A STUDY OF DRYING, THRESHING AND STORAGE CONDITIONS ON THE VIABILITY OF SOYBEAN SEEDS WITH A SUPPLEMENTARY STUDY OF THE EFFICIENCY OF A SIMPLE DRYING METHOD DEVELOPED.

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF AGRICULTURAL SCIENCE IN SEED TECHNOLOGY AT MASSEY UNIVERSITY NEW ZEALAND

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ABSTRACT

This study was designed to investigate the relevance of post-harvest factors in maintaining the viability and storability of soybean seeds. In order to obtain high quality seeds for the drying and storage aspects of the experiment, the sequence of seed development and physiological maturity of the crop was investigated to ascertain maximum viable seed yield. The soybean cultivar 'V-53' was sown and plants were randomly sampled at 32 days after peak flowering, and subsequently every 5 days until the seeds reached physiological maturity. The changes in seed moisture content, fresh weight, dry weight, percent germination and maximum viable seed yield in relation to time after peak flowering were measured. The soybean crop achieved a maximum viable seed yield of 1344.1 kg/ha 77 days after peak flowering. The development of the crop was prolonged by adverse weather conditions. After soybean seeds reached physiological maturity, the crop was harvested at a seed moisture content of 49.2% and germination of 96%.

Further studies were carried out to investigate those factors that affect seed viability before and during storage. The drying effect on seed viability was made by comparing the effect of 6 different drying methods i.e. dehumidification, refrigeration, ambient air and heated air at 30^{o}C, 40^{o}C or 50^{o}C. Seeds were dried to 8% moisture content in each case. Delays between harvest and the commencement of drying operations result in a decline of seed germinability, particularly in seedlot which was later used in the refrigeration drying system. Although drying method had no immediate effect on seed viability during drying, drying seed by refrigeration method was time consuming the drying rate being too slow and resulting in subsequent seed deterioration. The heated air methods were most efficient in assisting removal of moisture from the seed. Following drying, seeds were threshed from the pods by hand threshing or beating threshing methods. Seeds from different drying and threshing treatments were stored under 20^{o}C - 40%RH or 35^{o}C - 90%RH conditions for 16 weeks. The threshing of seed using a beating method caused a significant reduction in seed germinability when compared to the hand system used to remove seed

from the pod. Drying method had no significant effect on seed storability when seeds were stored under good storage conditions i.e. 20°C - 40%RH. However, when seeds were stored under poor storage conditions i.e. 35°C - 90%RH, seeds previously dried at 40°C and 50°C using heated air showed a more severe drop in germination after only 2 weeks when compared to seeds dried by 30°C heated air. The effect of unheated air on seed storability was possibly not detected since there was wide variation in the results and the storage conditions of 35°C - 90%RH had severely affected seed viability after only 4 weeks storage. Seeds stored under 35°C - 90%RH conditions rapidly gained moisture to a relatively high level. This high moisture content in seeds accelerated the rate of deterioration and favoured the growth of storage fungi which were greatly responsible for loss of viability. Although there was a reduction in the germination capacity of seed stored under 20°C - 40%RH conditions after 16 weeks, these conditions were vastly superior to storage conditions of 35°C - 90%RH. In the present study, the effect of drying method was not as important as storage conditions in maintaining seed viability. However, with proper harvesting, drying and threshing the problems of maintaining high level of seed viability could be eliminated.

A separate drying experiment was carried out to evaluate the possible use of the 'Kiwi' drier and its efficiency in drying various seed crops. The 'Kiwi' drier was designed at the Seed Technology Centre and consists of a cylindrical metal drum containing 2 metal tubes filled with silica gel as a dessicant. As presently constructed the drier resulted in very slow and inefficient drying of barley, pea and Tama ryegrass seeds. However, results suggest that by redesigning certain features in the 'Kiwi' drier to improve air circulation and increase the area of close contact between the silica gel and the seeds it's seed drying efficiency could be greatly improved. In addition, the 'Kiwi' drier provides an ideal storage container for seeds in tropical climates.

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GENERAL INTRODUCTION

Soybean is one of the major cultivated legume crops grown in the North, Central Plain and Northeast of Thailand. Demand for soybean grains has increased rapidly over recent years due to the expansion of domestic feed and oil extracting industries and new market development in neighbouring countries. Although government policy has been to encourage expansion of the soybean acreage, its production has not met the market demand. The rapid expansion of soybean acreage resulting in a great demand for high quality seeds has become a major problem confronting local farmers in their efforts to commercialise the crop. To overcome problems arising from an insufficient supply of high quality seeds produced under government seed production schemes, farmers have been forced to store their own seed stocks. However, the traditional seed saving practices used by farmers does not retain the viability of seed from harvest until the next planting season.

The present study was undertaken to obtain more information of the problems involved in handling soybean seed after harvest. Investigations were made on seed drying aspects, the effects of threshing method and the influence of the storage environment on the viability of stored soybean seed. To produce high quality seed for the experiment, physiological maturity of soybean seeds were produced, seeds being harvested at maximum viable seed yield. Comparisons were made between the effects of 3 different heated air systems and also the use of unheated air, refrigerated air and the chemical dehumidifier drying systems.

Storage performance of seed samples which had been subjected to different drying and threshing treatments was studied over a period of 16 weeks in both good (cool and dry) and bad (hot and humid) storage environments.

CHAPTER 1

A STUDY OF SEED DEVELOPMENT, MATURITY AND HARVEST RIPENESS IN SOYBEAN SEED.

1.1 INTRODUCTION

The soybean *Glycine max.* (L) Merrill, is an annual plant. It generally grows 90-120cm. high with first leaves simple and opposite and all others trifoliate and alternate. The vegetative parts are covered with fine hairs (Hicks, 1978). Plants are either determinate or indeterminate in flowering and development habit. Some types of soybean are adapted to tropical conditions and others to temperate conditions (Williams, 1950). Plants produce a typical legume seed which shows differences in size, shape and colour depending on the variety. Seeds range from small round beans to large oblong, flattened seeds, being yellow, brown, green or black or a combination of these colours. The common field varieties are nearly spherical and yellow (Wolf and Cowan, 1971). The surface of the cotyledons is covered with epidermis and the interior is filled with numerous elongated palisade-like cells filled with protein and oil. The oil content of seed is approximately 20% with 30-40% protein content.

1.2 REVIEW OF LITERATURE

The processes of seed development and physiological maturity of soybean seed will be discussed.

1.2.1 Seed Development

Seed development is concerned with the various processes and stages occurring during the period from fertilization until the seed is fully formed and ready for harvest.

The soybean is self-pollinated, pollination occurring when the flower opens or slightly previously. Flowering occurs over a 4 to 6 week period, depending upon season and growth habit (Shibles, Anderson and Gibson, 1975). Development of the soybean seed begins with double fertilization. The first division of the zygote is transverse and the embryo forms a rather large suspensor which persists for some time. Within the first 12 days after fertilization, the cotyledons are formed along the longitudinal axis of the seed. A root cap is initiated shortly after cotyledon formation. The epicotyl is initiated about the time the cotyledons begin their unilateral growth (Pamplin, 1963).

Cell division is completed in the embryo approximately 2 weeks after flowering (Kato, Sakaguchi and Naito, 1954). The endosperm consists of a large number of dividing cells during the early stage of seed growth but gradually disappears as the seed matures (Pamplin, 1963). By 26 days after flowering, the cotyledons had reached their maximum size. Then the fresh weight of the developing seed reaches its maximum (about 52 days after flowering), the cells of the cotyledons are filled with numerous starch grains and lipid and protein granules (Bils and Howell, 1963).

Beginning about 25 to 35 days after flowering, dry matter begins to accumulate rapidly in the seed reaching maximum at 75 days. The seed first becomes capable of germination when only about one-third of the dry weight has been accumulated (Delouche, 1974). Seed dry matter accumulation rates have been reported to be 88-149 kg/ha/day (Hanway and Weber, 1971).

Moisture content of the seed gradually decreases throughout the period of growth from an initial level of approximately 90% to approximately 50-60% as dry weight reaches its maximum (Howell et al, 1959; Andrew, 1966; Phillips et al, 1976). As the seed loses moisture during seed development its shape becomes more oval to spherical and the light green colour of fresh immature seed turns to a light straw-yellow at maturity.

1.2.2 Seed Maturation

The most generally accepted measure of maturity - the time when the seed has reached its maximum dry weight - is known as physiological maturity (Harrington, 1972a).

Attempts to describe the occurrence of physiological maturity (PM) in soybean relied heavily on pod and leaf characteristics for many years. Fehr et al (1971) described soybean physiological maturity ('pod yellowing, 50% of leaves yellow') as stage R7. However, Fehr, Caviness and Vost (1977) found this definition to be inaccurate since reduction in yield occurred in plants defoliated at stage R7, indicating that physiological maturity had not yet been attained.

According to Crookston and Hill (1978), the yellowing or dropping of leaves was found to be variable due to seasonal conditions and was therefore not a reliable index of seed maturity.

Hanway and Weber (1971), described the stage immediately prior to harvest maturity as occurring when the 'leaves 30 to 50% yellow with many falling and the lower pods yellow'. In their studies, soybean appeared to reach maximum seed dry weight at or shortly after this stage.

Howell et al (1959) reported that ripening soybean reach maximum dry weight while still green and containing 50 to 60% moisture,

Recently, Crookston and Hill (1978) compared 11 visual pod and

seed characteristics as indicators of the occurrence of PM (maximum seed dry weight) for six soybean cultivars. They reported that the onset of seed shrinkage most consistently coincided with the occurrence of PM, but felt that their estimated date of PM may have been slightly early and that loss of green colour in the pods may be the better indicator.

TeKrony et al (1978) studies soybean in the greenhouse using $^{14}CO_2$ which indicated that PM occurs when the pod or the seed is completely yellow. In field evaluations PM occurred at 54% to 62% moisture content.

The term 'physiological maturity" has been used most frequently to describe the point where the seed reaches its maximum dry weight (Shaw and Loomis, 1950; Harrington 1972a; Delouche,1974). The stage of seed maturity is known to be a major factor respondsible for the variation of viability and size of seed (Austin,1972).

Hyde (1950) reported that the white clover seed harvested at an early stage of seed development would possess viability but not seedling vigour. Vigour is a seed quality attribute which is not gain until the end of dry matter accumulation phase. He also showed that immature seed deteriorated more rapidly than mature seed. Perry (1969) also stated that one cause of low vigour in pea seed was due to premature harvesting of seed. Burris (1973) studied the effect of seed maturity on soybean seed quality and seedling performance. He concluded that seed viability and seedling dry matter both increased with increasing time after flowering

Many researchers (Wahab and Burris,1971; Delouche,1974; TeKrony et al, 1980) agree that PM in soybean should represent maximum seed quality and be referred to as the point of maximum dry seed weight accumulation. At PM, nutrients are no longer flowing into the seed from the mother plant, and seed has its highest vigour and can be dried to a low moisture content without loss of viability (Harrington,1972a).

Moorse, Carter and Harwig (1950) and Delouche (1965) have reported that seed deterioration begins as soon as the seed reaches functional maturity. However, unfavourable weather during the ripening period causes soybean to deteriorate while still in the field. Thus, PM is extremely important since it mark the moment the seed begins to age. Subsequently harvest losses can be substantially reduced in maximum yield obtained by proper harvest timing.

1.3 MATERIALS AND METHODS

The experiment was carried out in a Massey University Experimental field. The soil pH was 5.8. Soybean seed of cultivar 'V-53' was sown on 4 December 1979. The plot size was 70m x 20m. The planting space was .75m between rows and .25m between hills, resulting in a plant population of 6.6 plants per square metre. Normal cultural practices were carried out. Peak flowering was recorded on 9 February 1980, 67 days after planting.

Sampling of the crop was begun 32 days after peak flowering (DAF) and subsequently every 5 days. At each sampling, 5 plants were randomly harvested and taken to the laboratory. The pods were removed by hand, counted and weighed. By using a metal spatula the sample was divided into halves, quarters and then eighths. The modified halving method as prescribed in the International Seed Testing Association Rules (1976) allowed each alternative subportion to be combined into a representative subsample.

All seeds were removed from the subsample pods, and the following variables measured.

