *et al.,* 1984; Gane, 1985). However, the relationship between population density and/or row width and seed quality had not been previously considered.

Garden peas are grown in various environments that can greatly influence seed vigour. The high leachate conductivity and low CD germination of seeds from the 200 plants m^{-2} and 10 cm row width treatments harvested at 15% SMC indicated low vigour compared to seeds harvested from the 100 plants m^{-2} treatments (Table II.8; Figures II.4, II.5 and II.7). Furthermore, hollow heart incidence was highest in the bottom pod seeds from the 200 plants m^{-2} and 10 cm row width (Figures II.3 and II.6). This can be attributed to the high temperature and relative humidity within the crop canopy during seed development and maturation; although the air temperature was favourable for pea production, the canopy temperature was higher by 2°C - 5°C, especially at 200 plants m^{-2} and 10 cm row width (Figures II.14 and II.15). Temperature can also increase inside the pod above the already high canopy temperature (Perry and Harrison, 1973). Furthermore, the relative humidity within the canopy at 200 plants m^{-2} was higher than in the other population density treatments (Figure II.17). At lower population densities (50 and 100 plants m^{-2}) and for seeds harvested at 15% SMC, the top pod seeds had been exposed to variable environmental conditions for a longer period of time, which resulted in higher leachate conductivity in top pod seeds than that obtained from the bottom pod seeds. However, the leachate conductivity of top pod seeds at 50 plants m^{-2} at 15% SMC harvest was still lower than that obtained from seeds at any pod position in the 200 plants m^{-2} population density.

Seeds from the December sowing had higher vigour than seeds from the November sowing. The more favourable environment during seed development and maturity allowed the production of high vigour seeds. For the December sowing, seeds developed and matured during February or March when the temperature (2°C - 5°C lower than January) and RH (5% - 10% lower than January) were milder in the Manawatu (Figures II.19 and II.20). It is therefore recommended that sowing of garden peas in Manawatu be done during December for the production of high quality seeds for planting.

Low vigour seeds were obtained from the 40% SMC harvest, especially when machinery was used in harvesting and/or threshing. Although the seeds have attained physiological maturity and can germinate under favourable conditions (Le Deunff, 1989; Flinn and Pate, 1968; TeKrony *et al.,* 1979), they are prone to damage during harvest at high seed moisture content (Moreira *et al.,* 1989; Mashauri, 1991). However, when harvesting was done at 25% SMC, high vigour seeds were produced with low leachate conductivity and high CD germination, even when machinery was used in harvesting and threshing. But at 15% SMC harvest, seeds had a higher leachate conductivity presumably as a result of a greater exposure to high temperature and RH during seed maturation. This suggests that by harvesting at 15% SMC New Zealand growers are producing seed of lower quality, and that a change should be made to harvesting at 25% SMC. However, what is not known is how the drying which would then be necessary would affect seed vigour.

Windrown seeds can be exposed to high temperature in the field, which increases the risk of producing low vigour seeds. The three days in the windrow increased hollow heart incidence because the seeds were exposed to high temperature before threshing. It is therefore suggested that garden pea seeds should not be windrown for the production of high quality seeds for planting.

Seed vigour was a better criterion for the determination of seed storage potential in garden peas than the germination test (Section Three). Seed lots were categorised into high vigour (Pania 2), intermediate vigour (Pania 1 and Princess 1) and low vigour (Princess 2 and Princess 3) based on results from the conductivity and controlled deterioration tests. Low vigour seed lots declined faster than the high vigour seed lots in both germination and field emergence after storage, because of more rapid

deterioration as indicated by the higher leachate conductivity and lower CD germination. It is therefore suggested that vigour tests, i.e. conductivity and/or controlled deterioration tests, should be the basis for the determination of the potential storability of garden pea seed lots.

Although none of the laboratory tests gave highly significant predictions of germination and field emergence after storage in all storage conditions, conductivity and 6 day CD tests had significant correlations for most storage conditions. However the decline in germination and field emergence was better predicted by the conductivity and 6 day CD tests following controlled storage (i.e. controlled temperature and RH), than in uncontrolled storage conditions. This suggests that none of the laboratory methods used in this study can reliably predict the relative storability of commercial seed lots which are stored under uncontrolled (ambient) conditions. The process of ageing in controlled storage conditions may be controlled by a single mechanism which causes the seed to follow a definite pattern of deterioration. However, in uncontrolled storage conditions deterioration may be caused by several factors so that predicting seed responses during storage becomes more difficult. As yet however, what actually occurs is not well known.

Roberts (1972) showed that under controlled storage with high decline in germination, germination data follow a negative cumulative normal distribution in time when transformed into probits. In this study, high decline in germination was obtained from controlled storage at 25°C / constant 13% SMC condition, but fitting it to probit analysis produced significant chi square values (Table III.5). A significant chi square value is evidence of the inappropriateness of the model and the data points lie in a curve rather than follow the straight probit line (Appendices III.12 - III.16). The indeterminate growth character of garden peas probably results in heterogeneous seed lots due to the production of seeds with differing maturity which affects seed quality (Section Two). Further, seeds within different parts of the canopy developed at different temperatures and RH, some of which were stressful and caused lower vigour seeds. Also the use of normal seedlings as a criterion for germination might have resulted in an abrupt decline in germination, so that the data followed a curve and did not fit to a linear model (probit model) which is therefore not appropriate. These factors are likely to have contributed to the poor prediction of storage life using the probit analysis for heterogeneous seed lots of garden peas.

In order to know the influence of the storage environment and seed lot vigour on storability of garden peas, the intercept and slopes of the probit lines were compared to the findings of Ellis and Roberts (1980a) despite the limitations in the use of the probit analysis. The intercepts (K_i, probit % germination at the beginning of storage) differed between seed lots in each storage condition (Tables III.4 - III.6) but were similar within each seed lot for all storage conditions. This result agrees with the findings of Ellis and Roberts (1980a) that the K_i was not affected by the storage environment but specific for a seed lot. The seed lots had similar slopes (decline in germination of the probit line) in most of the storage conditions (Tables III.4 - III.6) which supports the findings of Ellis and Roberts (1980a) that the slope is species specific and dependent on the storage environment. The slopes in a harsh environment (i.e. 25°C / 95% RH storage) were higher than in a mild environment (i.e. 25°C / 45% RH), hence the shorter storage life of seeds under harsh environments.

SCOPE FOR FUTURE STUDY

Seed vigour can influence field emergence and the potential storability of garden pea seeds. Production practices in garden peas can influence seed vigour in several ways as reported in this study. However, there are problems which were not considered in this study which need further investigation.

Although conductivity testing can rank seed lots for vigour, it can not be used to determine the amount of seed to be sown, which is an attribute of the EFE. Studies leading to the improvement of EFE should be conducted using recently released cultivars at different sites. The influence of moisture in the field and how it affects temperature in the soil should also be taken into consideration in further studies.

Differences in seed quality and vigour following various mother plant environments were investigated in this study. However, the measurement of environment was limited to only temperature and RH. Avenues for further research could include other environmental parameters, i.e. light levels and air movement within the canopy, which are measurable continuously during seed development and maturity. Seed vigour associated with the culture of recently released cultivars, i.e., semi leafless and leafless

cultivars also needs further investigation because the change in the morphological character of the semi leafless or leafless cultivars could change the environment associated with the crop canopy, and therefore influence the vigour of the seed produced. For example the canopy environment of semi leafless and leafless cultivars might have higher temperature and RH which would probably affect seed vigour more than the leafy canopy of currently used cultivars.

Prediction of storage life is a problem in garden peas. Although conductivity and CD tests related well to germination and field emergence after storage, predictions beyond 24 months were not explored, and this is a good area for further study, especially for long term storage. The formulation of a mathematical model for the prediction of seed longevity in storage for garden peas is also a good area for further study, as the probit analysis does not seem entirely appropriate for garden peas. The decline in germination after storage of seeds with heterogeneous character might not follow the negative normal distribution appropriate in probit analysis. The use of other data transformations and other regression models (e.g. non linear regression), should be explored in order to accommodate the pattern of distribution appropriate for heterogeneous seed lots which might in fact be a non normal distribution.

BIBLIOGRAPHY

Abdalla, F. H. and E. H. Roberts. 1969. The effects of seed storage conditions on the growth and yield of barley, broad beans, and peas. Annals of Botany 33 : 169-184.

Abdul-Baki, A. A. 1980. Biochemical aspects of seed vigour. HortScience 15 : 765-771.

Adam, N. M.; M. B. M. McDonald, Jr. and P. R. Henderlong. 1989. The influence of seed position, planting and harvesting dates on soybean seed quality. Seed Science and Technology 17 : 143-152.

Adams, C. A. and R. W. Rinne. 1980. Moisture content as a controlling factor in seed development and germination. International Review of Cytology 68 : 1-8.

Alexander, G. 1990. Otago/Southland livestock and cropping gross margin 1990/1991. MAFtechnology, Ministry of Agriculture and Fisheries, Invercargill, New Zealand. 30 p.

Allen, J. D. 1961. Hollow heart of pea seed. New Zealand Journal of Agricultural Research 4 : 286.

Anderson, J. D. and K. Gupta. 1986. Nucleotide alterations during seed deterioration. In 'Physiology of Seed Deterioration', pp 47-64, Edited by M. B. McDonald, Jr. and C. J. Nelson. CSSA Special Publication Number 11, Crop Science Society of America, Inc., Madison, Wisconsin, U. S. A.

Anderson, J. A. D. and J. G. H. White. 1974. Yield of green peas II. Effects of water and plant density. New Zealand Journal of Experimental Agriculture 2 : 165-171.

AOSA. 1978. Rules for testing seeds. Journal of Seed Technology 3 : 1-126.

AOSA. 1983. Seed Vigor Testing Handbook. Contribution No. 32, Association of Official Seed Analysts. 88 p.

Askin, D. C.; J. G. H. White and P. J. Rhodes. 1985. Nitrogen fixation by peas and their effect on soil fertility. In 'The Pea Crop - A Basis for Improvement', pp 421-430, Edited by P. D. Hebblethwaite; M. C. Heath and T. C. K. Dawkins. Butterworths, London, U. K.

Austin, R. B. 1972. Effects of environment before harvesting. In 'Viability of Seeds', pp 104-109, Edited by E. H. Roberts. Syracuse University Press, Syracuse, New York, U. S. A.

Barker, D. J. 1983. The effects of summer moisture stress and its interaction with spring cutting managements on the production and persistence of a ryegrass (Lolium perenne L.) sward. M. Agr. Sc. Thesis, Massey University, New Zealand.

Baskin, C. C. 1987. Accelerated aging test. In 'Handbook of Vigour Test Methods', pp 42-48. The International Seed Testing Association, Zurich, Switzerland.

Bass, L. N. 1973. Controlled atmosphere and seed storage. Seed Science and Technology 1 : 463-492.

Bedford, L. V. and S. Matthews. 1975. The effect of seed age at harvest on the germinability and quality of heat dried seed peas. Seed Science and Technology 2 : 323-335.

Bewley, J. D. 1979. Physiological aspects of desiccation tolerance. Annual Review of Plant Physiology 30 : 195-238.

Bewley, J. D. 1986. Membrane changes in seeds as related to germination and the perturbations resulting from deterioration in storage. In 'Physiology of Seed Deterioration', pp 27-46, Edited by M. B. McDonald, Jr. and C. J. Nelson. CSSA Special Publication Number 11, Crop Science Society of America, Inc., Madison, Wisconsin, U. S. A.

Bewley, J. D. and M. Black. 1982. Physiology and Biochemistry of Seeds in Relation to Germination. Volume 2. Springer-Verlag, New York, U. S. A. 375 p.

Bewley, J. D. and M. Black. 1986. Seed. Physiology of Development and Germination. Plenum Press, London, U. K. 367 p.

Blair, I. D. 1952. Disease avoidance and crop rotation. Canterbury Chamber of Commerce Bulletin 272. Canterbury, New Zealand.

Bradford, K. J. 1983. Effects of soil flooding on leaf gas exchange of tomato plants. Plant Physiology 73 : 475-479.

Bradnock, W. T. and S. Matthews. 1970. Assessing field emergence potential of wrinkled-seeded peas. Horticultural Research 10 : 50-58.