Number of seeds
Seed fresh weight per plant
Hundred seed fresh weight
Percent moisture of the seed
Seed dry weight per plant
Seed dry weight yield kg/ha
Percent germination
Maximum viable seed yield kg/ha

Seeds were counted using a metal spatula as a precautionary measure, to minimise possible loss or gain of moisture by the seeds.

The fresh seed weight was recorded in grams to 2 decimal places, and was calculated using the following formulae:

$$\text{Fresh seed weight per plant} = \frac{\text{Wt. of total pods in sample}}{\text{Wt. of pods in subsample}} \times \frac{\text{wt. of seed in subsample}}{\text{No. of plants per sample}}$$

$$\text{Hundred seed fresh weight} = \frac{\text{Seed Fresh weight (subsample)} \times 100}{\text{No. of seeds (subsample)}}$$

Moisture tests were carried out in duplicate on a minimum of 5 gram samples. Due to seed tenderness and high moisture content, seeds were dried in a low constant temperature oven at $103 \pm 2^{o}C$ for 17 ± 1 hours. The dried seed was stored in a dessicator to prevent moisture gain or loss by the seed during cooling before reweighing.

$$\text{Percent seed moisture content} = \frac{\text{Moisture loss}}{\text{Fresh weight}} \times \frac{100}{1}$$

$$\text{Dry seed weight per plant} = \text{Fresh weight per plant} \times \frac{\text{100-Percent moisture}}{100}$$

$$\text{Hundred seed dry weight} = \frac{\text{Dry weight of seed per plant}}{\text{No. of seed per plant}} \times \frac{100}{1}$$

Four replicates of 50 seeds were used to determine germination using the rolled paper method, at $25^{o}C$. Seeds were treated with an Thiram fungicide to prevent mould growth on the seeds and seedlings. According to the ISTA Rules (1976) 5 and 8 days are required for the preliminary and final counts respectively. The percent of fresh ungerminated seeds, and normal seedlings was expressed as total percent viable seeds.

$$\text{Dry seed yield kg/ha} = \frac{\text{Dry seed weight per plant} \times 6.6 \times 10^4}{10^3}$$

Viable seed yield is the product of percent viability and dry seed yield per unit area.

This seed development study was terminated when the seed obtained its maximum viable seed yield, the crop being harvested on 4 May 1980.

1.4 RESULTS AND DISCUSSION

Soybean seed fresh weight (100 seed weight) increased from 9.3 to 26.8g during the period from 32 to 52 days after flowering (DAF). The fresh weight attained its maximum value of 28.3g at 72 days after flowering and then decreased (Figure 1.1). In this study, the fresh seed weight attained its maximum 5 days before the dry matter reached its maximum accumulation. This result was similar to that found by Obendorf et al, (1980). The maximum fresh weight does not indicate physiological maturity, because the maturing seed begins losing water while nutrients are still moving into the seed and biological processes are still occurring (Harrington, 1972a).

Seed dry weight (100 seed weight) accumulation increased from 1.9 to 8.3g from 32 to 52 DAF. Both seed fresh weight and dry weight increased rapidly. These results show that dry matter rapidly accumulated at an early stage of seed development as stated by Delouche (1974) and TeKrony (1979). Dry matter accumulation reached a maximum 77 days after peak flowering. Some slight decrease then occurred (Figure 1.1).

The point where the seed attained its maximum dry matter accumulation indicated that seed had reached PM. At this point it was fully developed as an independent biological unit and should have reached maximum seed viability and vigour (Andrew, 1966; Delouche, 1974 and TeKrony et al, 1980).

Moisture content in the seed gradually decreased throughout the period of seed development from 79% to 49.2% (Figure 1.1). This result agrees with similar findings by Delouche (1974) and TeKrony et al (1979) that seed moisture content decreases rather slowly to 40 - 50% at the time maximum dry weight is attained.

Seed dry weight per plant increased steadily from 2.0g at 32 DAF to 20.7g at physiological maturity (77 DAF). A corresponding increase in dry seed weight per hectare was recorded for the same period, i.e. 135.2 kg/ha to 1378.6 kg/ha (Figure 1.2).

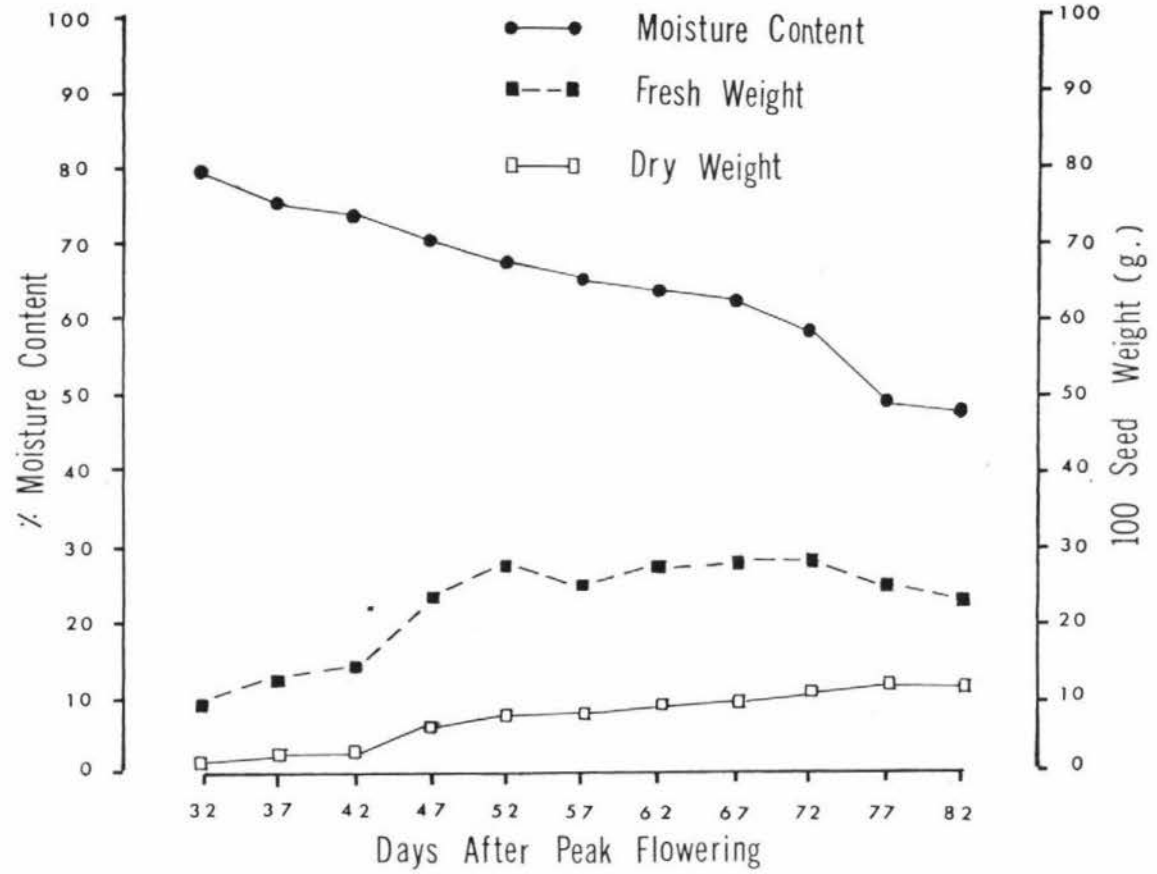


Figure 1.1 Changes in moisture content percentage, fresh and dry 100 seed weight (g) in relation to days after flowering

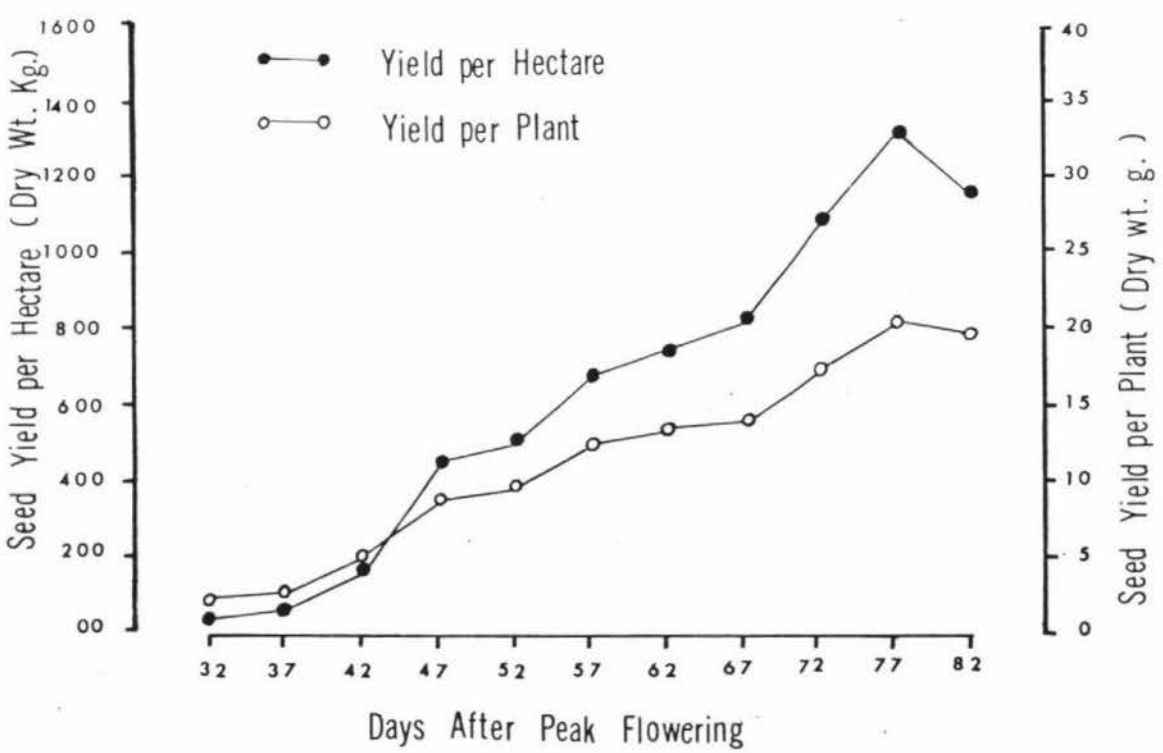


Figure 1.2 Seed Yield (dry wt.) per plant and seed yield (dry wt.) per hectare in relation to days after flowering

Viability of seed increased rapidly from 25% at 32 DAF to 77% at 47 DAF, this increase coinciding with the rate of seed dry matter accumulation. At this stage of seed development, it was not possible to strictly adhere to the germination count procedures prescribed in the ISTA Rules (1976). Due to the high level of immature seed, it was necessary to extend the test period to ensure that germination of the seed was complete. Preliminary and final counts of immature seeds were determined within 5 to 19 days. As seed samples became more mature, the determination was made as prescribed in the ISTA Rules (1976). As the seeds proceed to maturity, seedlings in the germination tests tend to exhibit more balanced development, i.e. well developed root and shoot systems, intact cotyledons and plumule; and more vigorous seedling and seedling uniformity. The seedlings showed the capacity for continued development into normal plants. The seed attained vigour and viability as stated by Hyde (1950); Perry (1969) and Burris (1973). Soybean seed attained its highest viability 97.5%, 77 days after peak flowering (as shown in Figure 1.3). This result showed that seed at physiological maturity had a high level of germinability as previously indicated by Delouche (1974).

Viable seed yield increased steadily with increasing seed dry weight and viability. In this study a maximum viable seed yield of 1344.1 kg/ha was attained 77 days after peak flowering (Figure 1.4). The level of viable seed yield was determined primarily by the levels of seed dry weight, seed viability being only a secondary contributor to this parameter of seed quantity and quality. Soybean seed was harvested as soon as it attained its maximum viable seed yield. This was thought necessary to ensure the recovery of seed from the field at the point where it had reached its maximum quality since the quality of seed is affected by the environment either before or after harvest maturity (TeKrony et al, 1980 and Moore, 1971). Similarly it has been shown that a dramatic decline in seed vigour can occur within 2 weeks of harvest maturity (Mondragon and Pott, 1974 and TeKrony et al 1980). While this emphasises the importance of harvesting seed when it first reaches maximum seed dry weight or physiological maturity. It should be noted that, the rate of development of the

crops in the present study was prolonged by adverse weather conditions of high rainfall, high humidity and low temperature.