Bramlage, W. J.; A. C. Leopold and D. J. Parrish. 1978. Chilling stress to soybean during imbibition. Plant Physiology 61 : 525-529.

Browning, T. H. and R. A. T. George. 1981. The effects of mother plant nitrogen and phosphorus nutrition on hollow heart and bleaching of pea (*Pisum sativum* L.) seed. Annals of Experimental Botany 32 : 1091-1103.

Burris, J. S. 1973. Effect of seed maturation and plant population on soybean seed quality. Agronomy Journal 65 : 440-441.

Carver, M. F. F. and S. Matthews. 1975. Respiratory measurements as indicators of field emergence ability in peas. Seed Science and Technology 3 : 871-879.

Casey, R. J. 1987. Garden pea cultivars - adaptability and uses. In 'Peas: Management for Quality', pp 63-65, Edited by W. A. Jermyn and G. S. Wratt. Agronomy Society of New Zealand Special Publication No. 6. Agronomy Society of New Zealand, Inc., Palmerston North, New Zealand.

Cherry, J. H. and R. W. Skadsen. 1986. Nucleic acid and protein metabolism during seed deterioration. In 'Physiology of Seed Deterioration', pp 65-88, Edited by M. B. McDonald, Jr. and C. J. Nelson. CSSA Special Publication Number 11, Crop Science Society of America, Inc, Madison, Wisconsin, U.S.A.

Ching, T. M. and S. Abu-Shakra. 1965. Effects of water vapour transmission rates of package material and storage conditions on seed quality. Agronomy Journal 57 : 285-287.

Chopra, U. K. and T. N. Chaudhary. 1981. Seedling emergence of wheat and grain in relation to soil and water potential, temperature and seeding depth. Journal of the Indian Society of Soil Science 29 : 437-440.

Christensen, C. M. and D. B. Suer. 1982. Microflora. In 'Storage of Cereal Grains and their Products', pp 219-240, Edited by C. M. Christensen. American Association of Cereal Chemist, Inc., St. Paul, Minnesota, U. S. A.

Copeland, L. O. and M. B. McDonald, Jr. 1985. Principles of Seed Science and Technology. Second edition, Burgess Publishing Co., Minnesota, U. S. A. 369 p.

Cowie, J. D. 1978. Soils and agriculture of Kairanga county, North Island, New Zealand. Soil Bureau Bulletin No. 33, Department of Scientific and Industrial Research (DSIR), Wellington, New Zealand.

Cowie, J. D.; B. S. Kear and G. E. Orbell. 1972. Soil map of Kairanga county, North Island, New Zealand. New Zealand Soil Bureau Map 102.

Cox, F. R. and P. H. Reid. 1964. Calcium-boron nutrition as related to concealed damage in peanut. Agronomy Journal 56 : 173-176.

Crawford, R. M. M. 1977. Tolerance of anoxia and ethanol metabolism in germinating seeds. The New Phytologist 79 : 511-517.

Crowe, J. H.; L. M. Crowe; F. A. Hoekstra and C. A. Wistrom. 1989. The effects of water on the stability of phospholipid bilayers: The problem of imbibition damage in dry organisms. In 'Seed Moisture', pp 1-14, Edited by P. C. Stanwood and M. B. McDonald. CSSA Special Publication Number 14, Crop Science Society of America, Inc., Madison, Wisconsin, U. S. A.

Dawkins, T. C. K. and M. McGowan. 1985. The influence of soil physical conditions on the growth, development and yield of vining peas (*Pisum sativum* L.). In 'The Pea Crop - A Basis for Improvement', pp 153-162, Edited by P. D. Hebblethwaite; M. C. Heath and T. C. K. Dawkins. Butterworths, London, U.K.

Delouche, J. C. 1974. Maintaining soybean seed quality. In 'Soybean Production, Marketing and Use', pp 46-62 NFDC, TVA, Muscle Shoals Alabama, U.S.A.

Delouche, J. C. 1980. Environmental effects on seed development and seed quality. HortScience 15 : 775-780.

Delouche, J. C. 1981. Harvest and post-harvest factors affecting the quality of cotton planting seed and seed quality evaluation. Proceedings, Beltwide Cotton Producers and Researchers Conference 289-305.

Delouche, J. C. and C. C. Baskin. 1973. Accelerated ageing techniques for predicting the relative storability of seed lots. Seed Science and Technology 1 : 427-452.

Dourado, A. M. and E. H. Roberts. 1984. Chromosome aberrations induced during storage in barley and pea seeds. Annals of Botany 54 : 767-779.

DSIR. 1990. Daily climatological observations (January and February 1990). Grasslands Division, Department of Scientific and Industrial Research. Palmerston North, New Zealand.

Duczmal, K. W. and L. Minicka. 1989. Further studies on pea seed quality and seedling emergence in the field. Acta Horticulturae 253 : 239-246.

Duffus, C. M. and J. C. Slaughter. 1980. Seeds and their Uses. John Willy and Sons, New York, U. S. A. 154 p.

Dunphy, E. J.; J. Hanway and E. E. Green. 1979. Soybean yields in relation to days between specific development stages. Agronomy Journal 71 : 917-920.

Edwards, A. L. 1976. An Introduction to Linear Regression and Correlation. W.H. Freeman and Company, San Francisco, U. S. A. 213 p.

Eeuwens, C. J. and W. W. Schwabe. 1975. Seed and pod wall development in *Pisum sativum* L., in relation to extracted and applied hormones. Journal of Experimental Botany 26 : 1-14.

Ellis, R. H. 1984. The meaning of viability. In 'Seed Management Techniques for Genebanks', pp 146-178, Edited by J. B. Dickie, S. Linington and J. T. Williams. International Board for Plant Genetic Resources, Rome, Italy.

Ellis, R. H. and E. H. Roberts. 1980a. Improved equations for the prediction of seed longevity. Annals of Botany 45 : 13-30.

Ellis, R. H. and E. H. Roberts. 1980b. The influence of temperature and moisture on seed viability period in barley (*Hordeum distichum* L.). Annals of Botany 45 : 31-37.

Ellis, R. H. and E. H. Roberts. 1980c. Towards a rational basis for testing seed quality. In 'Seed Production', pp 605-635, Edited by P. D. Hebblethwaite. Butterworths, London, U. K.

Ellis, R. H. and E. H. Roberts. 1982. Desiccation, rehydration, germination, imbbibition injury and longevity of pea seeds (*Pisum sativum).* Seed Science and Technology 10 : 501-508.

Ellis, R. H.; K. Osei-Bonsu and E. H. Roberts. 1982. The influence of genotype temperature and moisture on seed longevity in chickpea, cowpea and soybean. Annals of Botany 50 : 69-82.

Escasinas, A. B. 1986. A study of the causes of seed deterioration following processing in maize (Zea mays L.). M.Agr.Sc. Thesis, Massey University, Palmerston North, New Zealand.

Eua-Umpon, V. 1991. A study of vigour test methodology variables and the relationship between vigour tests and field emergence in mungbean (Phaseolus mungo L.), soybean (Glycine max (L.) Merril) and French bean (Phaseolus vulgaris L.). Dip. Agr. Sc. Thesis, Massey University, Palmerston North, New Zealand.

Evans, H. J. 1977. Molecular mechanisms in the induction of chromosome aberrations. In 'Progress in Genetic Toxicology', pp 57-74, Edited by D. Scott; B. A. Bridges and F. H. Sobels. North Holland, Amsterdam.

Fausey, N. R. and M. B. McDonald. 1985. Emergence of inbred and hybrid corn following flooding. Agronomy Journal 77 : 51-56.

Finney, D. J. 1971. Probit Analysis. Third Edition, Cambridge University Press, Great Britain. 333 p.

Flentje, N. T. 1964. Pre-emergence rotting of peas in South Australia. I. Factors associated with the seed. Australian Journal of Biological Science 17 : 643-650.

Flinn, A. M. and J. S. Pate. 1968. Biochemical and physiological changes during maturation of fruit of the field pea (*Pisum arvense* L.). Annals of Botany 32 : 479-495.

Freeman, C. L. 1987. Growing peas under irrigation. In 'Peas: Management for Quality', pp 19-22, Edited by W. A. Jermyn and G. S. Wratt. Agronomy Society of New Zealand Special Publication No. 6. Agronomy Society of New Zealand, Inc., Palmerston North, New Zealand.

Gane, A. J. 1985. The pea crop - agricultural progress, past, present and future. In 'The Pea Crop - A Basis for Improvement', pp 3-16, Edited by P. D. Hebblethwaite; M. C. Heath and T. C. K. Dawkins. Butterworths, London, U.K.

Gane, A. J.; A. J. Biddle; C. M. Knott and D. J. Eagle. 1984. The PGRO Pea Growing Handbook. Processors and Growers Research Organisation, Peterborough, England. 242 p.

Gill, N. S. and J. C. Delouche. 1973. Deterioration of seed corn during storage. Proceedings of the Association of Official Seed Analysts 63 : 33-50.

Gleeson, B. 1987. Pea exports for seed and commodity. In 'Peas: Management for Quality', pp 69-71, Edited by W. A. Jermyn and G. S. Wratt. Agronomy Society of New Zealand Special Publication No. 6. Agronomy Society of New Zealand, Inc., Palmerston North, New Zealand.

Gray, D. 1987. The potential of plant growth regulators for improving vegetable seed quality. In 'Growth Regulators and Seeds', pp 93-105, Edited by N. J. Pinfield and M. Black. Monograph No.15. British Plant Growth Regulator Group, Bristol, Great Britain.

Green, D. E.; L. E. Cavanah and E. L. Pinnell. 1966. Effects of seed moisture content, field weathering, and combine cylinder speed on soybean seed quality. Crop Science 6 : 7-10.

Hadavizadeh, A. and R. A. T. George. 1989. The effect of mother plant nutrition on seed yield and seed vigour in pea (*Pisum sativum* L.) cultivar 'sprite'. Acta Horticulturae 253 : 55-61.

Halligan, E. A. 1986. The effect of elevated temperatures and their duration on the incidence of hollow heart in pea seeds. Annals of Applied Biology 109 : 619-625.

Halloin, J. M. 1986. Microorganisms and seed deterioration. In 'Physiology of Seed Deterioration', pp. 89-100, Edited by M. B. McDonald and C. J. Nelson. CSSA Special Publication Number 11. Crop Science Society of America, Madison, U. S. A.

Hampton, J. G. 1984. Pea seed vigour. In 'Annual Report 1984', pp 40-47, Edited by J. G. Hampton. Official Seed Testing Station, Ministry of Agriculture and Fisheries, Palmerston North, New Zealand.

Hampton, J. G. 1990. Seed vigour. Proceedings of an ISTA/USSR Seed Quality Workshop, Novosibirsk (In Press).

Hampton, J. G. and P. Coolbear. 1990. Potential versus actual seed performance - can vigour testing provide an answer? Seed Science and Technology 18 : 215-228.

Hampton, J. G. and M. J. Hill. 1990. Herbage seed lots: are germination data sufficient? Proceedings of the New Zealand Grasslands Association 52 : 59-64.

Hampton, J. G. and D. J. Scott. 1982. Effect of seed vigour on garden pea production. New Zealand Journal of Agricultural Research 25 : 289-294.

Harman, G. E. and A. L. Granett. 1972. Deterioration of stored pea seed: Changes in germination, membrane deterioration and ultrastructure resulting from infection by *Aspergillus ruber* and from aging. Physiological Plant Pathology 2 : 271-278.

Harrington, J. F. 1972. Seed storage and longevity. In 'Seed Biology Volume 3', pp 145-245, Edited by T. T. Kozlowski. Academic Press, New York, U. S. A.

Harrington, J. F. 1978. Problems of seed storage. In 'Seed Ecology', pp 251-263, Edited by W. Heydecker. Butterworths, London, U. K.

Harris, H. B.; M. B. Parker and B. J. Johnson. 1965. Influence of molybdenum content on soybean seed and other factors associated with seed source on progeny and response to applied molybdenum. Agronomy Journal 57 : 397-399.

Harrison, J. G. and D. A. Perry. 1973. Effects of hollow heart on growth of peas. Annals of Applied Biology 73 : 103-109.

Hebblethwaite, P. D. and M. McGowan. 1980. The effects of soil compaction on the emergence, growth and yield of sugar beet and peas. Journal of the Science of Food and Agriculture 31 : 1131-1142.

Heydecker, W. 1969. The 'vigour' of seeds - A review. Proceedings of the International Seed Testing Association 34 : 201-219.

Heydecker, W. 1972. Vigour. In 'Viability of Seeds', pp 209-252, Edited by E. H. Roberts. Syracuse University Press, Syracuse, New York, U. S. A.

Heydecker, W. and D. M. Feast. 1969. Studies of the hollow heart condition of pea (*Pisum sativum*) seeds. Proceedings of the International Seed Testing Association 34 : 319-328.

Heydecker, W. and M. R. Kohistani. 1969. Hollow heart and poor stands of peas (*Pisum sativum*). Annals of Applied Biology 64 : 153-160.

Hunt, W. H. and S. W. Pixton. 1974. Moisture - its significance, behavior, and measurement. In 'Storage of Cereal Grains and their Products', pp 1-45, Edited by C. M. Christensen. Amaerican Association of Cereal Chemists, Inc., St. Paul, Minnesota, U. S. A.

Ibrahim, A. E. and E. H. Roberts. 1983. Viability of lettuce seeds. I. Survival in hermetic storage. Journal of Experimental Botany 34 : 620-630.

ISTA. 1985. International Rules for Seed Testing 1985. Seed Science and Technology 13 : 300-520.

ISTA. 1987. Handbook of Vigour Test Methods. Second Edition. International Seed Testing Association, Zurich, Switzerland. 72 p.

Jackson, M. B. 1985. Responses of leafed and leafless peas to soil waterlogging. In 'The Pea Crop - A Basis for Improvement', pp 163-172, Edited by P. D. Hebblethwaite; M. C. Heath and T. C. K. Dawkins. Butterworths, London, U.K.

James, E.; L. N. Bass and D. C. Clark. 1967. Varied differences in longevity of vegetable seeds and their response to various storage conditions. Proceedings of the American Society of Horticultural Science 91 : 521-528.

Justice, O. L. and L. N. Bass. 1978. Principles and Practices of Seed Storage. USDA Agricultural Handbook 506. US Government Printing Office, Washington D.C., U. S. A. 289 p.

Koller, D. 1972. Environmental control of seed germination. In 'Seed Biology Volume 2', pp 2-102, Edited by T. T. Kozlowski. Academic Press, New York, U. S. A.

Kuo, W. H. J. 1989. Delayed-permeability of soybean seeds: characteristics and screening methodology. Seed Science and Technology 17 : 131-142.

Ladonne, F. 1989. Relationship between standard germination test, conductivity test and field emergence of pea seeds. Acta Horticulturae 253 : 153-162.

Laughland, J. and D. H. Laughland. 1939. The effect of age on the vitality of soybean seeds. Scientific Agriculture (Ottawa) 20 : 236-237.

Le Deunff, Y. 1989. Pea seed development and evolution of its ability to germinate. Acta Horticulturae 253 : 73-81.

Le Deunff, Y. and Z. Rachidian. 1988. Interruption of water delivery at physiological maturity is essential for seed development, germination and seedling growth in pea (*Pisum sativum* L.). Journal of Experimental Botany 39 : 1221-1230.

Leggatt, C. W. 1948. Germination of boron deficient peas. Scientific Agriculture 28 : 131-139.

Leibovitz, B. E. and B. V. Siegel. 1980. Aspects of free radical reactions in biological systems: Aging. Journal of Gerontology 35 : 45-56.

Leopold, A. C. and C. W. Vertucci. 1989. Moisture as a regulator of physiological reaction in seeds. In 'Seed Moisture', pp 51-68, Edited by P. C. Stanwood and M. B. McDonald. CSSA Special Publication Number 14, Crop Science Society of America, Inc., Madison, Wisconsin, U. S. A.

Logan, L. A. 1983. Crop production and utilisation in New Zealand. Crop Research Division, D.S.I.R. Report No. 81. 210 p.

Makasheva, R. Kh. 1973. The Pea. Oxonian, New Delhi, India. 267 p.

Marinos, N.G. 1970. Embryogenesis of the pea (*Pisum sativum)* I. The cytological environment of the developing embryo. Protoplasma 70 : 261-279.

Mashauri, I. M. 1991. Relationship between initial seed moisture content, processing damage and storage on the quality of maize(Zea mays L.) seeds. Dip. Agr. Sc. Thesis, Massey University, Palmerston North, New Zealand.

Matthews, S. 1973. The effect of time of harvest on the viability and pre-emergence mortality in soil of pea (*Pisum sativum* L.) seeds. Annals of Applied Biology 73 : 211-219.

Matthews, S. 1977. Field emergence and seedling establishment. In 'The Physiology of Garden Pea', pp 83-118, Edited by J. F. Sutcliffe and J. S. Pate. Academic Press, London, U. K.

Matthews, S. 1980. Controlled deterioration: a new vigour test for crop seeds. In 'Seed Production', pp 647-660, Edited by P. D. Hebblethwaite. Butterworths, London, U. K.

Matthews, S. and W. T. Bradnock. 1967. The detection of seed samples of wrinkled-seeded peas (*Pisum sativum* L.) of potentially low planting value. Proceedings of the International Seed Testing Association 32 : 553-563.

Matthews, S. and W. T. Bradnock. 1968. Relationship between seed and field emergence in peas and French beans. Horticultural Research 8 : 89-93.

Matthews, S. and A. A. Powell. 1986. Environmental and physiological constraints on field performance of seeds. HortScience 21 : 1125-1128.

Matthews, S. and A. A. Powell. 1987a. Controlled deterioration test. In 'Handbook of Vigour Test Methods', pp 49-56. The International Seed Testing Association, Zurich, Switzerland.

Matthews, S. and A. A. Powell. 1987b. Electical conductivity test. In 'Handbook of Vigour Test Methods', pp 37-41. The International Seed Testing Association, Zurich, Switzerland.

Meadley, J. T. and G. M. Milbourn. 1970. The growth of vining peas. II. The effect of density of planting. Journal of Agricultural Science, Cambridge 174 : 273-278.

Millerd, A.; J. A. Thomson and H. E. Schroeder. 1978. Cotyledonary storage proteins in *Pisum sativum*. III. Patterns of accumulation during development. Australian Journal of Plant Physiology 5 : 519-534.

Moore, R. P. 1963. Previous history of seed lots and differential maintenance of seed viability and vigour in storage. Proceedings of the International Seed Testing Association 28 : 691-699.

Moore, R. P. 1964. Garden pea cotyledon cavities. Newsletter Association of Official Seed Analysts of North America 38 : 12.

Moreira, S. M.; G. W. Krutz and G. H. Foster. 1981. Crack formation in corn kernels subject to impact. Transactions of the ASAE 24 : 889-892.

Myers, A. 1948. Hollow heart: An abnormal condition of the cotyledons of *Pisum sativum* L. Proceedings of the International Seed Testing Association 14 : 35-37.

Nichols, M. A.; I. J. Warrington; L. M. Green and D. J. Scott. 1978. Pre-harvest treatment effects on some quality criteria of pea seeds. Acta Horticulturae 83 : 113-124.

Pate, J. S. and A. M. Flinn. 1977. Fruit and seed development. In 'The Physiology of the Garden Pea', pp 431-468, Edited by J.F. Sutcliffe and J.S. Pate. Academic Press, London, U. K.

Pate, J. S.; C. A. Atkin and M. W. Perry. 1980. Significance of photosynthate produced at different stages of growth as carbon source for fruit filling and seed reserve accumulation in *Lupinus angustifolius* L. Australian Journal of Plant Physiology 7 : 283-297.

Perry, D. A. 1969. Seed vigour in peas. Proceedings of the International Seed Testing Association 34 : 221-232.

Perry, D. A. 1970. The relation of seed vigour to field establishment of garden pea cultivars. Journal of Agricultural Science, Cambridge 74 : 343-348.

Perry, D. A. 1980. The concept of seed vigour and its relevance to seed production techniques. In 'Seed Production', pp 585-591, Edited by P. D. Hebblethwaite. Butterworths, London, U. K.

Perry, D. A. and J. G. Harrison. 1970. The deleterious effect of water and low temperature on germination of pea seed. Journal of Experimental Botany 21 : 504-512.

Perry, D. A. and J. G. Harrison. 1973. Causes and development of hollow heart in pea seed. Annals of Applied Biology 73 : 93-101.

Perry, D. A. and P. J. Howell. 1965. Symptoms and nature of hollow heart in pea seed. Plant Pathology 14 : 111-116.

Powell, A. A. 1985. Impaired membrane integrity - a fundamental cause of seed quality differences in peas. In 'The Pea Crop - A Basis for Improvement', pp 383-394, Edited by P. D. Hebblethwaite; M. C. Heath and T. C. K. Dawkins. Butterworth, London, U. K.

Powell, A. A. 1986. Cell membranes and seed leachate conductivity in relation to the quality of seed for sowing. Journal of Seed Technology 10 : 81-100.

Powell, A. A. 1988. Seed vigour and field establishment. In 'Advances in Research and Technology of Seeds Part 11', pp 29-61, Edited by S. Matthews for the International Seed Testing Association (ISTA), Pudoc, Wageningen, The Netherlands.

Powell, A. A. and S. Matthews. 1981. Evaluation of controlled deterioration, a new vigour test for crop seeds. Seed Science and Technology 9 : 633-640.

Powell, A. A. and S. Matthews. 1984. Prediction of the storage potential of onion seed under commercial storage conditions. Seed Science and Technology 12 : 641-647.

Powell, A. A.; R. Don; P. Haigh; G. Phillips; J. H. B. Tonkin and O. E. Wheaton. 1984. Assessment of the repeatability of the controlled deterioration vigour test both within and between laboratories. Seed Science and Technology 12 : 659-668.

Powell, A. A.; S. Matthews and M. de A. Oliveira. 1984. Seed quality in grain legumes. Advances in Applied Biology 10 : 217-285.

Powell, A. A.; M. de A. Oliveira and S. Matthews. 1986. The role of imbibition damage in determining the vigour of white and coloured seed lots of dwarf French bean (*Phaseolus vulgaris*). Journal of Experimental Botany 37 : 716-722.

Presley, J. T. 1958. Relation of protoplast permeability to cotton seed viability and predisposition to seedling disease. Plant Disease Reporter 42 : 852.

Priestley, D. A. 1986. Seed Aging. Cornell University Press, London, U.K. 304 p.

Priestley, D. A.; M. B. McBride and A. C. Leopold. 1980. Tocopherol and organic free radical levels in soybean seeds during natural and accelerated aging. Plant Physiology 66 : 715-719.

Pumphrey, F. V. and R. E. Ramig. 1990. Field response of peas to excess heat during the reproductive stage of growth. Journal of American Society of Horticultural Science 115 : 898-900.

Ridge, P. E. and D. L. Pye. 1985. The effects of temperature and frost at flowering on the yield of peas grown in a mediterranean environment. Field Crops Research 12 : 339-346.

Roberts, E. H. 1960. The viability of cereal seed in relation to temperature and moisture. Annals of Botany 24 : 12-31.

Roberts, E. H. 1972. Storage environment and the control of viability. In 'Viability of Seeds', pp 14-58, Edited by E. H. Roberts. Syracuse University Press, Syracuse, New York, U.S.A.

Roberts, E. H. 1973a. Loss of seed viability: Ultrastructural and physiological aspects. Seed Science and Technology 1 : 529-545.

Roberts, E. H. 1973b. Predicting the viability of seeds. Seed Science and Technology 1 : 499-514.

Roberts, E. H. 1984. The control of seed quality and its relationship to crop productivity. Proceedings of the Australian Seed Research Conference 11-25.

Roberts, E. H. 1986. Quantifying seed deterioration. In 'Physiology of Seed Deterioration', pp 101-123, Edited by M. B. McDonald and C. J. Nelson. CSSA Special Publication No. 11. Crop Science Society of America, INC. Madison, U. S. A.

Roberts, E. H. and R. H. Ellis. 1984. The implications of the deterioration of orthodox seeds during storage for genetic resource conservation. In 'Crop Genetic Resources: Conservation and Evaluation', pp 18-37, Edited by J. W. Holden and J. T. Williams. IBPGR and George Allen and Unwin, London, U. K.