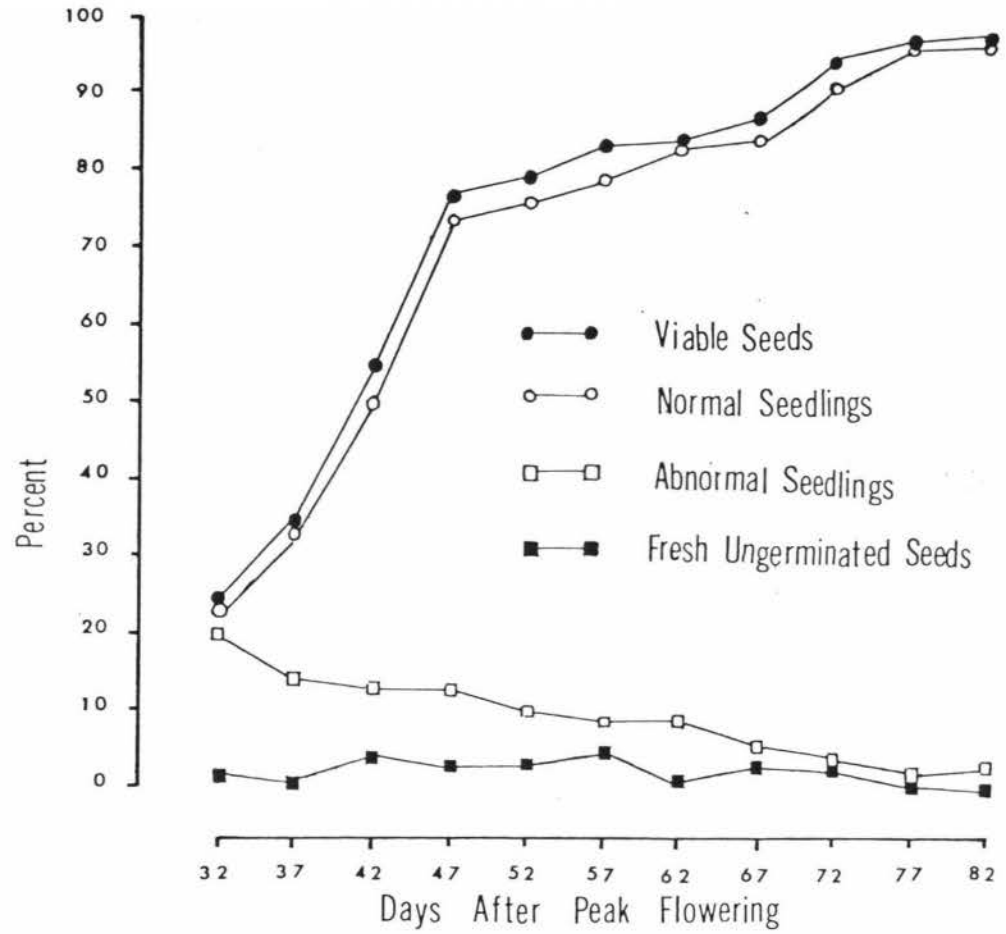


Figure 1.3 Germination percentage during seed development

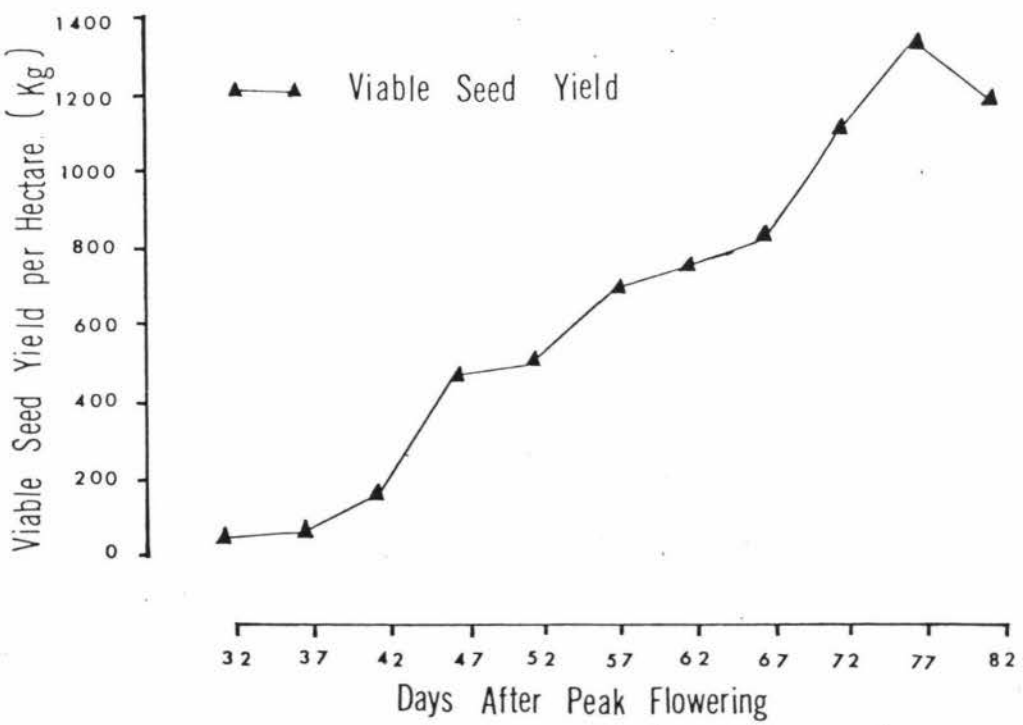


Figure 1.4 Viable seed yield (dry wt. kg/ha) in relation to days after flowering

1.5 CONCLUSION

The physiological maturity of soybean seed was obtained when seed reached maximum dry weight accumulation 77 days after peak flowering. At this point, seed was fully developed as shown by the more rapid appearance of balance of seedling structure as well as at its highest germination capacity of 97.5%. A total viable seed yield of 1344.1 kg/ha was achieved at physiological maturity at a moisture content of 49.2%. This study of seed development and the attainment of physiological maturity of soybean seed was a useful indicator of the optimum time for harvesting highest yields of soybean seed of maximum quality.

CHAPTER 2

PART A

A COMPARISON OF 6 DRYING SYSTEMS AND THEIR EFFECT ON SEED VIABILITY .

2.1 INTRODUCTION

Soybean seed attains physiological maturity at seed moisture content ranging from 40-50%. At this stage of development the seed possesses maximum germination capacity and vigour, which may or may not be high depending on conditions during the growth of the plant and maturation of seed. Harvesting seed at high moisture contents poses immediate and serious problems, since high moisture seed will heat and deteriorate very rapidly. Seed moisture content during storage is therefore the most important factor influencing seed deterioration. This is particularly important because of its effect on mould growth which can begin at 12-14% seed moisture content. Heating due to increased rate of respiration and micro-organism activity can begin at 16% seed moisture content and seed will germinate at 35-60% moisture content. This enormous influence of seed moisture levels on seed longevity makes some form of drying necessary in the production of high quality seed. Most mechanical seed drying systems utilise heated air blown through the seed. However, drying with air at excessively high temperatures may cause both physical and chemical damage to the seeds. This study was designed to investigate the effects of a number of different drying systems on seed viability.

2.2 REVIEW OF LITERATURE

2.2.1 Principles of Seed Drying

Drying is simply the evaporation of moisture. Every liquid at a given temperature has a definite vapour pressure, which tends to produce vapourization. The moisture in a seed and also in the atmosphere exerts such a pressure. Whenever the vapour pressure within a seed is greater than that of the surrounding air, vapour will move out of the seed. When the two vapour pressures are equal, there is no movement of vapour. At this point the moisture content of the seed is in a state of equilibrium with the surrounding air (Hall, 1957; Brandenburg et al, 1961; Harrington 1972b and Boyd et al, 1975).

The relative humidity of the air is a measure of actual weight of moisture in a given weight of air in relation to total weight of moisture the air will hold when saturated. As the temperature of the air increases, the weight of moisture a given weight of air can hold also increases. To dry seeds the RH of the air must be at a level which is at or below equilibrium with the seed moisture so there will be a moisture gradient from the seed into the air (Pixton and Griffiths, 1971 and Harrington, 1972b).

The moisture in seed to be removed in drying is associated with seed in two ways: Surface moisture which occurs in the outer surface, and is readily absorbed by the air under proper conditions.

Internal moisture which is distributed throughout the inner parts of the seed. Its removal involves capillary action or diffusion of the moisture to the surface, where evaporation takes place (Brandenburg et al, 1961).

The rate at which seed will give up moisture (rate of drying) is determined by how fast moisture migrates from the interior to the surface of seed and by the speed at which the surface moisture is transferred to the surrounding air. The rate of moisture migration

from the centre to the surface of a seed is influenced by seed temperature, physical structure, chemical composition of the seed and seedcoat permeability. The rate of moisture removal from the surface of the seed is influenced by the degree of surface saturation and the relative humidity and temperature of the drying air (Kreyger, 1963 and Boyd et al 1975).

2.2. Methods of Drying Seeds

There are many ways of drying seeds which can be classed as either natural or artificial drying. Natural drying takes place with typical atmospheric air moving naturally around damp seed spread on trays, canvas floor or fields. Artificial drying includes unheated, heated and dehumidified air drying, vacuum drying, drying in storage, drying with dessiccant and freeze drying (Brandenburg et al, 1961 and Justice and Bass, 1978).

Artificial drying is basically an acceleration of the natural process of diffusion and the extent to which this acceleration occurs depends upon the characteristics of moisture retention and movement within the particular seed, in response to the external environment to which it is exposed (Nellist and Hughes, 1973). However, all drying operations involve some movement of air through the seed. In normal vaporization each seed tends to become surrounded by a film of saturated vapour which obstructs heat transfer and limits the evaporation of moisture. Air movement is needed to replace this wet air continuously with drier air so the drying process can go on (Brandenburg et al, 1961 and Brook et al, 1974).

The methods of drying used in the experiment will be briefly reviewed.

a. Heated air method

Heating the air facilitates drying because the heat increases its capacity to take up vapour. The use of heated air assists drying

by increasing the vapour pressure of the moist seed and causing an increase in the rate of diffusion of moisture from the inner tissue to the outer seed surface. This results in a difference between the seed vapour pressure and the atmospheric vapour pressure resulting in evaporation. Thus, rapid drying is achieved (Brandenburg et al, 1961; Brooker et al, 1974 and Copeland, 1976).

b. Dehumidified air method

Generally the dehumidified air system is used within a closed system, the drier passing air through the seed to pick up moisture and then through a dehumidifier to remove this moisture from the air. The dried air is then blown back through the seed for further moisture absorption. The air acts as a carrier of moisture from the seed to the dehumidifier, the process continuing until the seed moisture is reduced to the level desired (Harrington and Douglas, 1970 and Justice and Bass, 1978). Silica gel is the chemical dehumidifier most commonly used for this purpose. It can pick up moisture from air up to a total of 30% of its dry weight, and can be reactivated for further use by removal of absorbed water at 120^{o}C for 16 hours or 175^{o}C for 6 hours (Harrington and Douglas, 1970 and Brandenburg et al, 1961).

c. Refrigeration method

An alternative method of dehumidifying air is to employ refrigeration to drop air temperature below its dew point causing moisture to condense. Such a process reduces the moisture holding capacity of the air and removes surplus vapour, which can then be withdrawn from the system (Brandenburg et al, 1961). However, if the refrigeration system is to be used for drying purposes, the relative humidity must be adjusted to a low level by reheating the cool air slightly (Burrell, 1974).

2.2.3 Drying Effects on Seed Viability

Although high temperature will increase the drying rate, excessive speed of drying or too high temperature may cause both physical and chemical damage to seed (Griffeth and Harrison, 1954). The types of

damage associated with the use of excessive heat during the drying of seed include loss of viability, the production of abnormal seedlings, internal cracks, split seed coats and discolouration (Nellist and Hughes, 1973 and Brooker et al, 1974). Rapid drying in some seed leads to the shrinking of the seed coat which becomes impervious to the movement of moisture. This is known as case hardening, a condition which can prevent further drying and produce dormant seeds (Harrington 1972b).

Kreyger (1963) illustrated results for sugar beet seeds dried in a layer 21.5cm thick and from an initial m.c. of 39%. His work clearly showed that when drying with air at 70°C and reducing seed moisture to 6% bottom layers of seed in the drier showed a serious reduction in viability after only 70 minutes of drying. At this time the temperature in the middle layer was still less than 60°C although the seed moisture content had fallen to 12% and there was a slight loss of viability. The top seed layer which had only reached 30°C and 32% m.c. showed no reduction in viability. Similar results for barley are given by Woodforde and Lawton (1965a) and also Kreyger (1960). Therefore using excessive high drying temperatures can kill seed, especially if its moisture content is high.

Harrington (1972b) pointed out that if air temperatures are not high enough to kill the seed immediately, the seed can be injured and exhibit both loss of vigour and a shortening of storage life. He also recommended that for any crop seed, if high vigour and longevity is desired, drying should not be carried out at temperatures above 45°C. Nellist and Hughes (1973) commented that the effect of heat on seed viability is complex, because while it is easy to demonstrate that the extent of damage depends on the interaction of temperature with time exposure and seed moisture content, it is not easy to devise experiments to unravel these effects in the dynamic situation of artificial drying.

Many workers (Hutchinson et al, 1945; Wellington and Bradnock, 1964; Woodforde and Lawton, 1965b and McKnight and Moysey, 1971) have

reported that seeds heated in sealed containers are more sensitive to injury than those allowed to dry at the same temperature in an open system. One reason for this is that the removal of moisture during drying helps to keep temperature several degrees below that of the heating medium in the initial stages of heating. This therefore shortens the total time seed spends at the maximum temperature. In sealed heating, heat which may have been dissipated as latent heat remains within the seed.

Overdrying, the drying seeds to very low moisture contents also reduced seed viability. Evans (1957) and Nutile (1964) have both reported that after 5 years storage the viability of seeds of celery, egg plant, pepper and Kentucky bluegrass sealed at approximately 1 and 0.4% moisture and carrot, tomato and red fescue seeds sealed at 0.4% moisture was seriously impaired. Sealing seeds at 4% moisture resulted in no injury.

2.3 MATERIALS AND METHODS

2.3.1 'Mini' Drier

A 'Mini' drier designed by staff of the Seed Technology Centre was used for the drying experiment (Plate 2.1). The 'Mini-Drier' consists of a central plenum through which air can be forced up to 30 cu.ft/min. using an electrically operated fan. The plenum contains a refrigeration coil with a chilling capacity of 3,000 B.T.U., and a heater element with a 1,000 watt heating capacity. The air temperature in the plenum can be regulated by controls. The temperature of the air is measured by a thermometer placed in the air stream entering the drying bin and by another thermometer recording air temperature as it escapes from the top of the bin. An electric motor is used to power the fan, which forces air into the plenum and through the perforated base of the drying bin. By regulating the refrigeration unit (and leaving the heating unit off) the air can be delivered at a cool temperature. By regulating the heating unit the air can be delivered into the seed at a warm temperature. Finally, the flow of air delivered by the fan can be controlled at the air inlet by an adjustable aperture. The drying bin has a capacity of about 8kg of soybean pods.

Soybean seeds which had been harvested in the pod at physiological maturity as previously described in Chapter 1 were used in the drying experiment. Six lots of 8kg of soybean pods each were held at $5^{o}C$ awaiting drying.

2.3.2 Drying Treatments

The six drying treatments used in the experiment are described as follows:

Heated Air - Air passing through the drier was electrically heated to obtain a temperature of $30^{o}C$, $40^{o}C$ or $50^{o}C$ as required.

Refrigeration - The ambient air was blown through the refrigerator coil reducing the air temperature to dew point. The condensed water

was collected in a container below the coil. The cool air was then heated to bring the relative humidity of the air down to about 47%.

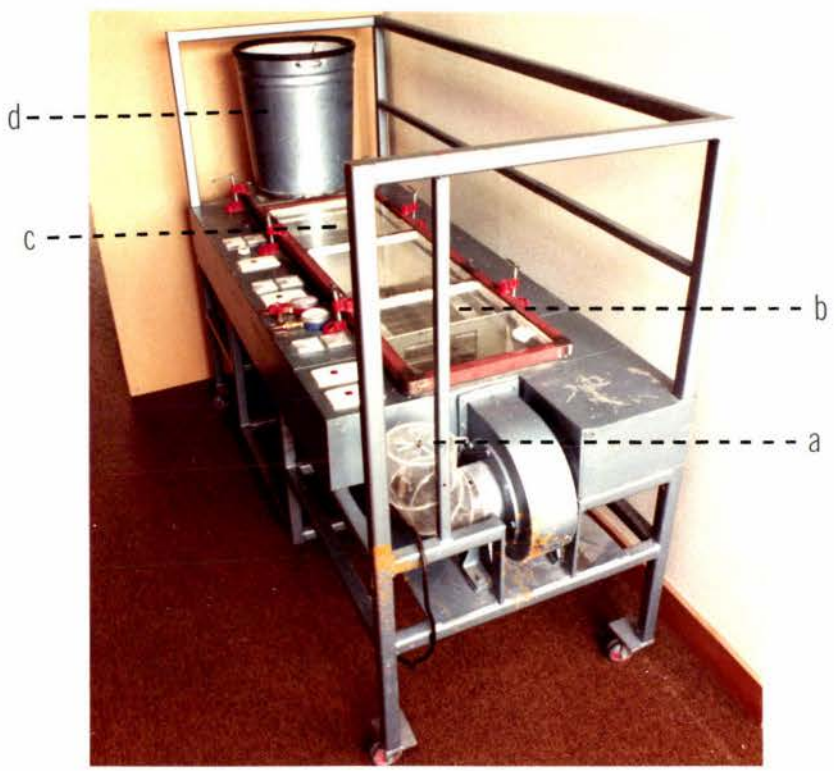
Dehumidification - A plastic tube filled with silica gel (78cm in height and 14cm in diameter) was placed on the top of the air inlet duct. The ambient air was sucked through the column of silica gel, resulting in a reduction of relative humidity to 35%. The dry air at ambient temperature was then blown through the pods in the drying bin.

Ambient Air - The ambient air was used as a control treatment. The average relative humidity was recorded at 65%.

The rate of air flow in all drying treatments was maintained at 25cu.ft/min. The temperature and relative humidity levels at the air inlet, dried air and air outlet were recorded at regular intervals. Seed moisture and germination were tested at intervals throughout the drying process.

When the seed had been dried to 8% moisture content, seed from each drying treatment was stored in polyethene bags and allowed to equilibrate to ambient temperature, awaiting threshing. The threshing and storage procedures of soybean seeds will be presented in Chapter 3.

Plate 2.1 'Mini' drier (a = Air inlet; b = Refrigeration coil; c = Heater element; d = Drying bin).


d
c
b
a

2.4 RESULTS

Results showing the time taken for seed to be dried using each drying method and the effect of drying methods on viability are presented in Table 2.1

2.4.1 Seed Germination Percentage Before Commencing Drying

Seed obtained a maximum germinability of 96% at harvest. All soybean seed lots showed a significant decrease in germinability during the time between harvest and the commencement of drying except for the seed lot which was later used for the 30°C heated air drying treatment. This general trend for a reduction in germination capacity occurred even when seed was held at 5°C following harvest until drying. The seed lots which were later used for the refrigeration drying treatment and the 50°C heated air drying treatment were most seriously affected as a result of a delay of up to 9 days following harvest and prior to the commencement of drying. Such seed lots resulted in lowest germinability.

2.4.2 Changes in Seed Moisture Content during Drying

The relationship between seed moisture content and the time taken for seed to reach the desired level of 8% moisture in each drying treatment is shown in Figure 2.1.

Seeds dried at a temperature of 50°C, 40°C or 30°C using heated air showed a similar pattern of moisture reduction. However, the higher the temperature, the less time was required to dry seeds to the desired level. Drying seeds with heated air at 50°C reduced moisture content rapidly. In the first 7 hours the moisture level was reduced by approximately 25% (48.3 to 23.6%). Subsequently moisture content fell steadily to 8% in 24 hours. The completion of drying of seeds dried with heated air at 40°C or 30°C was achieved in 37 and 64 hours respectively. Seeds dried with unheated ambient air required approximately 90 hours for the moisture content to be reduced to the desired level.

Drying times of 78 and 160 hours were recorded for dehumidification and refrigeration drying methods respectively. In the latter case only 15% moisture was removed in the first 30 hours, and another 12% removed during the next 30 hours. Subsequently there was a slow decline to reach 8% seed moisture content with a total drying time of 160 hours.

2.4.3 Effect of Drying Methods on Seed Viability during the Drying Process

Seeds from each drying method were tested for germination at intervals during the drying process. The germination and the analysis of variance results are presented in Figure 2.2 and Table 2.1 respectively.

Drying seed using fast-drying systems (heated air systems) or slowed and cool drying systems (refrigeration or unheated air drying) had no immediate effect on seed germination during drying. Although there was no statistical difference in seed germinability between treatments during drying, seeds dried by the refrigeration method with its low initial germinability showed a tendency to be lower in germination than seeds obtained from other drying methods. If seeds are to be used for purposes other than for planting, the choice of the drying method used is not important in terms of retaining seed viability since the results from the present study show that drying method has no significant effect on seed germination.

TABLE 2.1 Comparison of time taken and the germination of soybean seed dried by different methods (all seed harvested 4 May 1981 with a germination of 96%).

Drying method	Days from harvest to the beginning of drying	Days required for drying to be complete	Percent germination Sampling during drying						
			Commencing drying					Finishing drying	
Dehumidification	5	4	81	85	87	82	85	81	82
Refrigeration	9	8	72	79	74	77	75	79	70
Ambient air	8	3	79	82	76	71	78	81	80
Heated air - 30°C	6	2	85	83	81	83	77	86	81
Heated air - 40°C	7	2	82	82	79	76	80	81	81
Heated air - 50°C	9	1	74	85	79	76	80	80	85
			NS	NS	NS	NS	NS	NS	NS