Roberts, H. A. 1984. Crop and weed emergence patterns in relation to time of cultivation and rainfall. Annals of Applied Biology 105 : 263-275.

Robertson, R. N.; H. R. Highkin; J. Smydzuk and F. W. Went. 1961. The effect of environmental conditions on the development of pea seeds. Australian Journal of Biological Science 15 : 1-15.

Roos, E. E. 1980. Physiological, biochemical and genetic changes in seed quality during storage. HortScience 15 : 781-784.

Roos, E. E. 1986. Precepts of successful seed storage. In 'Physiology of Seed Deterioration', pp 1-26, Edited by M. B. McDonald, Jr. and C. J. Nelson. CSSA Special Publication Number 11, Crop Science Society of America, Inc., Madison, Wisconsin, U. S. A.

Salter, P. J. 1963. The effect of wet or dry conditions at different growth stages on the components of yield of a pea crop. Journal of Horticultural Science 38 : 321-334.

SAS. 1988. SAS Technical Report P-179, Additional SAS/STAT Procedures, Release 6.03. Cary, North Carolina, U. S. A. 255 p.

St. Angelo, A. J.; J. C. Kuck and R. L. Ory. 1979. Role of lipoxygenase and lipid oxidation in quality oilseeds. Journal of Agricultural Food Chemistry 27 : 229-234.

Schow, J. B.; D. J. Jeffers and J. G. Streeter. 1978. Effects of reflectors, blackboard, or shades applied at different stages of plant development on yield of soybeans. Crop Science 18 : 29-35.

Scott, D. J. and R. C. Close. 1976. An assessment of seed factors affecting field emergence of garden pea seed lots. Seed Science and Technology 4 : 287-300.

Scotter, D. R.; B. E. Clothier and R. B. Corker. 1979. Soil water in a fragiaqualf. Australian Journal of Soil Research 17 : 443-453.

Sharma, K. D. 1977. Biochemical changes in stored oil seeds. Indian Journal of Agricultural Research 11 : 137-141.

Short, G. E. and M. L. Lacy. 1976. Carbohydrate exudation from pea seeds: Effect of cultivar, seed age, seed colour and temperature. Phytopathology 66 : 182-187.

Simon, E. W. 1974. Phospholipids and plant membrane permeability. The New Phytologist 73 : 377-420.

Simon, E. W. and R. M. Raja Harun. 1972. Leakage during seed imbibition. Journal of Experimental Botany 23 : 1076-1085.

Sinclair, T. R. and C. T. DeWit. 1976. Analysis of carbon and nitrogen limitations to soybean yield. Agronomy Journal 68 : 319-324.

Singer, S. J. and G. L. Nicolson. 1972. The fluid mosaic model of the structure of cell membranes. Science 175 : 720-731.

Smith, D. L. 1973. Nucleic acid, protein, and starch synthesis in developing cotyledons of *Pisum arvense* L. Annals of Botany 37 : 795-804.

Smith, T. J. and H. M. Camper. 1975. Effect of seed size on soybean performance. Agronomy Journal 67 : 681-684.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods. Seventh Edition, Iowa State University Press, Ames, Iowa, U.S.A. 507 p.

Southwick, J. R. 1974. Packing of cereal products. In 'Storage of Cereal Grain and their Products', Second Edition, pp 509-539, Edited by C. M. Christensen. Monograph Series, American, Association of Cereal Chemist, Inc., St. Paul, Minnesota, U.S.A.

Stoker, R. 1975. Effect of plant population on yield of garden peas under different moisture regimes. New Zealand Journal of Experimental Agriculture 3 : 333-337.

TeKrony, D. M.; D. B. Egli and J. Balles. 1980. The effect of seed production environment on soyabean seed quality. In 'Seed Production', pp 403-420, Edited by P. D. Hebblethwaite. Butterworths, London, U. K.

TeKrony, D. M.; D. B. Egli; J. Balles; T. Pfeiffer and R. J. Fellow. 1979. Physiological maturity in soybean. Agronomy Journal 71 : 771-775.

Thompson, J. R. 1979. An Introduction to Seed Technology. Leonard Hill, Glasgow, U. K. 251 p.

Villiers, T. A. 1975. Genetic maintenance of seeds in imbibed storage. In 'Crop Genetic Resources for Today and Tomorrow', pp 297-316, Edited by O. H. Frankel and J. G. Hawkes. Cambridge University Press, Cambridge, U. K.

Wang, Y. R. 1989. A study of the relationship between seed vigour and seed performance in Trifolium pratense L. cv. Grasslands Pawera. M.Agr.Sc. Thesis, Massey University, Palmerston North, New Zealand.

Wang, Y. R. and J. G. Hampton. 1989. Red clover (*Trifolium pratense* L.) seed quality. Proceedings of the Agronomy Society of New Zealand 19 : 63-69.

Wang, Y. R. and J. G. Hampton. 1991. Seed vigour and storage in Grasslands Pawera red clover. Plant Varieties and Seeds 4 : 61-66.

Ware, G. W. and J. P. McCollum. 1980. Producing Vegetable Crops. Third Edition, The Interstate Printers and Publishers, Inc., Danville, Illinois, U. S. A. 558p.

Warham, E. J. 1986. A comparison of packaging materials for seed with particular reference to humid tropical environments. Seed Science and Technology 14 : 191-211.

White, J. G. H. 1987. The importance of peas in New Zealand arable agriculture. In 'Peas: Management for Quality', pp 7-12, Edited by W. A. Jermyn and G. S. Wratt. Agronomy Society of New Zealand Special Publication No. 6. Agronomy Society of New Zealand, Inc., Palmerston North, New Zealand.

White, J. G. H. and J. A. D. Anderson. 1974. Yield of green peas I. Responses to variation in plant density and spatial arrangement. New Zealand Journal of Experimental Agriculture 2 : 159-164.

White, J. G. H.; G. W. Sheath and G. Meijer. 1982. Yield of garden peas - field responses to variation in sowing rate and irrigation. New Zealand Journal of Experimental Agriculture 10 : 155-160.

Wilson, D. O.; M. B. McDonald, Jr. and S. K. St. Martin. 1989. A probit planes method for analyzing seed deterioration data. Crop Science 29 : 471-476.

Wilson, D. R. 1987. New approaches to understanding the growth and yield of pea crops. In 'Peas: Management for Quality', pp 23-28, Edited by W. A. Jermyn and G. S. Wratt. Agronomy Society of New Zealand Special Publication No. 6. Agronomy Society of New Zealand, Inc., Palmerston North, New Zealand.

Woodroof, J. G. 1973. Peanuts: Production, Processing, Products. Second Edition, AVI Publishing Company, Westport, Connecticut, U. S. A. 330 p.

Woodstock, L. W.; K. Furman and H. R. Leffler. 1985. Relationship between weathering deterioration and germination, respiratory metabolism, and mineral leaching from cottonseed. Crop Science 25 : 459-466.

Appendix I.1. Seed quality results for 82 seedlots in the 1988 season.

SEED LOT NO.	A	B	C	D	E	F
1	97.3	5.3	20	88.5	72.7	71.3
2	97.5	8.5	21	87.3	84.7	94.0
3	94.5	5.5	17	87.2	78.0	88.7
4	83.0	18.5	33	69.3	56.0	60.0
5	85.5	1.1	29	79.6	63.3	68.7
6	88.0	13.5	23	78.5	65.3	83.3
7	88.0	6.0	25	80.6	62.7	71.3
8	71.0	17.0	40	61.5	48.0	46.7
9	98.5	25.5	19	82.7	86.0	82.7
10	90.5	21.5	20	78.2	81.3	82.0
11	87.5	3.5	19	81.5	67.3	75.3
12	99.4	1.5	14	92.7	82.7	92.0
13	97.0	2.1	20	89.4	81.3	90.7
14	92.5	26.0	20	78.1	75.3	68.7
15	98.5	1.6	16	91.6	85.3	93.3
16	98.5	1.1	13	92.4	79.3	93.3
17	70.5	0.6	32	68.6	69.3	69.3
18	97.5	0.1	15	91.6	81.3	94.0
19	99.0	3.0	18	90.9	80.0	87.3
20	95.0	1.5	15	89.3	87.3	84.7
21	99.4	1.1	11	93.5	77.3	94.0
22	94.5	18.0	24	81.3	68.0	64.7
23	96.0	6.0	16	88.2	84.7	92.0
24	94.5	26.5	24	78.4	87.3	90.7
25	89.5	9.5	27	80.0	73.3	80.0
26	97.0	18.0	24	83.1	79.3	89.3
27	95.5	24.5	15	81.9	74.7	86.0
28	90.5	16.5	21	79.7	80.7	87.3
29	96.5	13.0	25	84.1	86.0	92.6
30	99.9	2.0	14	92.9	76.7	92.0
31	85.0	13.5	18	77.6	84.0	86.7
32	90.5	15.0	36	76.8	76.7	74.0
33	85.5	2.1	21	81.1	84.7	86.0
34	85.5	23.0	20	74.2	78.0	84.0
35	81.0	3.0	22	77.4	71.3	78.7
36	68.5	2.5	25	68.2	64.7	75.3
37	70.0	3.1	22	69.7	83.3	90.0
38	89.0	0.6	18	84.8	78.7	89.3
39	87.5	0.1	16	84.4	81.3	88.7
40	69.0	3.0	33	66.5	61.3	70.0
41	91.5	13.5	28	79.8	68.7	81.3
42	99.4	0.1	11	93.9	81.3	91.3
43	96.5	12.0	22	85.2	85.3	93.3
44	92.0	14.7	17	82.3	84.0	0.0
45	94.0	16.7	18	82.8	83.3	0.0
46	91.5	12.0	37	78.3	72.7	70.7
47	92.0	7.5	31	81.5	75.3	79.3
48	95.5	14.0	31	81.8	81.3	94.0
49	88.5	9.0	28	79.1	78.7	80.0

50	90.0	2.5	27	82.7	80.0	89.3
51	79.0	2.1	25	75.7	66.7	81.3
52	97.0	1.6	17	90.3	85.3	84.7
53	87.5	0.6	18	83.7	72.7	86.0
54	96.5	2.0	18	89.5	81.3	92.0
55	90.0	1.1	18	85.3	82.0	90.0
56	94.5	4.0	18	87.5	80.7	88.0
57	75.0	0.6	20	74.5	70.7	82.0
58	78.5	4.0	32	73.0	66.0	70.7
59	90.5	2.5	14	86.1	83.3	88.7
60	75.0	6.0	28	70.8	68.0	70.0
61	85.0	6.0	26	78.3	64.7	76.0
62	93.5	1.1	15	88.5	89.3	90.7
63	56.5	13.5	28	55.3	55.3	52.0
64	82.0	3.4	24	77.6	78.0	0.0
65	47.5	18.5	47	43.0	39.3	37.3
66	92.5	10.0	18	84.0	80.0	88.7
67	97.0	4.5	16	89.5	83.3	94.7
68	93.5	0.1	14	89.0	80.7	92.7
69	96.5	39.5	20	76.3	80.0	86.0
70	96.5	27.0	20	80.6	86.0	90.7
71	95.0	1.5	13	89.8	84.7	98.0
72	97.0	9.0	16	88.0	84.7	88.7
73	95.5	4.0	17	88.4	93.3	96.0
74	92.5	14.5	23	81.3	86.7	87.3
75	91.5	17.0	20	80.5	88.0	90.0
76	85.0	30.0	29	69.4	83.3	86.7
77	85.5	36.0	25	68.7	85.3	86.0
78	88.5	42.0	23	69.2	82.7	84.7
79	89.5	3.5	18	84.1	77.3	93.3
80	95.0	0.1	13	90.3	85.3	90.7
81	76.7	4.0	26	73.2	76.0	82.7
82	87.5	9.0	24	79.5	55.3	68.7

A = Mean percent normal seedlings from germination test.
B = Mean percent hollow heart
C = Mean Conductivity reading ($\mu S\ g^{-1}$ seed)
D = Mean Expected Field Emergence
E = Mean November Field Emergence
F = Mean December Field Emergence

Appendix I.2. Regression table for November 1988.