NS = Non Significant

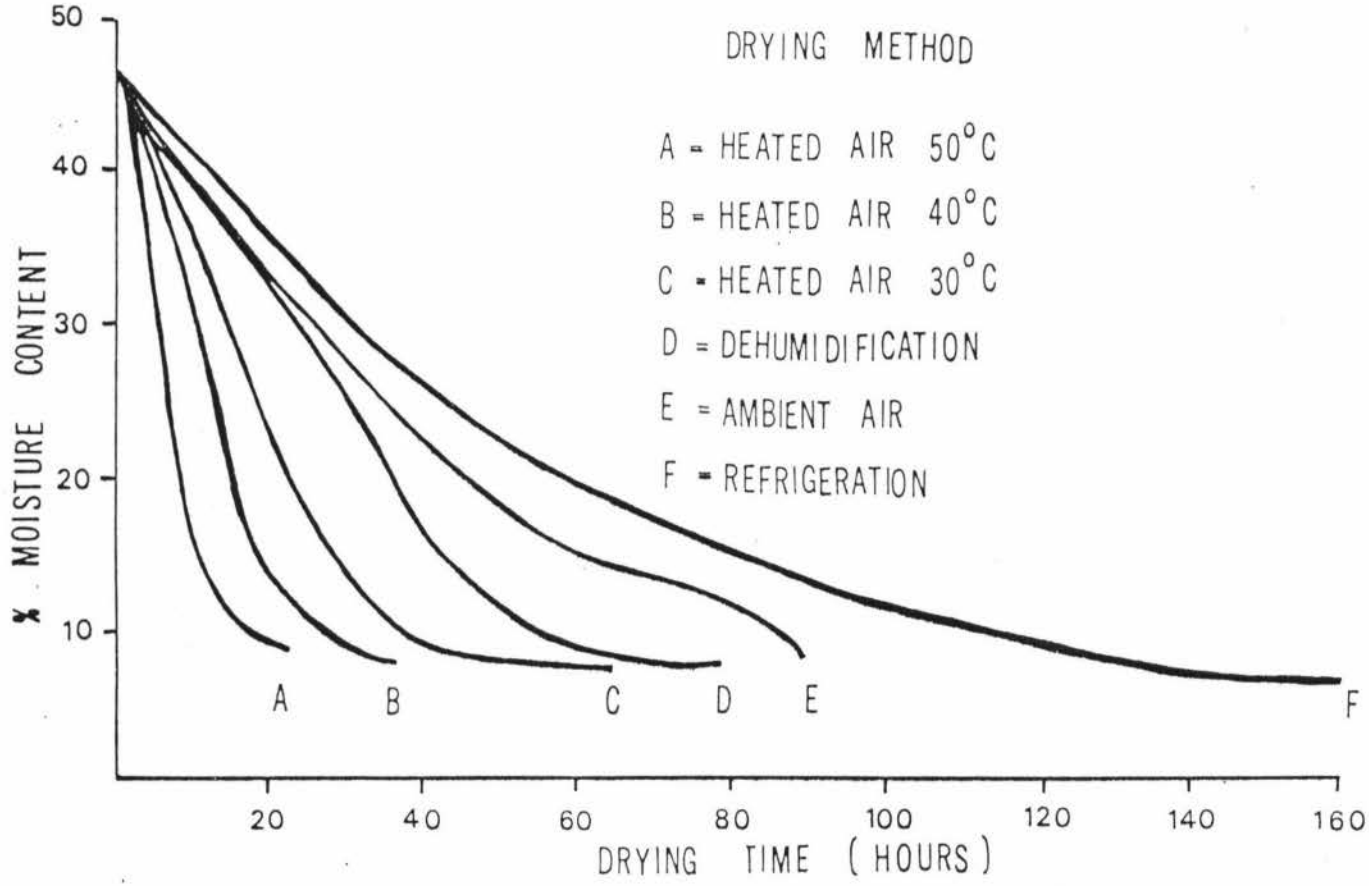
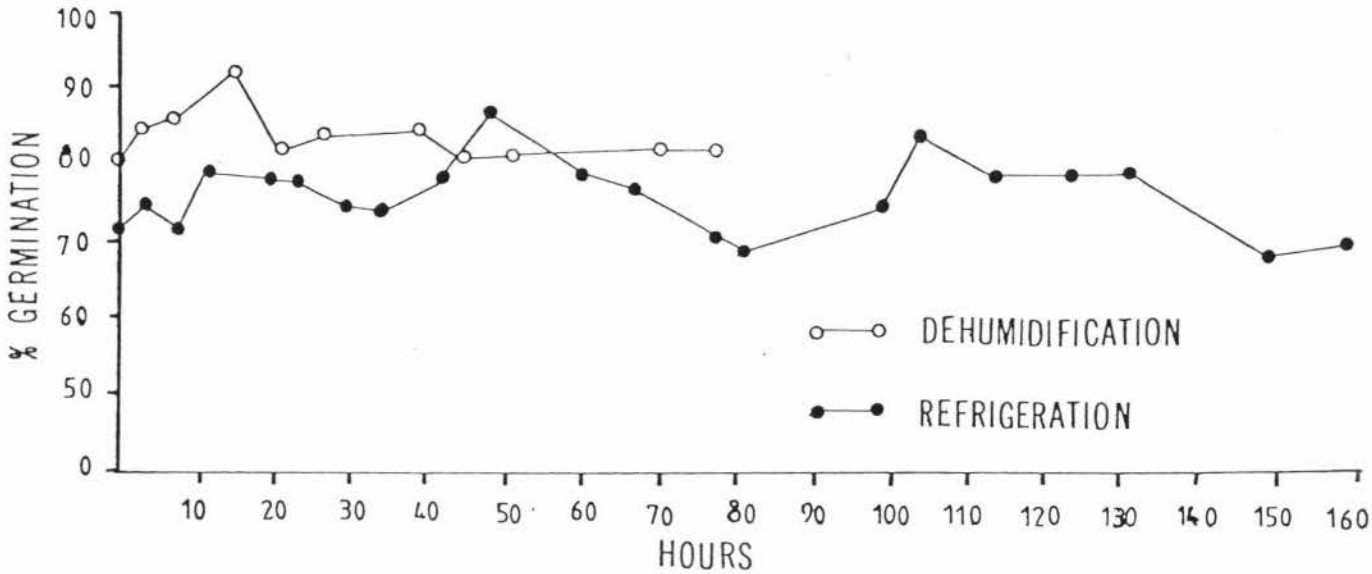
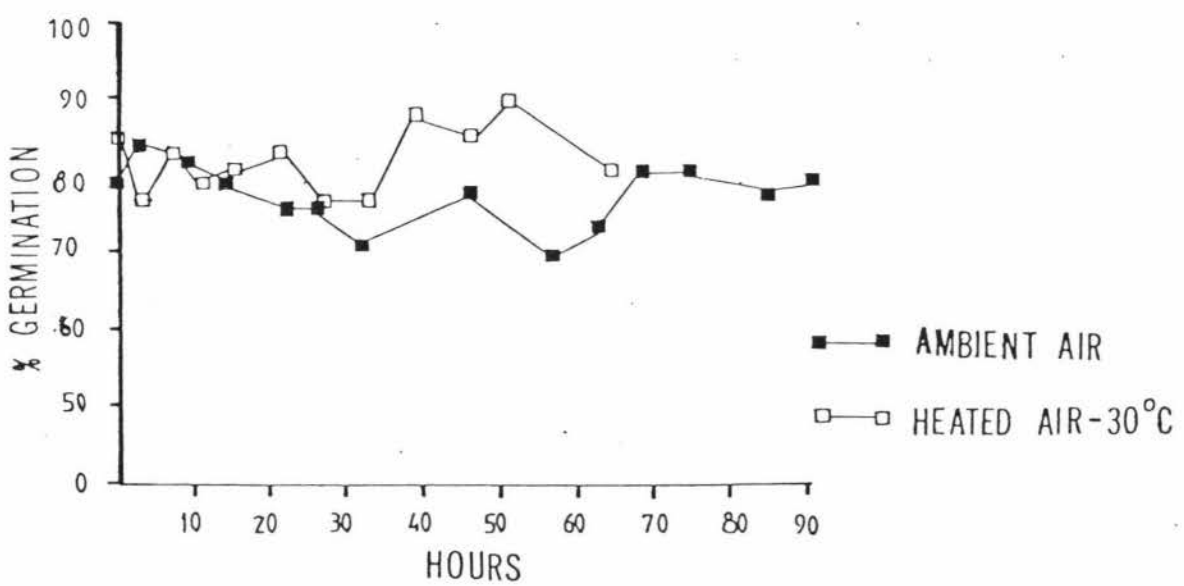
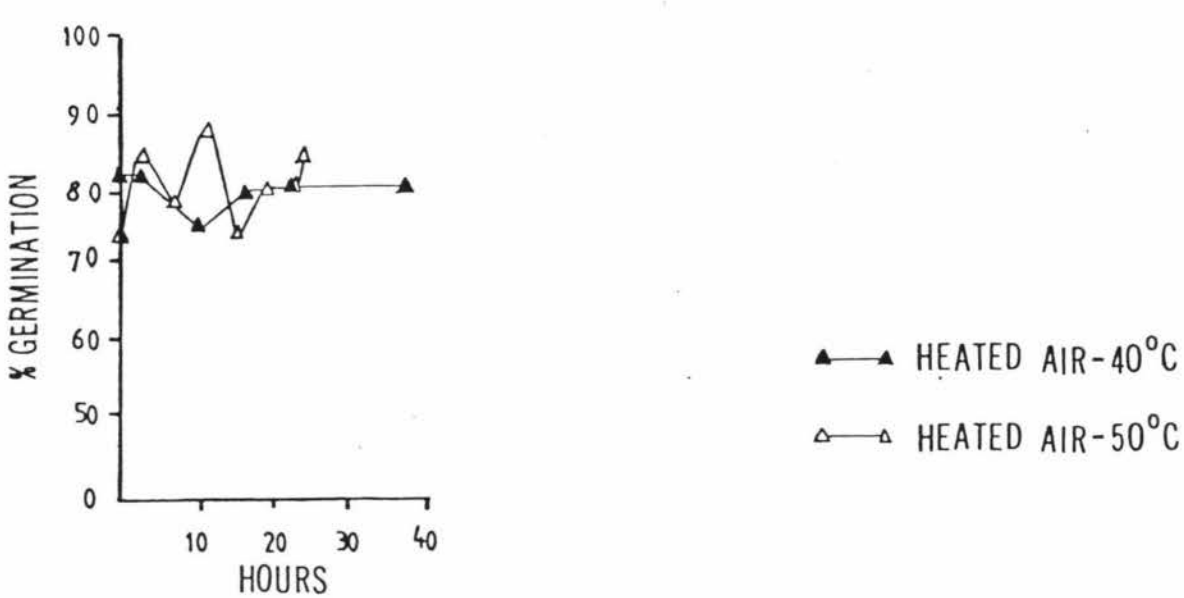


Figure 2.1 Changes in seed moisture content and the time taken for seed to reach the desired 8% moisture content in different drying treatments

Figure 2.2 Changes in seed germination percentage obtained during the drying of soybean seeds in 6 different drying treatments







2.5 DISCUSSION

In the present work the viability of seed decreased rapidly after harvest and before drying. This was probably due to the high level of moisture (46 - 47%) in seeds when harvested and also to the delay (5 - 9 days) before different drying treatments were begun. Although seeds were held at 5°C after harvest and before drying it is possible that storage moulds could still have developed and were responsible for the decline in germinability. This is particularly likely in those seed samples which were ultimately used in the refrigeration and 50°C heated air drying systems. Soybean seeds used in this experiment had undergone development and maturation under wet and cold late season conditions. Such conditions could have contributed to variation in seed quality. Green et al (1965), Metzer (1967), Moore (1971), Delouche (1974) and TeKrony et al (1980) have all shown that exposure of the crop to adverse weather conditions during seed maturation can result in poor seed quality.

The results in Figure 2.1 show a marked reduction in the length of the drying period with an increase in the air temperature used to dry seed. These heated air systems facilitate moisture removal better than other drying systems. This is because the heated air increases the vapour pressure of the moisture in the seed (Brandenburg et al 1961). Transferring heat to the seed also stimulates the transfer of moisture from the seed to the surrounding air (Kreyger, 1963; Brooker et al, 1974). Drying seed without the use of supplemental heat results in a marked reduction in seed drying rate. In the present study the ambient air drying treatment involved the use of air with a relative humidity of approximately 65%. This air would dry seed to an equilibrium moisture content for soybean of approximately 12,5% (Delouche, 1977). Therefore with no addition of heat to decrease the RH of the air, the seed could never have reached the required level of 8%. This was the reason why a small amount of supplemental heat was applied to raise the air temperature to approximately 20°C during the later part of the drying process. In the drying treatment involving dehumidification, less drying time was required than with the ambient air system. This was due to the efficiency of the dessicant (silica gel) used to absorb moisture from the air.

In the present study, drying seeds with heated air of 30°C, 40°C or 50°C, ambient air, dehumidified air or with a refrigeration system had no deleterious effects on seed viability. However, drying seeds using a refrigeration system was found to be disadvantageous as it is a time-consuming method. The low temperature of the air in the refrigeration system resulted in a very slow drying rate with high moisture content remaining within the seed for a long period of time. Ching et al (1939), Hummel et al (1954) and Christensen (1955) have all stated that deterioration occurs in seeds when a slow drying process is likely to be associated with high rates of seed metabolism and resultant mold growth.

Although none of the 6 drying methods used had an immediate deleterious effect on seed viability it is possible that such seeds may behave differently in subsequent storage. Therefore further investigations on seed storage performance are discussed in the next chapter.

2.6 CONCLUSION

The germinability of soybean seeds after harvest is adversely affected when drying to a safe moisture level is delayed. Drying seeds using unheated air, heated air, dehumidified air or a cool air system had no serious effect on seed viability during drying. The time taken to dry seed to the desired level of moisture content decreased as the temperature increased. Drying seed with a refrigeration method was a prolonged and time consuming process.

CHAPTER 2

PART B

A STUDY OF THE DRYING PERFORMANCE OF THE 'KIWI' DRIER ON TAMA RYEGRASS, BARLEY AND PEA SEEDS.

2.7 INTRODUCTION

Thai farmers often face a problem of drying seed crops in the wet season. The idea of using some form of artificial drying system such as a heated air drier, while desirable in itself, is often resisted by the local farmers because of the cost of the drier itself and the fact that fuel and electricity are too expensive for most farmers to afford. As one possible step in overcoming these objections a 'Kiwi' drier was developed at the Seed Technology Centre. The drier is easy to operate and uses silica gel as a dessicant which can be reactivated. The drier can be built by local farmers and the cost is reasonable. The study was designed to investigate the possibility of using this drier and to evaluate its efficiency in drying various seed crops. In particular this section is a summary report of drying trials with 3 crops: Tama ryegrass, barley and peas.

2.8 MATERIALS AND METHODS

The 'Kiwi' drier consists of a cylindrical metal drum 55cm. in diameter and 85cm. long, with 2 metal tubes arranged inside in a diagonal cross. Within the tubes there are open slots which are covered by 2 layers of fine woven mesh (Plate 2.2). Dial thermometers and Durotherm hygrometers are installed to measure the temperature and RH of seeds and silica gel (Plate 2.3). The drier is operated by filling the two tubes with silica gel and placing seeds in the drum (Plate 2.4). The drum is turned occasionally by hand to assist air and seed circulation inside the drum (Plate 2.5). Silica gel has been dyed with lithium chloride which is blue when dry and pink when saturated with moisture. When the silica gel is pink, it is removed and replaced with dry silica gel. Wet silica gel can be dried to its original blue (dry) condition by heating it to $175^{o}C$ for 6-7 hours. This renders it totally reusable.

Plate 2.2 Silica gel tubes arranged in a diagonal cross placed inside the drum.

Plate 2.3 'Kiwi' drier front view (a = Dial thermometer attached to one of the silica gel tubes; b = Durotherm hygrometer attached to the filler cap of another silica gel tube).

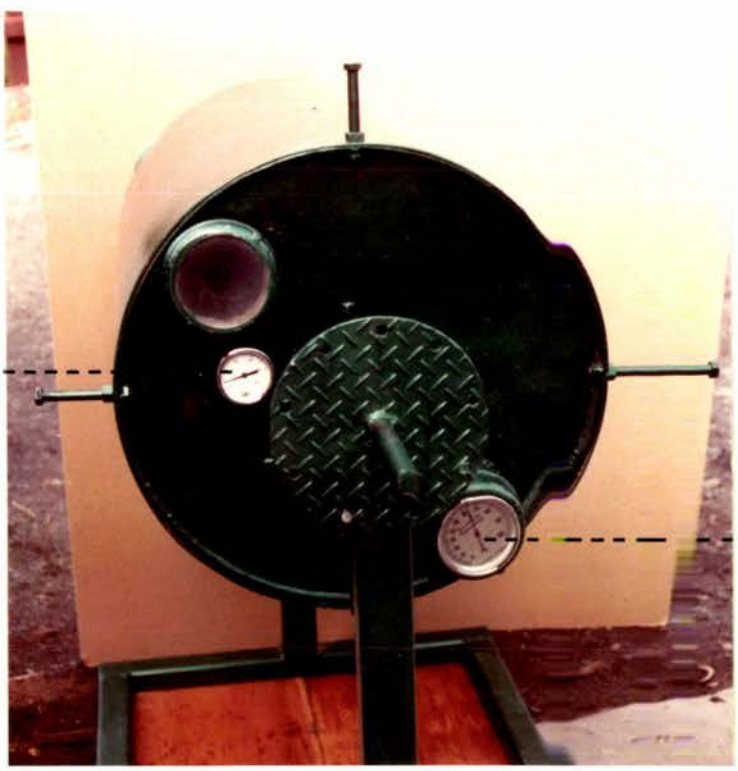
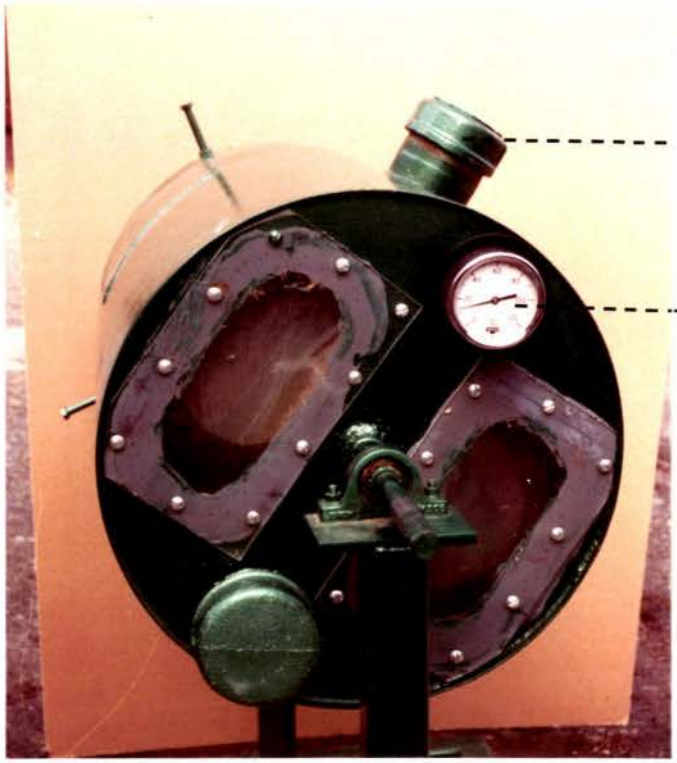

a
b

Plate 2.4 'Kiwi' drier end view (c = fill in seed with a Durotherm hygrometer attached to the filler cap; d = Dial thermometer to measure temperature inside the drum).

Plate 2.5 'Kiwi' drier side view (e = handles for turning the drum).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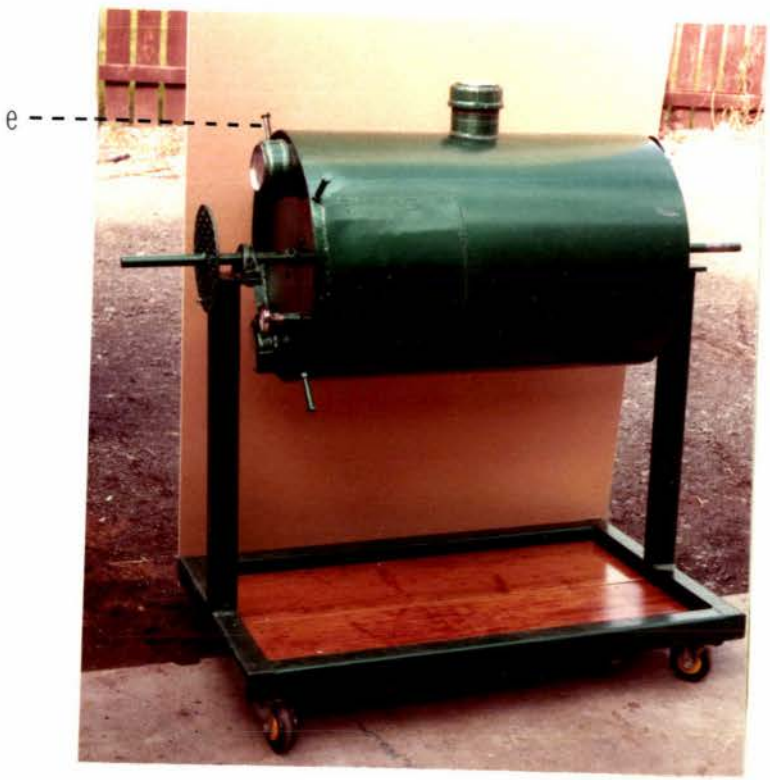

e

2.9 RESULTS AND DISCUSSION

2.9.1 Moisture Content of Silica Gel in Equilibrium with Different Relative Humidities

Different levels of RH were obtained in sealed jars using water-glycerine mixtures (Hill 1965). A package of 50gm of silica gel was packed in muslin cloth and placed on a wire stand in each jar. The jars were held at 25°C for 72 hours. The amount of moisture absorption by the silica gel was calculated following weighing and expressed as a percentage (Table 2.2).

Table 2.2 Moisture content of silica gel in equilibrium with different levels of relative humidity

Relative humidites (%)	0	10	20	30	40	50	60	70	80	90	100
Percent absorption of silica gel (by wt.)	1.4	4	4.8	6.2	9	10.6	13.6	16.9	19	25.5	29.7

This result shows that the absorption of moisture by silica gel reaches a maximum of approximately 30% of dry weight at saturation.

2.9.2 Drying Performance of Tama Ryegrass in the 'Kiwi' Drier

The quantities of Tama ryegrass seeds and silica gel used in the drier were 37.5kg and 12.5kg respectively (or 3:1 ratio by weight). The initial moisture content of the seed was 47%. The drum was turned occasionally by hand and the silica gel was changed when its blue colour changed to pink at which stage the RH of the silica gel was recorded at about 30%. Seeds dried using this process for 4 days resulted in only a 4% reduction in moisture content whereas seeds dried in ambient air as a control showed a 12% reduction in seed moisture content over the same period. By the 4th day, a great amount of mold had infected the seeds in the drier. It was likely that the seeds were too moist to be kept in a closed drum system and the seeds

respired rapidly, produced heat and therefore increased the seed temperature. These conditions favoured mold growth. The chaffy characteristic of Tama ryegrass also caused difficulties in mixing the seeds during turning, since they tended to stick together in a bulk. The inability of silica gel to absorb the excess moisture was also responsible for the failure to achieve a sufficiently acceptable drying rate in this trial.

2.9.3 Drying Performance of Barley Seed in the 'Kiwi' Drier with Continious Turning

An electric motor was installed to turn the drum automatically at 5-6 rpm in order to improve the air circulation and seed mixing inside the closed system of the drier. Barley seeds (36kg) and silica gel (12kg) were used for this drying trial. The initial moisture content of barley seeds was 16.7%. The rate of seed moisture reduction obtained using this drier method was 1.6% per day compared with 0.6% reduction per day from an ambient air-dried control sample.

Therefore, the drying rate of seed was improved when the drier was provided with a continuous mixing and air circulation facility in the closed system of the drier.

2.9.4 Drying Performance of Pea Seeds

a. Drying performance of pea seeds in the 'Kiwi' drier

A ratio of 3:1 by weight of seeds and silica gel was used in the drier. The initial seed moisture content was 18.3%. The drying procedure used was as previously mentioned in drying Tama ryegrass seeds. The drying process was carried out for 3 days and resulted in a 0.4% seed moisture reduction per day. The reduction of moisture content of pea seeds in the control sample was 0.3% per day. The drying rate obtained in the drier however was considered to be too slow for satisfactory moisture reduction.

b. Drying performance of pea seeds in the 'Kiwi' drier with battery fan

In an attempt to improve the rate of moisture loss from pea seed, a 1.5 volt battery fan was placed inside the drier to improve air circulation. The same drying procedure was carried out as before. With improved air circulation, the seed moisture reduction rate was increased to 1.1% per day.

c. Drying performance of pea seed in the 'Mini' drier with a column of silica gel

An attempt was made to further increase seed drying rate by sucking the ambient air through a column of silica gel before it was blown through the seeds. This procedure was carried out using the same dehumidification method as described earlier. This drying trial was set up to support the contention that a better air circulation system would be needed to improve the efficiency of the 'Kiwi' drier. The moisture reduction rate of pea seeds using this dehumidification method proved to be superior to all other methods i.e. 7.6% per day.

2.9.5 Drying Trial Using a Closed Contact System with Barley Seeds and Silica Gel

Layers of 1, 2, 3, 4, 5, 6 and 8cm of barley seeds and silica gel were alternately arranged in plastic cylindrical containers and enclosed in a large plastic bag. The objective of this trial was to observe the moisture reduction rate of seeds in close contact with silica gel in order to provide more information on the necessary improvements required to increase the drying efficiency of the 'Kiwi' drier.

Table 2.3 Moisture reduction rate of barley seeds

Seed later thickness (cm)	1	2	3	4	5	6	8
Moisture reduction per day (%)	6.3	5.7	5.0	4.3	3.0	1.0	0.6

These results show that drying efficiency increased when seeds and silica gel were arranged in more close contact, the thinner the layer between seeds and silica gel, the better the moisture absorption rate by the silica gel.