SEED LOT	GERMINATION A	GERMINATION B	GERMINATION R^2	EXP FIELD EMERG A	EXP FIELD EMERG B	EXP FIELD EMERG R^2	CONDUCTIVITY A	CONDUCTIVITY B	CONDUCTIVITY R^2	HOLLOW HEART A	HOLLOW HEART B	HOLLOW HEART R^2
ALL LOTS (82)[1]	14.68	0.70	0.49	17.94	0.73	0.43	97.52	-0.94	0.43	76.72	0.02	0.0004
AB 85% GERM(67)[1]	21.45	0.63	0.15	55.11	0.29	0.06	89.10	-0.47	0.14	79.04	0.05	0.006
PANIA[2] (21)[1]	-11.35	1.00	0.66	2.57	0.97	0.57	112.16	-1.44	0.72	76.92	0.02	0.001
PANIA (18)[1]	49.04	0.36	0.06	67.00	0.19	0.03	96.12	-0.65	0.23	81.61	0.03	0.002
PATEA[2] (12)[1]	5.13	0.78	0.28	20.50	0.68	0.29	92.97	-0.74	0.39	78.50	-0.04	0.006
SSF[2] (22)[1]	17.82	0.67	0.63	5.79	0.88	0.68	93.56	-0.71	0.37	76.74	-0.01	0.001
SSF (16)[1]	-24.46	1.13	0.46	-2.20	0.97	0.46	89.44	-0.44	0.21	81.58	-0.32	0.07

A = Intercept (CONSTANT TERM)
B = Slope
R^2= Coefficient of determination

Appendix I.3. Seed quality characters of different seed lots used during the 1989 sowing season for field emergence experiments.

SEED LOT NUMBER	GERMINATION (PERCENT)	CONDUCTIVITY (uS/g SEED)	HOLLOW HEART (PERCENT)	E. F. E. (PERCENT)
1	90.5	21.3	20.5	78.3
2	98.8	18.2	3.0	90.8
3	96.4	24.9	13.0	84.1
4	90.5	35.9	15.0	76.8
5	96.9	18.2	1.8	89.8
6	87.5	17.7	0.9	83.7
7	96.4	18.0	2.1	89.4
8	90.0	17.9	1.3	85.2
9	94.4	20.1	4.0	86.9
10	96.8	16.0	4.5	89.4
11	99.1	14.0	2.0	92.3
12	98.4	16.0	2.0	91.3
13	97.4	15.2	0.5	91.3
14	94.5	24.8	18.0	81.1
15	89.0	18.3	0.5	84.7
16	85.0	15.7	0.5	82.5
17	96.4	20.7	39.5	76.1
18	94.5	22.1	11.0	84.1
19	96.0	20.6	10.5	85.7
20	96.0	19.1	1.6	89.1
21	99.1	18.3	11.5	88.1
22	93.5	21.3	11.0	83.6
23	99.5	15.6	5.5	91.0
p-value	**	**	**	**
cv 3.21	5.03	39.98	2.86	
$lsd_{0.05}$	4.29	1.3883	4.421	3.47

** Significant at 1% level

Appendix I.4. Percent field emergence in irrigated plots sown at different dates in 1989.

SEED LOT NUMBER	SOWING TIME* 1	2	3	4	5	6
1	32.5	55.0	49.0	70.5	71.5	61.0
2	33.5	70.0	59.0	69.0	80.5	70.5
3	35.0	92.5	75.5	91.0	96.5	64.5
4	25.0	77.0	64.0	83.0	83.5	53.0
5	42.5	68.5	62.5	81.0	90.5	74.5
6	44.0	65.5	66.0	78.0	87.5	76.5
7	34.0	68.0	62.0	77.0	90.0	78.0
8	48.0	65.5	56.0	75.5	83.5	78.0
9	43.0	60.5	60.5	77.0	86.0	63.0
10	52.5	66.0	67.0	93.5	97.0	85.5
11	49.5	59.5	74.5	84.0	87.5	83.0
12	47.0	61.5	76.0	84.5	84.0	84.5
13	59.0	73.0	69.5	92.0	89.0	81.0
14	19.0	62.0	45.5	52.5	70.0	63.0
15	58.5	71.0	67.5	79.0	91.0	78.0
16	55.0	68.5	70.0	82.0	91.0	81.5
17	54.0	68.0	62.0	75.5	92.0	64.5
18	44.0	82.5	83.0	95.9	93.5	53.0
19	45.0	71.5	65.5	79.0	91.5	62.0
20	56.0	80.5	79.5	81.5	90.0	74.0
21	59.5	80.0	76.0	91.5	94.8	72.5
22	47.5	70.0	56.5	82.5	87.5	66.5
23	48.5	68.5	66.0	81.0	90.5	80.0
p-value	**	**	**	**	**	**
cv	15.52	17.90	13.08	8.20	7.08	5.70
$lsd_{0.05}$	9.84	17.63	12.145	9.342	8.774	5.792

** Significant at 1% level

*SOWING TIME:
1 = 30 OCTOBER 1989
2 = 10 NOVEMBER 1989
3 = 21 NOVEMBER 1989
4 = 30 NOVEMBER 1989
5 = 11 DECEMBER 1989
6 = 20 DECEMBER 1989

Appendix I.5a. Percent field emergence without irrigation at different sowing times as influenced by different weather conditions in the field during spring 1989.

LOT NO.	SOWING TIME* 1	2	3	4
1	59.0	64.0	42.5	34.0
2	63.0	78.5	48.5	45.5
3	85.0	77.5	46.0	32.5
4	79.5	73.0	51.0	25.5
5	72.0	74.5	62.5	50.5
6	79.0	71.5	53.5	54.5
7	75.0	81.5	64.0	43.5
8	77.5	77.0	68.0	43.0
9	84.0	70.0	44.0	42.5
10	87.0	74.5	56.0	55.0
11	85.5	77.0	64.5	57.0
12	75.0	73.0	53.0	52.5
13	82.5	70.0	59.0	50.0
14	48.0	65.5	48.5	34.0
15	73.5	74.0	51.5	60.5
16	74.5	71.0	54.5	58.0
17	75.5	70.5	50.5	37.5
18	78.5	76.5	57.0	43.0
19	70.0	69.5	48.5	40.0
20	74.0	75.0	57.0	53.0
21	84.5	75.0	61.5	66.0
22	67.5	71.5	48.5	29.5
23	78.0	71.0	58.5	59.5
p-value	**	ns	*	**
cv	10.10	11.31	18.62	12.83
$lsd_{0.05}$	10.71	11.68	14.04	8.40

** Significant at 1% level ns Not significant

*SOWING TIME:

1 = 21 OCTOBER 1989
2 = 30 OCTOBER 1989
3 = 10 NOVEMBER 1989
4 = 21 NOVEMBER 1989

Appendix I.5b. Percent field emergence without irrigation at different sowing times as influenced by different weather conditions in the field during spring 1989.

LOT NO.	SOWING TIME* 5	6	7
1	61.0	71.0	74.0
2	72.0	76.5	72.0
3	63.0	73.5	76.5
4	53.0	69.0	73.5
5	76.0	77.0	84.5
6	68.5	70.5	76.5
7	62.0	86.5	80.0
8	80.5	83.0	87.5
9	60.5	73.5	77.5
10	88.5	84.0	87.0
11	82.0	85.0	86.0
12	82.0	85.5	91.5
13	83.5	91.0	86.5
14	47.0	63.0	69.0
15	84.5	84.0	91.5
16	78.5	89.0	85.0
17	75.5	74.0	80.5
18	73.5	84.5	86.5
19	65.0	86.0	80.0
20	74.0	82.0	80.0
21	86.0	84.0	81.5
22	61.0	65.0	75.5
23	85.0	83.0	86.0
p-value	**	**	**
cv	8.81	5.10	3.92
$lsd_{0.05}$	8.995	5.69	4.49

** Significant at 1% level

*SOWING TIME:
5 = 30 NOVEMBER 1989
6 = 11 DECEMBER 1989
7 = 20 DECEMBER 1989

Appendix I.6. Regression table for 1989 irrigated and unirrigated sowings for the all seed lots group.

SEED LOT		GERMINATION A	GERMINATION B	GERMINATION R^2	EXP FIELD EMERG A	EXP FIELD EMERG B	EXP FIELD EMERG R^2	CONDUCTIVITY A	CONDUCTIVITY B	CONDUCTIVITY R^2	HOLLOW HEART A	HOLLOW HEART B	HOLLOW HEART R^2
21 OCTOBER	UNIRR	39.61	0.38	0.027	20.72	0.63	0.11	83.25	-0.42	0.04	77.28	-0.27	0.08
30 OCTOBER	IRRIG	28.75	0.17	0.004	-24.10	0.80	0.12	74.96	-1.54	0.42	47.24	-0.30	0.07
30 OCTOBER	UNIRR	46.48	0.28	0.077	38.47	0.40	0.22	75.79	-0.14	0.02	74.52	-0.18	0.17
10 NOVEMBER	IRRIG	43.30	0.28	0.018	73.85	-0.05	0.001	57.18	0.64	0.12	69.48	0.04	0.002
10 NOVEMBER	UNIRR	21.58	0.35	0.041	- 9.39	0.74	0.26	67.50	-0.68	0.20	56.86	-0.33	0.19
21 NOVEMBER	IRRIG	11.38	0.57	0.63	- 0.05	0.77	0.15	74.34	-0.44	0.04	68.11	-0.30	0.09
21 NOVEMBER	UNIR I	10.13	0.38	0.02	-76.75	1.43	0.39	82.03	-1.82	0.58	51.56	-0.66	0.31
30 NOVEMBER	IRRIG	37.24	0.46	0.04	28.10	0.61	0.10	87.13	-0.33	0.03	82.60	-0.24	0.06
30 NOVEMBER	UNIRR	7.45	0.69	0.06	-41.84	1.33	0.30	108.00	-1.83	0.54	75.87	-0.46	0.14
11 DECEMBER	IRRIG	55.23	0.34	0.04	52.48	0.41	0.08	95.13	-0.38	0.06	88.73	-0.12	0.03
11 DECEMBER	UNIRR	41.87	0.39	0.04	- 4.47	0.97	0.35	100.16	-1.07	0.39	82.48	-0.42	0.25
20 DECEMBER	IRRIG	41.27	0.32	0.02	-46.06	1.37	0.45	105.60	-1.74	0.67	76.76	-0.65	0.38
20 DECEMBER	UNIRR	69.11	0.13	0.007	29.25	0.61	0.21	97.12	-0.81	0.36	83.49	-0.29	0.18

A = Intercept (CONSTANT TERM)
B = Slope
R^2= Coefficient of determination

Appendix I.7. Regression table for 1989 irrigated and unirrigated sowings for cultivar Patea.

SEED LOT		GERMINATION A	GERMINATION B	GERMINATION R^2	EXP FIELD EMERG A	EXP FIELD EMERG B	EXP FIELD EMERG R^2	CONDUCTIVITY A	CONDUCTIVITY B	CONDUCTIVITY R^2	HOLLOW HEART A	HOLLOW HEART B	HOLLOW HEART R^2
21 OCTOBER	UNIRR	8.51	0.69	0.094	-13.00	1.01	0.26	114.76	-2.17	0.54	76.53	-0.24	0.08
30 OCTOBER	IRRIG	62.23	-0.13	0.003	- 1.15	0.59	0.07	87.67	-2.06	0.39	51.70	-0.26	0.07
30 OCTOBER	UNIRR	61.48	0.13	0.022	48.52	0.28	0.17	79.32	-0.38	0.14	73.17	-0.10	0.12
10 NOVEMBER	IRRIG	77.77	-0.08	0.002	74.18	-0.04	0.001	60.88	0.52	0.05	70.75	-0.03	0.002
10 NOVEMBER	UNIRR	4.72	0.53	0.18	- 8.34	0.73	0.45	75.00	-1.09	0.44	56.54	-0.20	0.17
21 NOVEMBER	IRRIG	31.06	0.40	0.03	-22.44	1.06	0.26	96.79	-1.52	0.23	72.10	-0.40	0.19
21 NOVEMBER	UNIRR	39.08	0.11	0.002	-66.62	1.34	0.32	97.70	-2.60	0.54	54.48	-0.59	0.32
30 NOVEMBER	IRRIG	41.84	0.42	0.03	- 4.56	1.00	0.21	111.89	-1.63	0.25	84.73	-0.36	0.13
30 NOVEMBER	UNIRR	32.35	0.45	0.03	-30.49	1.23	0.27	129.55	-2.92	0.67	78.70	-0.40	0.14
11 DECEMBER	IRRIG	91.41	-0.03	0.00	77.50	0.13	0.01	101.73	-0.70	0.13	89.00	-0.04	0.005
11 DECEMBER	UNIRR	78.70	0.03	0.00	- 4.06	1.00	0.31	117.58	-1.95	0.53	85.20	-0.45	0.32
20 DECEMBER	IRRIG	64.51	0.085	0.001	-37.93	1.28	0.39	123.53	-2.74	0.79	77.48	-0.56	0.37
20 DECEMBER	UNIRR	86.25	-0.034	0.001	29.86	0.62	0.23	108.93	-1.39	0.51	85.57	-0.29	0.25

A = Intercept (CONSTANT TERM)
B = Slope
R2= Coefficient of determination

Appendix I.8. Regression table for 1989 irrigated and unirrigated sowings for cultivar SSF.