2.10 SUMMARY

In summary it can be concluded that in its present form, the drying efficiency of the 'Kiwi' drier is not satisfactory. However, there are a number of aspects that might help to improve the efficiency of the drier:

1. Air movement inside the drum using some type of battery fan, or automatic rotation of the drum with an electric motor were both found to improve seed drying rate.

2. The removal of moist air from the drum and continuously replacing moist air with dried air greatly improved the drying rate.

3. The close contact of seeds and silica gel improved the moisture absorption rate by silica gel. The layer thickness between seeds and silica gel used in the drier was found to have a marked effect on dry efficiency.

At the present stage, more research is obviously needed to improve the 'Kiwi' drier's efficiency. However, it is possible that modification of the design of the drier to incorporate improved air circulation and increased contact between the seed and silica gel could result in greatly improved drying efficiency.

In addition it should be noted that the 'Kiwi' drier provides an ideal storage container for seeds in tropical climates where the RH is high. In addition to its ability to prevent invasion of seed by rodents and insects the use of silica gel with the system effectively prevents the readsorption of moisture by seeds from the surrounding air. It seems likely that a modified 'Kiwi' drier could provide a relatively simple and effective method of maintaining high seed quality in tropical environments.

CHAPTER 3

THE PERFORMANCE OF SOYBEAN SEED UNDER DIFFERENT STORAGE CONDITIONS

3.1 INTRODUCTION

The problems of maintaining high levels of seed viability are important in a number of applied fields. The factors affecting seed viability before harvest are of special concern to seed producers, and the problems of maintaining the viability of seed in storage have always been of important concern to seedsmen. Seed storage is not just the time seed remains in the warehouse. Seed is being stored from the moment it matures on the plant until it is sown. After harvest, seed maintains its original germination capacity for some period of time; it then generates steadily and often rapidly. The aim in storage is to maintain the germination capacity of the seed and generally this requires more stringent conditions than the conservation of nutritional or industrial qualities.

Because of the high relative humidity and high temperature in tropical countries, soybean seeds stored by traditional methods often do not maintain their viability until the next planting season. An attempt was made in the present study to obtain information of the effect of different storage condtions on soybean seed viability.

3.2 REVIEW OF LITERATURE

A. STORAGE AND VIABILITY OF SEED

This review will cover preharvest and postharvest technology in relation to the retention of seed viability in storage.

3.2.1 Inherent Characteristics

Soybean seeds are inherently short-lived compared with most of the major agronomic crops. Under the same environmental conditions, seeds of corn, wheat, sorghum and cotton are better storers and have longer lifespans (Crocker and Barton 1954; Barton 1961, Delouche 1972).

This inherent difference is also found among cultivars of the same species (Barton 1961; Justice and Bass 1978). Shands, Janisch and Dickson (1967) reported that seeds of Oderbrucker barley had greater resistance to germination loss in storage than other cultivars. James, Bass and Clark (1967) also found significant differences in the storage of various cultivars of bean, cucumber, peas, sweet corn and water melon. Toole and Toole (1954) found that the cultivar 'Black Valentine bean' has a longer lifespan in storage than 'Brittle wax'.

Although inherent differences in seed storability among soybean varieties have not been demonstrated, observations and experience indicate that seed of the older 'forage type' soybean varieties may store better than those of modern 'grain type' varieties (Delouche 1977).

3.2.2 Quality of Seed Entering Storage

Hyde (1950) listed three important aspects of seed quality as viability, seedling vigour, and storage life. The storability of seed is very much influenced by the degree to which it has deteriorated prior to storage. The influence of initial seed quality on longevity in storage is clearly demonstrated by Mondragon (1972). Soybean seed lots with high initial germination and vigour maintained their germinability

remarkably well, while those seed lots exhibiting low germination and vigour as a result of severe weathering before harvest, lost 20-30% of germination capacity under identical storage conditions and time. Delouche et al (1973) stated that low quality seeds do not store well even under very good conditions.

Ketring (1971) exposed high quality and low quality peanut seed-lots to the same storage conditions. He found that low quality and high quality seeds deteriorated at a similar rate under high RH conditions. However, changes in total germination and vigour occurred more rapidly and to a greater extent in low quality seed.

Seed quality can be reduced by a wide range of factors which can occur during the seed production process including anthesis, development, maturation and harvesting of the seed progeny (TeKrony et al 1980).

3.2.3 Seed Viability and Storability as Affected by Field Environment

The most obvious preharvest factor affecting seed quality is weather, especially seasonal variations. A number of investigations have shown the detrimental effect of allowing soybeans to stand in the field after they reach a harvestable stage.

Moorse et al (1950) reported that unfavourable weather during the ripening period, exposure to damp periods after seeds mature, and frost occurring while seeds are green, causes soybeans to deteriorate while still in the field. They further stated that very hot weather during seed maturation result in the wrinkling of the seed coats.

Harris, Parker and Johnson (1965) also reported that high temperatures during the last 45 days of seed maturation of the soybean 'Hill cultivar' were associated with poor seedling vigour.

Rainfall prior to harvest has also been reported to have deleterious effects on the germination and vigour of the seed crop (Flentze,

1964). Green et al (1965) stated that soybean plants from early planting dates which matured seed during hot, dry weather produced seed of reduced quality. Seed from later dates of planting which reached maturity after the hot, dry weather conditions had ended, were high in quality.

Metzer (1967) and Moore (1971) both agreed that exposure of mature soybean seed to alternate wetting and drying in the field resulted in lower quality. Moore (1971) also attributed this reduction to rapid and differential absorption of water by localised tissues, especially the seed coat which lead to embryo destruction and loss in germination. Mondragon and Potts (1974) concluded that soybean seed of 'Lee 68 cultivar' when subjected to ambient environmental conditions had declined significantly in germination by four weeks after physilogical maturity while seed harvested from plots shaded to remove 50% of the incident sunlight deteriorated at a much slower rate.

Seeds of high initial viability are much more resistant to unfavourable storage humidities and temperatures than those of low initial viability. Seed deterioration, once started, proceeds rapidly under unfavourable storage conditions until the death of all seeds (Barton 1941; McKee and Musil 1948; Brewer and Butt 1950).

3.2.4 Seed Viability and Storability as Affected by Mechanical Damage

As harvesting and threshing machinery and the combine harvester came into general usage, damage to seeds and grain increased accordingly. The relationship of mechanical damage to seed viability has been extensively studied.

Douglas, Brooks and Winstead (1955) compared the effect of mechanical harvesting and hand harvesting damage on the germination and vigour of cotton seed. Hand harvested seed germinated 27% better than mechanically harvested seed. Furthermore, the adverse effect of mechanical damage on germination percentage was more severe when seeds were

germinated at temperature approximating those encounterd in the field.

Cobb and Jones (1960) investigated the germination impairment of alfalfa seed. They reported that mechanical injury was the major cause of germination failure.

Mechanical injury sustained during harvesting and processing operations is frequently a further factor in reducing seed longevity in subsequent storage (Harrington 1972a).

Beattie and Boswell (1939) and Moore (1972) reported that damaged seed does not store well and that fungi enter through cracks in the seed coat. Since the seed coat serves as a protective covering for the embryo, germination of soybean seed can be greatly affected by the condition of the seed coat and cotyledons (Stanway 1978).

Brett (1952) stated that scarification of alfalfa and clover seed caused the rate of loss of viability to be more rapid than in unscarified seed when stored under the same conditions. Mamicpic and Caldwell (1966) also illustrated that mechanical injury caused low initial germination and shorten soybean longevity during storage. Similar results were found in wheat seed (Kulik 1973).

A three year study conducted by Green, Pinnell and Cavanaugh (1966) clearly showed the influence of threshing method on soybean seed quality. They found that the percentage of split and cracked seed coats and of abnormal seedlings was greatly increased as combine cylinder speed was increased from 500 to 900 revs/min. Hand-harvested seed lots had a much higher viability than machine harvested lots of the same cultivar, the difference being ascribed to differences in seed coat damage.

Moisture content of seed has a considerable influence on the nature and intensity of damage following mechanical impaction. Seeds which are moist tend to be bruised whereas dried seeds tend to fracture

(Moore 1972). Available evidence (Green et al 1971; Delouche 1972 and Monti 1972) suggests, however, that there is a rather narrow range of seed moisture contents that are optimal for harvesting soybean seed, i.e. about 13-15%. Seed cracking and splitting increases sharply as moisture content decreases below 13%, while seed bruising and other less visible but nevertheless detrimental injuries increase at moisture contents above 15%.

Moore (1972) discussed the influence of seed characteristics in relation to mechanical injuries. Seeds of small-seeded crops tend to escape serious injuries during harvest. Flat seeds such as sesame (*Sesamum indicum*) with very thin, flexible seed coats, are extremely susceptible to critical mechanical injuries. The natural profusion of the tip of the radicle in onion and peanut seeds likewise promotes root-tip injuries, which lead to accelerated deterioration and loss of viability. Because of weight and size, the large-seeded legumes in particular tend to be especially susceptible to injuries that reduce viability.

Stanway (1974, 1978) reported that soybean seed with tranverse breaks, even though the cotyledons remained intact, gave reduced germination. He suggested that the position of the break was more important than the size of the piece that was severed.

Moore (1972) also pointed out that injuries on or near the embryo structures are more critical to seed viability than those located in non embryonic tissues.

Copeland (1972) classified the characteristics of injured large-seeded legumes as follows:

Cracked coat - This is the mildest form of damage and in itself does not cause germination abnormalities but it may indicate that the seed has more serious internal damage.

Baldheads - This condition results when the growing point of the young plant is broken off.

Broken root-shoot axis - A seed of this kind will not produce a normal seedling. This is the worst damage caused by excessive mechanical abuse and is usually accompanied by broken and shattered cotyledons.

Detached cotyledons - Injury sometimes causes detachment of one or both cotyledons. At least one cotyledon is needed to provide adequate nutritive support to the germination seedling. When cotyledons remain attached, but are broken or cracked, the seedling is abnormal.

3.2.5 Effects of Storage Conditions on Seed Longevity

The two most critical factors affecting the mainenance of seed quality in storage are relative humidity and temperature (Owen 1956; Barton 1961; James et al 1967; Delouche 1968; Christensen and Kaufmann 1974).

The physiological quality of seed is affected by relative humidity in two ways:

a. seed moisture content is a function of ambient relative humidity
b. The infestation, growth and reproduction of storage fungi and insects are strongly influenced by relative humidity of the micro-environment in the seed mass (Delouche et al 1973).

Since seeds are hygroscopic they absorb moisture from the atmosphere or release moisture to it until the vapour pressure of seed moisture and atmosphere reach equilibrium. For most species each seed has its own moisture equilibrium value for a given relative humidity (Pixton and Griffits 1971; Harrington 1972b and Delouche et al 1973).

The hygroscopic moisture equilibrium values of soybean seed are given as follows: (Christensen and Kaufmann 1969 and Delouche 1977).

Relative humidity (%)	30	45	60	65	75	85	90
Seed moisture content (%)	6.5	7.4	9.3	12.5	14.0	18.0	18.1

Relative humidity is extremely important bacause it directly controls moisture content in the seed. Seed moisture content has been considered as the major factor involved in seed deterioration through its effect on mold growth which can begin at 12-14%; heating due to increased rates of respiration and micro-organism activity which begins at 16%; and seed germination which occurs at 35-60%m.c. (Harrington 1959; Delouche 1968; Giles and Ashmann 1971).

Harrington (1960) also indicated that the period during which seed may be stored without a significant decline in germination is doubled for each 1% drop in seed moisture and for each 5°C drop in temperature. This rule applies when seed moisture content is between 5-14% and the storage temperature is within the range of 0-45°C.

The other main environmental factor which has a great influence on the maintenance of seed quality is the storage temperature (Delouche 1968; Byrd and Delouche 1971; Harrington 1972b). Just as with high relative humidities, high temperatures are conductive to the activity of micro-orgnaisms and insects. The precise role of high temperature in speeding seed deterioration is not well understood. It is generally assumed that high seed respiration at high temperature is related in some way to rapid loss in germination (Harrington 1972b).