SEED LOT		GERMINATION A	GERMINATION B	GERMINATION R^2	EXP FIELD EMERG A	EXP FIELD EMERG B	EXP FIELD EMERG R^2	CONDUCTIVITY A	CONDUCTIVITY B	CONDUCTIVITY R^2	HOLLOW HEART A	HOLLOW HEART B	HOLLOW HEART R^2
21 OCTOBER	UNIRR	64.60	0.16	0.014	93.50	-0.16	0.02	78.33	0.07	0.009	77.85	0.38	0.17
30 OCTOBER	IRRIG	27.89	0.13	0.003	-68.53	1.27	0.40	64.06	-1.12	0.70	46.41	-1.11	0.49
30 OCTOBER	UNIRR	38.06	0.39	0.16	52.86	0.26	0.09	76.75	-0.09	0.023	75.06	-0.02	0.001
10 NOVEMBER	IRRIG	18.50	0.56	0.04	153.00	-0.96	0.17	52.23	0.86	0.32	62.81	1.43	0.62
10 NOVEMBER	UNIRR	61.56	-0.06	0.001	-10.25	0.77	0.15	67.81	-0.58	0.19	60.49	-0.91	0.34
21 NOVEMBER	IRRIG	20.83	0.46	0.09	80.50	-0.19	0.02	59.89	0.20	0.06	61.06	0.59	0.32
21 NOVEMBER	UNIRR	25.30	0.19	0.005	-103.73	1.72	0.52	73.00	-1.41	0.79	51.81	-1.58	0.72
30 NOVEMBER	IRRIG	-0.22	0.88	0.23	80.56	0.01	0.00	78.62	0.16	0.02	78.52	0.65	0.28
30 NOVEMBER	UNIRR	17.40	0.55	0.03	-68.96	1.61	0.35	95.98	-1.28	0.50	75.28	-1.18	0.31
11 DECEMBER	IRRIG	-4.96	1.01	0.51	38.14	0.60	0.24	94.61	-0.25	0.10	88.80	0.10	0.01
11 DECEMBER	UNIRR	0.83	0.82	0.21	-16.38	1.09	0.51	90.50	-0.63	0.40	80.40	-0.62	0.26
20 DECEMBER	IRRIG	23.50	0.51	0.03	-84.93	1.83	0.57	102.00	-1.43	0.79	79.43	-1.46	0.59
20 DECEMBER	UNIRR	41.95	0.41	0.08	10.00	0.82	0.45	92.16	-0.56	0.48	83.44	-0.58	0.36

A = Intercept (CONSTANT TERM)
B = Slope
R^2 = Coefficient of determination

Appendix II.1. Percent germination and hollow heart obtained from the crop canopy experiments in the 1989-1990 and 1990-1991 seasons.

CULTIVAR/ TREATMENT		GERMINATION 1989-1990	GERMINATION 1990-1991	HOLLOW HEART 1989-1990	HOLLOW HEART 1990-1991
CV. PRINCESS					
50 plants m^{-2}					
	top pods	99		10.5	
	middle pods	98		5.5	
	bottom pods	98		4.5	
100 plants m^{-2}					
	top pods	97		7.5	
	middle pods	98		6.5	
	bottom pods	98		8.5	
200 plants m^{-2}					
	top pods	97	97	8.5	11.0
	middle pods	98	98	8.0	7.5
	bottom pods	97	96	13.5	14.5
CV. PANIA					
200 plants m^{-2}					
	top pods		97		15.5
	middle pods		97		11.5
	bottom pods		94		21.5
P-LEVEL		ns	ns	*	**
$lsd_{0.05}$		2.09	4.20	3.16	
$lsd_{0.01}$					5.23
c.v.		0.63	1.06	11.62	9.55

* Significantly different at 5% level.

** Significantly different at 1% level.

ns Not significant

Appendix III.1. Percent seed moisture content of the various seed lots exposed to different times of controlled deterioration before storage.

SEED LOT	% SMC AT VARIOUS CONTROLLED DETERIORATION TIMES			
	1 DAY	2 DAY	4 DAY	6 DAY
PANIA 1	20.1	20.3	19.5	20.3
PANIA 2	19.7	20.4	20.5	20.3
PRINCESS 1	20.3	20.3	19.7	20.4
PRINCESS 2	19.8	20.3	19.8	19.7
PRINCESS 3	20.1	19.7	20.1	19.9
MEAN	20.0	20.2	19.9	20.1

Appendix III.2. Percent seed moisture content of the various seed lots exposed to different times of accelerated ageing before storage.

SEED LOT	% SMC AT VARIOUS ACCELERATED AGEING TIMES			
	1 DAY	2 DAY	4 DAY	6 DAY
PANIA 1	18.9	19.8	23.2	25.0
PANIA 2	18.1	20.9	22.5	27.3
PRINCESS 1	18.8	20.5	22.4	26.2
PRINCESS 2	18.6	19.9	22.7	26.3
PRINCESS 3	18.9	19.8	22.2	25.9
MEAN	18.7	20.2	22.6	26.14

Appendix III.3. Relationship between germination after various times of storage at 5°C / 45% RH and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.48*	0.16	0.67**	0.26	0.33	0.04	0.31
2 day CD	0.41	0.32	0.07	0.33	0.52*	0.20	0.51*
4 day CD	0.39	0.33	0.52	0.29	0.10	0.07	0.37
6 day CD	0.44*	0.42	0.54*	0.46*	0.54*	0.31	0.55*
1 day AA	0.41	0.17	0.20	0.30	0.39	0.31	0.42
2 day AA	0.02	-0.15	0.004	0.08	0.20	0.19	0.14
4 day AA	0.14	-0.04	0.36	0.06	0.18	0.39	0.24
6 day AA	0.13	0.31	0.31	0.23	0.39	0.57**	0.39
E.F.E.	0.34	0.17	0.24	0.22	0.19	0.11	0.43
GERM.	0.42	0.38	0.53*	0.18	0.38	0.22	0.34
COND.	-0.47*	-0.36	-0.53*	-0.43	-0.47*	-0.29	-0.53*
H. H.	0.10	0.25	0.36	0.03	0.27	0.17	-0.07

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.4. Relationship between germination after various times of storage at 5°C / 95% RH and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.35	0.12	0.57**	0.41			
2 day CD	0.19	0.04	0.27	0.26			
4 day CD	0.03	0.25	0.49*	0.21			
6 day CD	0.22	0.11	0.51*	0.40			
1 day AA	0.13	0.14	0.51*	0.40			
2 day AA	0.27	0.09	0.16	0.11			
4 day AA	-0.01	0.004	0.25	0.18			
6 day AA	0.15	0.28	0.51*	0.27			
E.F.E.	0.05	0.18	0.24	0.04			
GERM.	0.24	0.24	0.52*	0.48*			
COND.	-0.23	-0.41	-0.69**	-0.41			
H. H.	0.24	0.12	0.41	0.54*			

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.5. Relationship between germination after various times of storage at 5°C in sealed bags and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.34	0.42	0.38	0.16	0.47*	0.36	0.01
2 day CD	0.23	0.31	0.19	0.11	0.21	0.13	0.11
4 day CD	0.39	0.37	0.47*	0.50*	0.09	0.36	0.31
6 day CD	0.49*	0.57**	0.34	0.33	0.46*	0.24	0.28
1 day AA	0.58**	0.47*	0.02	0.10	0.39	0.36	-0.05
2 day AA	0.47*	0.04	-0.10	0.05	0.13	0.28	0.30
4 day AA	0.34	0.21	0.08	0.37	0.29	0.21	0.08
6 day AA	0.09	0.49*	0.19	0.10	0.45*	0.29	0.07
E.F.E.	-0.002	0.30	0.12	0.03	-0.01	0.17	-0.34
GERM.	0.21	0.46*	0.20	0.37	0.12	0.14	-0.15
COND.	-0.40	-0.53*	-0.40	-0.25	-0.60**	-0.43	-0.16
H. H.	0.34	0.21	0.17	0.38	0.35	0.06	0.39

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.6. Relationship between germination after various times of storage at 25°C / 45% RH and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.42	0.16	0.27	0.45*	0.32	0.31	0.18
2 day CD	0.02	0.07	-0.24	0.24	0.25	0.46*	0.69**
4 day CD	-0.14	0.36	0.40	0.28	0.10	0.15	0.53*
6 day CD	0.13	0.35	0.35	0.42	0.24	0.46*	0.68**
1 day AA	0.07	0.24	-0.10	0.22	0.47*	0.13	0.44*
2 day AA	0.08	0.16	0.02	0.01	-0.18	-0.006	0.52*
4 day AA	-0.14	0.21	0.47*	0.25	0.18	0.12	0.34
6 day AA	-0.007	0.29	0.25	0.42	0.53*	0.43	0.14
E.F.E.	-0.01	0.01	-0.01	0.26	0.42	0.25	-0.09
GERM.	0.32	0.23	0.39	0.73**	0.59**	0.68**	0.21
COND.	-0.23	-0.34	-0.34	-0.50*	-0.50*	-0.52*	-0.40
H. H.	0.39	0.32	0.50*	0.51*	0.16	0.48*	0.46

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.7. Relationship between germination after various times of storage at 25°C / 95% RH and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	1	3	6	9	12	15	18
1 day CD	0.67**	0.36					
2 day CD	0.49*	0.25					
4 day CD	0.54*	0.37					
6 day CD	0.67**	0.28					
1 day AA	0.61**	0.37					
2 day AA	0.14	0.30					
4 day AA	0.36	0.10					
6 day AA	0.38	0.47*					
E.F.E.	0.22	0.06					
GERM.	0.47*	0.03					
COND.	-0.59**	-0.44*					
H. H.	0.35	0.11					

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.8. Relationship between germination after various times of storage at 25°C in sealed bags and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	21
1 day CD	0.47*	0.41	0.31	0.38	0.28	0.32	0.42
2 day CD	0.62**	0.49*	0.54*	0.39	0.57**	0.55*	0.44*
4 day CD	0.44*	0.52*	0.48*	0.60**	0.37	0.69**	0.49*
6 day CD	0.82**	0.59**	0.82**	0.89**	0.80**	0.83**	0.64**
1 day AA	0.53*	0.32	0.43	0.37	0.52*	0.36	0.37
2 day AA	0.33	-0.04	0.22	0.27	0.35	0.36	0.16
4 day AA	0.56*	0.18	0.64**	0.76**	0.67**	0.62**	0.45*
6 day AA	0.51*	0.27	0.45*	0.45*	0.40	0.38	0.53*
E.F.E.	0.22	0.08	0.14	0.13	0.26	0.23	0.54*
GERM.	0.43	0.42	0.53*	0.50*	0.29	0.38	0.49*
COND.	-0.64**	-0.54*	-0.61**	-0.62**	-0.57**	-0.57**	-0.59**
H. H.	0.34	0.47*	0.53*	0.52*	0.12	0.25	-0.05

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.9. Relationship between germination after various times of storage in ambient open bags and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.19	0.32	0.16	0.67**	0.40	0.50*	0.48*
2 day CD	0.36	0.34	0.32	0.07	0.34	0.09	0.41
4 day CD	0.37	0.01	0.33	0.52*	0.37	0.22	0.49*
6 day CD	0.53*	0.25	0.42	0.54*	0.51*	0.42	0.58**
1 day AA	0.31	0.21	0.17	0.20	0.32	0.63**	0.65**
2 day AA	0.36	0.15	-0.15	0.004	0.32	0.24	0.11
4 day AA	0.33	0.005	-0.04	0.36	0.43	0.27	0.32
6 day AA	0.19	0.09	0.35	0.31	0.48*	0.37	0.56*
E.F.E.	0.18	0.06	0.17	0.24	0.26	0.27	0.41
GERM.	0.39	0.21	0.18	0.07	0.26	0.43	0.62**
COND.	-0.26	-0.32	-0.34	-0.43	-0.48*	-0.43	-0.72**
H. H.	0.20	0.23	0.27	0.07	0.07	0.19	0.28

CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

Appendix III.10. Relationship between germination after various times of storage in ambient sealed bags and seed quality characters obtained before storage.

SEED QUALITY TEST	CORRELATION COEFFICIENT BETWEEN % GERMINATION AFTER VARIOUS MONTHS OF STORAGE AND SEED QUALITY BEFORE STORAGE						
	3	6	9	12	15	18	24
1 day CD	0.16	0.26	0.12	0.57**	0.34	0.33	0.43
2 day CD	0.73**	0.33	0.04	0.27	0.51*	0.52*	0.64**
4 day CD	0.41	0.29	0.25	0.49*	0.61**	0.10	0.38
6 day CD	0.56*	0.46*	0.11	0.51*	0.77**	0.54*	0.79**
1 day AA	0.55*	0.30	0.14	0.51*	0.46*	0.39	0.73**
2 day AA	0.06	0.08	0.09	0.16	-0.16	0.20	0.20
4 day AA	0.25	0.06	0.004	0.25	0.40	0.18	0.39
6 day AA	0.62**	0.23	0.28	0.51*	0.36	0.39	0.60**
E.F.E.	0.23	0.22	0.18	0.24	0.26	0.19	0.37
GERM.	0.21	0.30	0.22	0.44*	0.61**	0.63**	0.54*
COND.	-0.47*	-0.46*	-0.47*	-0.50*	-0.50*	-0.51*	-0.69**
H. H.	0.06	0.40	0.38	0.54*	0.39	0.56*	0.24

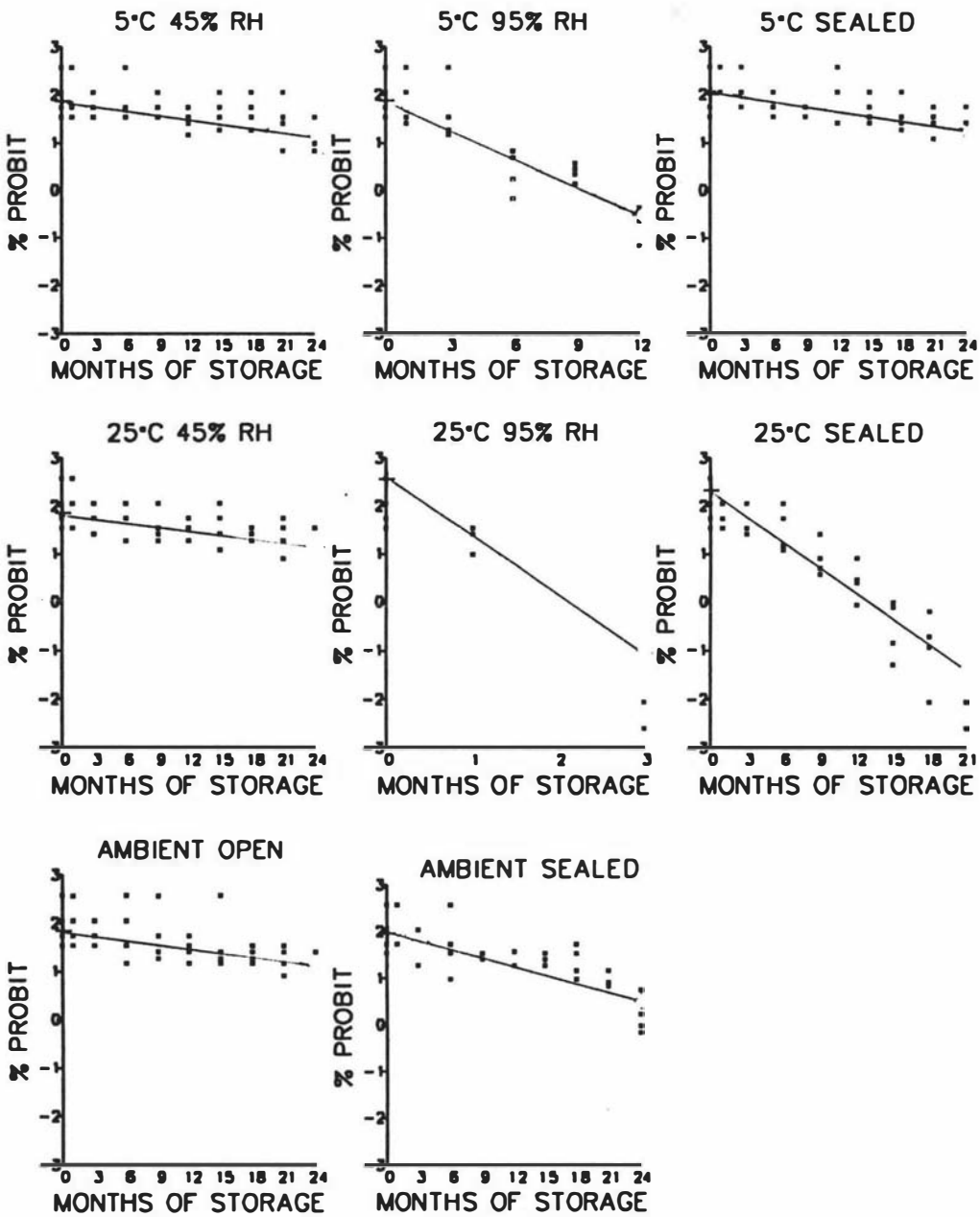
CD = Controlled deterioration
AA = Accelerated ageing
E.F.E. = Expected field emergence
GERM. = % Normal seedlings from germination test
COND. = Conductivity reading ($\mu S\ g^{-1}$ seed)
H.H. = % Hollow heart

* = Significant at 0.05 level
** = Significant at 0.01 level

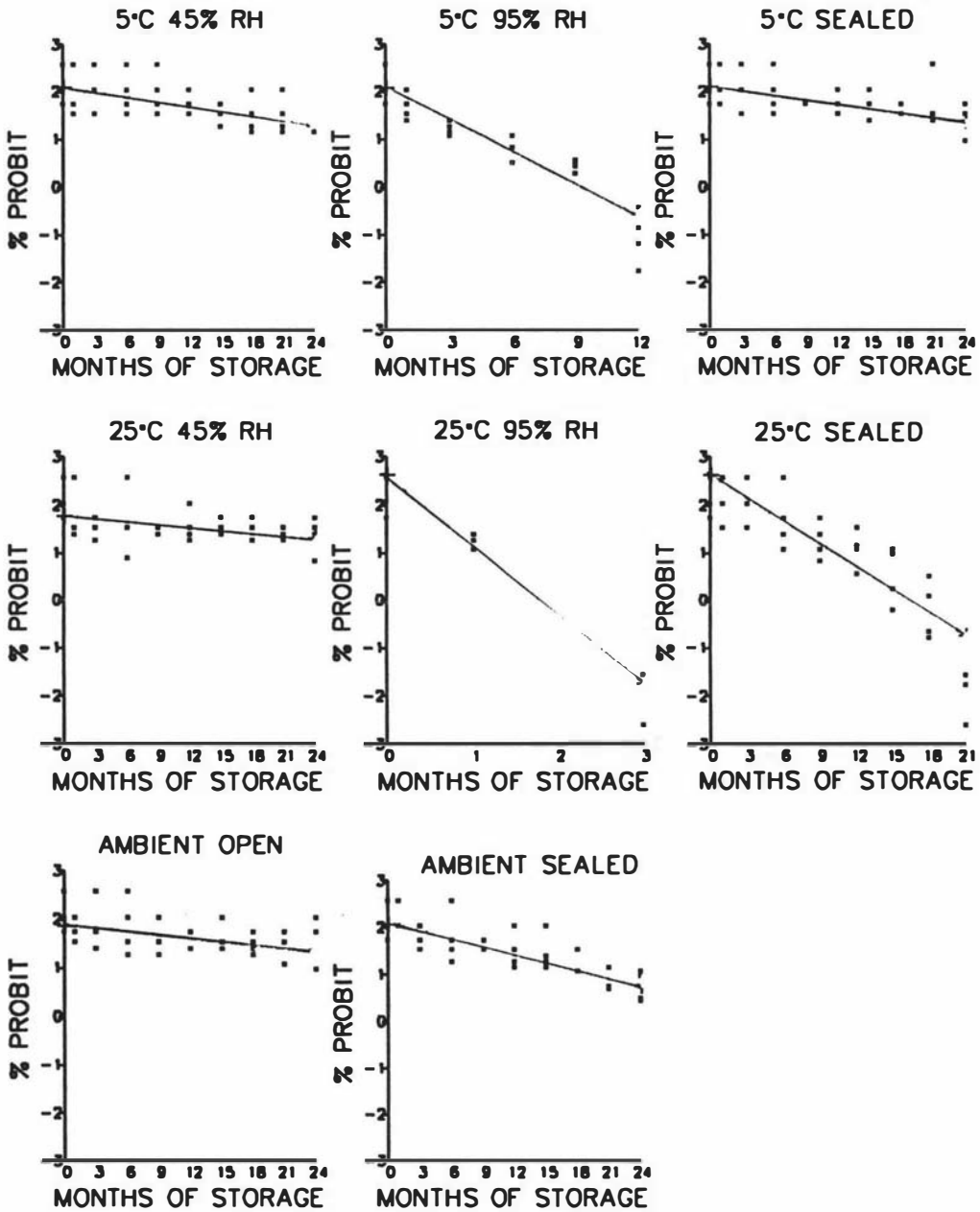
Appendix III.11. Relationship between field emergence after storage in various conditions for 12 and 18 months and various initial seed quality tests.

SEED QUALITY TEST	STORAGE CONDITION AND MONTHS OF STORAGE											
	5°C 45% RH		5°C SEALED		25°C 45% RH		25°C SEALED		AMBIENT OPEN		AMBIENT SEALED	
	12	18	12	18	12	18	12	18	12	18	12	18
1 day CD	0.48*	0.39	0.39	0.57**	0.50*	0.45*	0.36	0.17	0.54*	0.21	0.03	0.34
2 day CD	0.31	0.46	0.60**	0.46*	0.56*	0.47*	0.61**	0.40	0.13	0.32	0.42	0.52*
4 day CD	0.55*	0.42	0.60**	0.52*	0.57**	0.47*	0.42	0.54*	0.21	0.32	0.10	0.59**
6 day CD	0.60**	0.49*	0.82**	0.80**	0.71**	0.81**	0.81**	0.83**	0.27	0.36	0.42	0.88**
1 day AA	0.49*	0.49*	0.41	0.49*	0.49*	0.42	0.50*	0.28	0.35	0.54*	0.19	0.29
2 day AA	-0.25	0.41	0.31	0.22	0.31	0.33	0.44*	0.22	-0.25	0.16	0.16	0.16
4 day AA	0.41	0.30	0.56*	0.50*	0.39	0.59**	0.47*	0.67**	0.01	0.18	0.42	0.72**
6 day AA	0.53*	0.42	0.36	0.53*	0.32	0.20	0.45*	0.45*	0.26	0.52*	0.51*	0.58**
E.F.E.	0.51*	0.19	0.07	0.27	0.15	0.09	0.30	0.18	0.25	0.36	0.18	0.27
GERM.	0.49*	-0.03	0.25	0.68**	0.35	0.52*	0.45*	0.42	0.30	0.34	0.55*	0.60**
COND.	-0.59**	-0.42	-0.48*	-0.72**	-0.58**	-0.52*	-0.64**	-0.59**	-0.35	-0.63	-0.53*	-0.68**
H. H.	-0.02	-0.12	0.31	0.52*	0.34	0.54	0.24	0.36	0.07	0.06	0.46*	0.44*

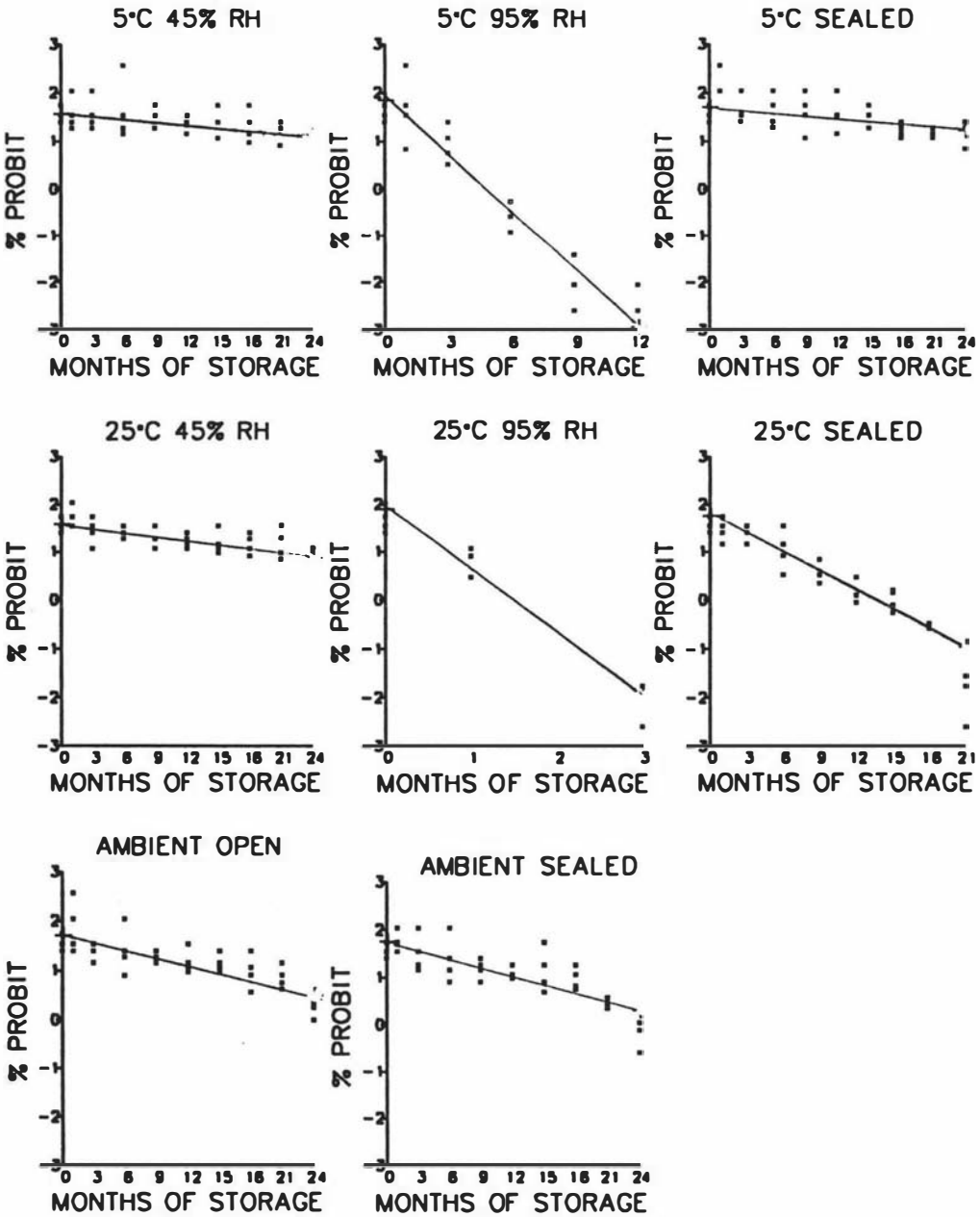
CD= Controlled deterioration AA = Accelerated ageing EFE = Expected field emergence
GERM= % Normal seedlings from the germination test COND= Conductivity ($\mu S\ g^{-1}$ seed) HH= % Hollow heart *=significant at 0.05 level **= significant at 0.01 level



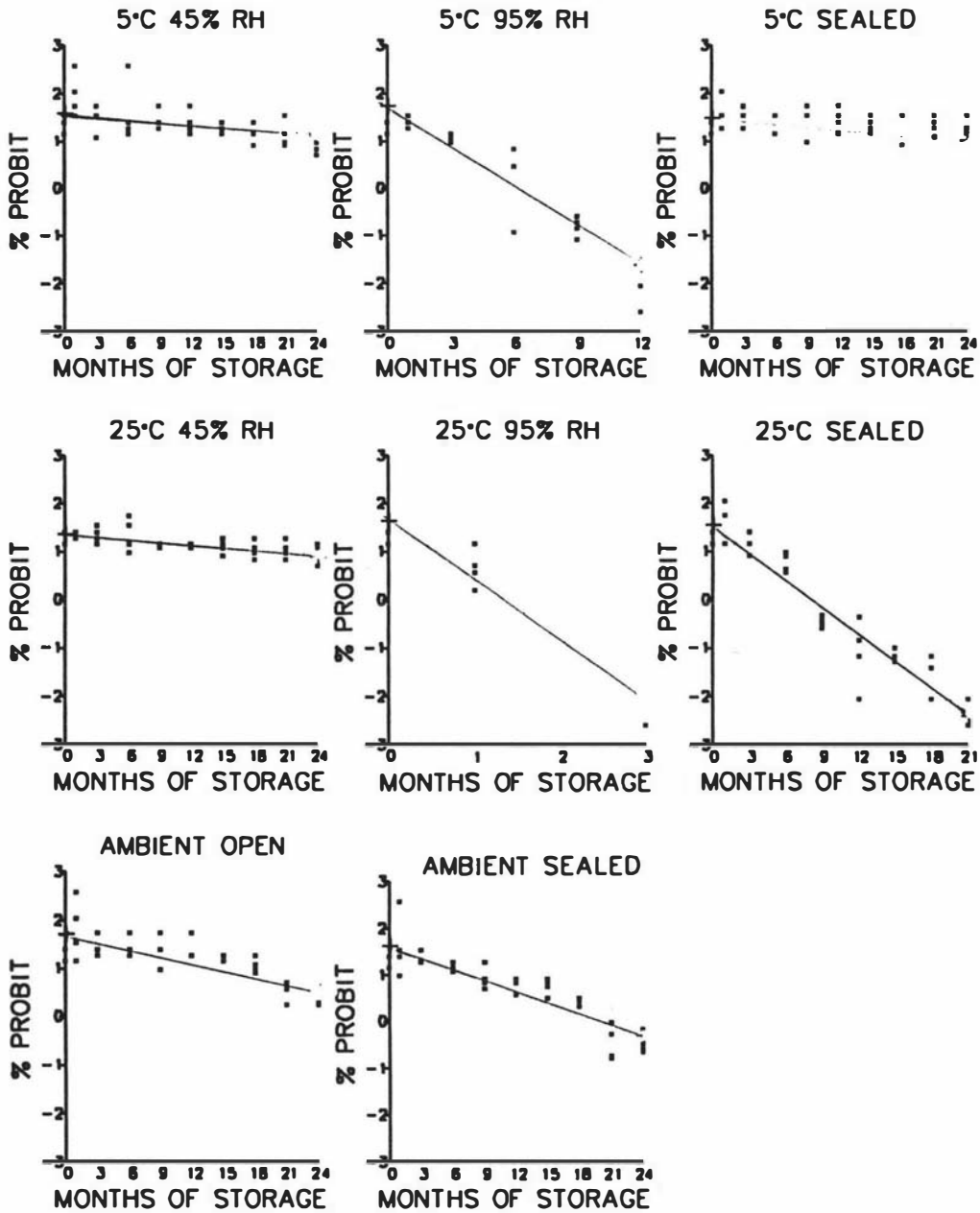
Appendix III.12. Probit lines from probit analysis of Pania 1 seed lot at different storage conditions and times of storage. The points represent the actual percentage germination converted into percent probit.



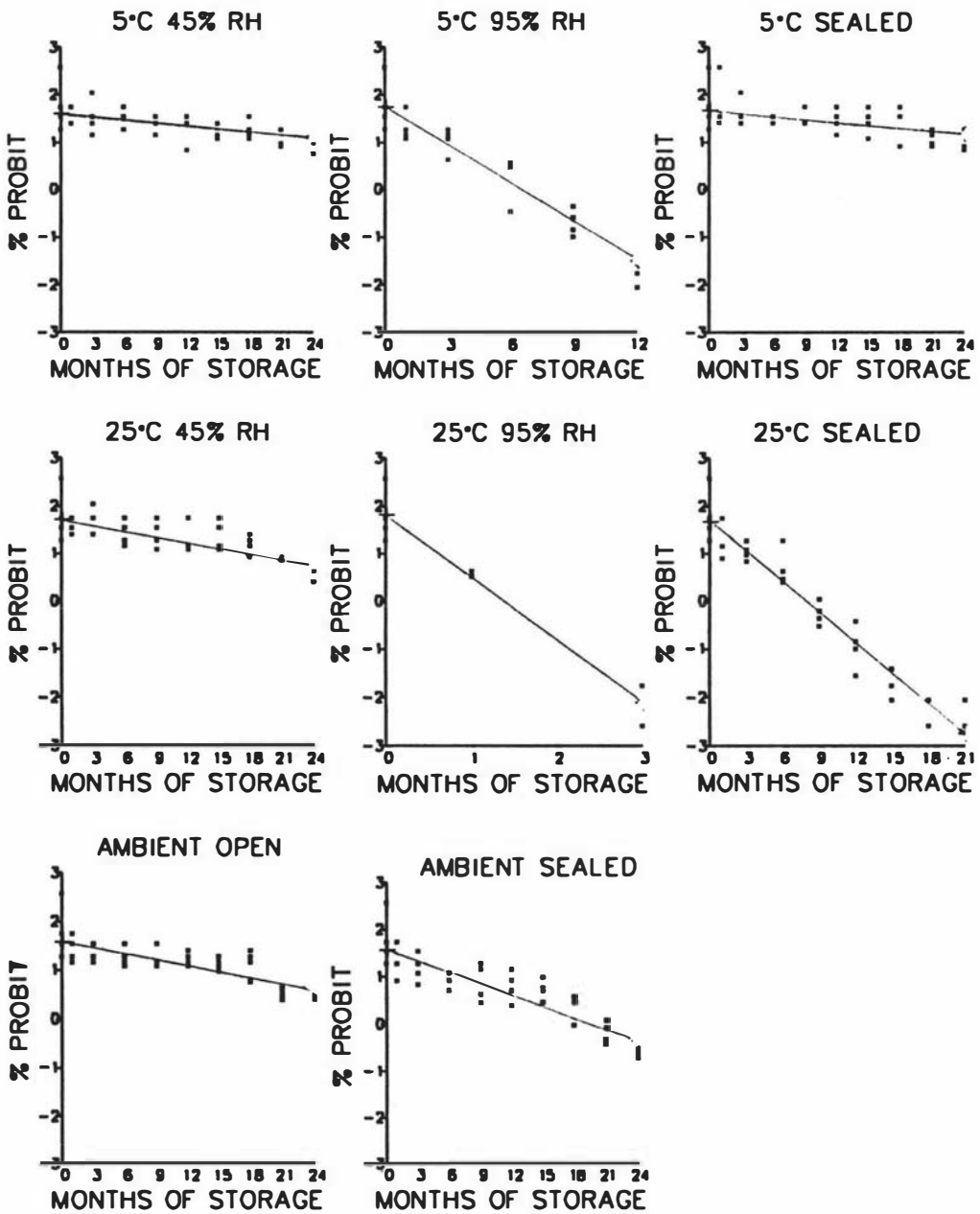
Appendix III.13. Probit lines from probit analysis of Pania 2 seed lot at different storage conditions and times of storage. The points represent the actual percentage germination converted into percent probit.



Appendix III.14. Probit lines from probit analysis of Princess 1 seed lot at different storage conditions and times of storage. The points represent the actual percentage germination converted into percent probit.



Appendix III.15. Probit lines from probit analysis of Princess 2 seed lot at different storage conditions and times of storage. The points represent the actual percentage germination converted into percent probit.



Appendix III.16. Probit lines from probit analysis of Princess 3 seed lot at different storage conditions and times of storage. The points represent the actual percentage germination converted into percent probit.