Numerous studies have been conducted on the maintenance of seed viability in relation to seed moisture content, relative humidity and the temperature of the storage conditions. The study by Toole and Toole (1946) illustrated very well the effect of temperature and seed moisture content on the longevity of soybean seed in storage. Germination of 9.4% moisture seeds was maintained above 80% for more than 10 years at 10°C, for five years at 20°C, and one year at 30°C. In contrast, germination of 13.9% moisture seed decreased below 90% within five years at 10°C, two years at 20°C and 0.5 year at 30°C.

Toole et al's (1948) experiments on 15 kinds of vegetable seeds have emphasised the importance of low moisture content, relative humidity and temperature in relation to the maintenance of seed longevity. Seeds only slightly deteriorated when stored at 21°C - 65%RH for 36 months, but seriously deteriorated at 21°C - 73%RH. None of the seeds decreased significantly in viability at 10°C - 50%RH. However, loss of all kinds of seed was progressively faster with an increase of either temperature or humidity and the effect of the two factors was additive. Delouche (1965) reported that crimson clover seeds stored at 30°C - 92%RH are dead in six months. However, when seeds were stored at 30°C - 32%RH and at 7°C - 50%RH the germination capacity remained relatively stable for 48 months.

Seeds of five lettuce cultivars stored at -12°C and 70%RH did not deteriorate during 210 weeks, while seed at 21°C and 90%RH began to deteriorate in less than 14 weeks (Bass 1970).

Bass (1965) has shown that relative humidity has a greater effect on the longevity of Kentucky bluegrass seeds than temperature. Seeds stored for 93 months at 32°C and 15%RH retained fair to good germination while those at 2°C and 70%RH germinated very poorly. Bass and Clark and James (1970) also found that relative humidity has a marked effect on the longevity of green and bleached lima beans stored at 21°C. After 36 months, no significant loss of viability had occurred in seeds stored at 50%RH. After 18 months at 70%RH, no significant loss of viability was found for the green seeds, but the bleached seeds were all dead. At 90%RH, the bleached seeds lost all viability during three months storage, whereas the green seeds lost only about half their initial viability. According to Toole (1950), most crop seeds lose viability rapidly at a RH approaching 80% and a temperature between 25 and 30°C, but can be kept for many years at relative humidities of 50% or less and at temperatures of 5°C or lower.

Seed moisture content (or relative humidity) and temperature reinforce and compensate each other in their effect on seed longevity. High moisture content seed (14 to 16%) of field crops can be stored

for a year or more at a temperature of 10°C or lower, while low moisture seed (10% or less) can withstand temperatures in the range 30 - 34°C for the same period without appreciable loss of viability (Delouche 1968). Furthermore, Delouche (1977) suggested that the maintenance of high germination and vigour in soybean seed during carry-over storage requires:

a. conditioning of the storeroom environment so that it does not exceed 60 - 65°C and 60%RH

or b. reduction of the seed moisture content to about 9% and packaging in moisture vapour proof packages.

Similarly, Grabe (1965) and Douglas (1975) have emphasised the importance of storing seed of low moisture content under conditions of low relative humidity and temperature to extend the storage life of seed.

3.2.6 Storage Fungi and Seed Deterioration

In general, the fungi that grow on and in seeds have been divided into two groups, primarily based on their moisture content requirements - field fungi and storage fungi.

Seeds may be invaded by a great variety of field fungi such as species of *Alternaria, Cladosporium, Helminthosporium and Fusarium.* All field fungi require a high moisture in equilibrium with relative humidities of at least 90 to 95% (Koehler 1938 and Christensen and Lopez 1963). The field fungi invade seeds before harvest and because of their obligatory requirement for high moisture content, they are unlikely to be of importance in storage (Lutey and Christensen 1963; Christensen and Kaufmann 1974). Unlike the field fungi, storage fungi can attack seed of moisture contents in equilibrium with relative humidities of 65 to 90%. The optimum temperature for the growth of most storage fungi is about 30 - 33°C, with a maximum of about 50 - 55°C and a minimum of 0 - 5°C (Christensen 1973). The storage fungi can invade and destroy any kind of seeds when storage conditions become favourable for their growth (Tuite and Christensen 1957; Christensen and Lopez 1963).

The storage fungi comprise mainly several group species of *Aspergillus* plus a few of *Penicillium*, the latter occurring principally in seed stored at low temperatures and at moisture contents in equilibrium with relative humidities about 85%.

Invasion of seeds by storage fungi may result in loss of viability, increase in free fatty acids, decrease in non reducing sugars, development of musty odours and discolouration (Christensen and Kaufmann 1974).

Christensen (1964) reported that seeds of corn, wheat and barley which are free of storage fungi decrease in germinability at a much slower rate than similar seeds in which storage fungi are present.

The study by Fields and King (1962) showed that after seven months storage at 30°C and 92%RH pea seeds inoculated with *Aspergillus flavus* dropped in germination from 97% to 22% whereas seed free from *Aspergillus* spp. was influenced by four factors: moisture content of the stored seed, storage temperature, duration of storage and species of fungi involved.

Most storage fungi are saprophytic and require some damaged tissue for their growth on the seed. Douglas (1975) reported that damage or cracked seeds are more rapidly invaded by storage fungi than sound seed. It is evident that under conditions favourable for the growth of storage fungi, the damaged tissue offers an ideal foothold for fungal invasion and rapid degeneration spreads from these focal points resulting in the eventual loss of viability (Matthews and Hill 1967).

According to Delouche et al (1973) drying seed to a moisture content in equilibrium with relative humidities below 65 - 70% and maintaining moisture content at this level during storage, eliminates the storage fungi problem regardless of other conditions of storage. However, the seed moisture level which influences the activities of storage fungi is rather critical. At moisture contents just above those that permit any given species of storage fungus to grow, small differnences in moisture content make a great difference to the growth of that fungus and to the damage it may do to the seed (Christensen and Lopez 1963).

The two group species consistently associated with beginning or incipient deterioration are *A. restrictus and A. glaucus*. For example, soybean seed at 12 - 12.5%mc will be invaded by *A. restrictus* while at seed moisture contents of 12.5 - 13.0% *A. glaucus* is found. As the seed moisture content increases a succession of other spp. of *Aspergillus and Penicellium* occurs at seed moisture contents of 16.0 - 18.5% (Christensen and Kaufmann 1974).

In general, levels of invasion by storage fungi and reduction in seed germination are increased by an increase in the storage temperature as well as by the length of the storage period. Consequently, it is possible to reduce the amount of fungal invasion and maintain high germination by lowering the storage temperature, decreasing moisture content of the seed, or by shortening the storage period (Field and King 1962; Christensen and Kaufmann 1974).

B. GERMINATION AND SEEDLING EVALUATION

According to the ISTA Rules (1976) germination in a laboratory test is defined as the emergence and development of those essential structures which indicate the ability to grow into a normal plant in favourable field conditions. A seedling which displays these essential structures is said to be normal. Usually, the normal seedlings are removed at the interim counts, but the categorisation of any of the doubtful or abnormal seedlings is not made until the final count.

The normal seedling comprises essential structures as follows:

1. A well-developed root system
2. A well-developed and intact hypocotyl or epicotyl and a normal plumule, or in cereals and grasses a well developed first leaf.
3. Intact coleoptile in monocotyledonous plants and intact cotyledons in seedlings of dicotyledonous plants.

Causes and types of abnormal seedlings

Abnormal seedlings are of three general types - damaged, deformed and decayed (Thomson 1979). Examples of damage are rootless seedlings in cereals and pulses and fractured hypocotyls in clovers. Most injuries are caused by rough treatment in threshing and subsequent cleaning but they can also be caused by rodents and insects in store. Seed that has been infected with insects may produce seedlings which lack essential structures, or are stunted or weakened. The most intensive injuries reduce seed viability immediately and may result in only vestiges of seedling development. Such seedlings commonly exhibit 'completely shattered' characteristics as a result of mechanical damage (Anon 1952).

Deformed seedlings have parts that are missing, misshapen or which show unbalanced development. Examples in cereals are short thickened leaf sheaths and roots, torn leaves and inverted embryos. Such abnormalities may be due to defects in the development of the embryo on the mother plant. This is often due to environmental factors such as bad weather after pollination or mineral deficiency.

Boron deficiency has been reported in peas to cause injury to the plumule which may be stunted, multiple branch or undeveloped (Justice 1972).

More commonly, the causes of seedling deformities affect the embryo after harvest. High temperatures during drying can produce deformed seedlings in barley which show stunted and poorly developed seminal roots or delayed development or absence of plumules.

Nutile (1964) studied the effect of dessication on the viability of vegetable and grass seeds and reported that much of the injury was revealed as abnormal sprouts with stubby roots and shoots.

Defects may also follow from storage under unsuitable conditions, such as high temperature or high humidity. Typical symptons which have been described for deteriorated seeds include stunted plumules or failure of the first leaf to develop within the coleoptile in Gramineae (Griffiths and Pegler 1962; Mackay and Flood 1969). In Leguminoseae and Cruciferae the breakdown of hypocotyl tissue results in a glassy or watery appearance and restricted root and shoot development (Mackay and Flood 1969, 1970).

Decayed seedlings arise from seeds that have been infested by fungi or bacteria. An intact embryo is immune to saprophytic organisms, but these may gain entry if injury causes the death of any part of the embryo. A seedling is regarded as decayed only if it is clear that the decaying organisms have come from the seed itself and have not spread from another seed or seedling during the test (Thomson 1970).

3.3 MATERIALS AND METHODS

The soybean seeds previously subjected to different drying methods as described in Chapter 2, were used in the threshing and storage experiment.

EXPERIMENTAL DESIGN

The experiment was a factorial design consisting of 6 drying methods x 2 threshing methods x 2 storage conditions x 3 replicates.

THRESHING METHOD

Each lot of dry pods obtained from each drying method was divided using the modified halving method (ISTA Rules, 1976). One half was threshed by hand, the other by beating.

Hand Threshing

About 50% of the pods had dehisced during the drying period, the rest of the pods being removed by hand. The seeds were cleaned using a 'Clipper' air screen cleaner to remove foreign matter and debris.

Beating

The dried pods were put in a cloth bag and beaten with a wooden stick. This is a traditional threshing method used by farmers in Thailand. The seeds were cleaned using the same procedure as mentioned above.

After threshing, seeds were stored at $5^{o}C$ in closed containers to avoid moisture changes.

STORAGE CONDITIONS

The storage effects on seed moisture and viability were tested under two differnt environmental combinations of temperature and relative

humidity. The high temperature and high relative humidity (35°C - 90%RH) environment was chosen to represent a typical climate in the tropics. This was compared with a safe storage environment (20°C - 40%RH).

Thirty-five grams of seed from each treatment were taken randomly and packed in muslin cloth bags. A total of 432 packages was prepared and stored in controlled relative humidity glass jars.

The required level of relative humidity were obtained using water-glycerine mixtures for a total volume of 100 ml. at 28°C as used previously by Hill (1965).

The proportions of water and glycerine used in this experiment were as follows:

Relative humidity (%)	Glycerine (ml.)	Water (ml.)
40	81	19
90	30	70

Six soybean packages of 35g each were placed inside each jar supported by a wire mesh to prevent them from coming into contact with the water glycerine mixture. Jars were sealed with airtight screw caps.

The experiment was designed with 3 replicates, each replicate comprising 144 seed packages in 24 jars.

SAMPLING TIME

An initial sample was tested for moisture and germination before storage. During the storage period, sampling was carried out after 2, 4, 6, 8, 12 and 16 weeks. At each sampling seed moisture content and percent germination were determined.

SEED MOISTURE CONTENT DETERMINATION

According to the ISTA Rules (1976) the low constant temperature oven method is recommended for use when the seed moisture content of

soybeans is less then 10%. Approximately 5g duplicate seed samples were ground and dried in an air oven maintained at a temperature of 103 $\pm$ 2°C for 17 $\pm$ 1 hours. The seed weight loss was determined following drying and cooling and was used to calculate moisture percentage on a wet weight basis. When the seed moisture exceeded 10%, the two stage drying method is obligatory (ISTA Rules, 1976). The procedure is described as follows:

The sample of about 6 - 7g was initially dried at 130°C for 5 - 10 minutes, removed from the oven, exposed to air at room temperature for 2 hours and the loss of weight determined. The partially dried sample was then ground and dried in the low constant temperature oven as mention above.

The percentage of moisture content was determined on a wet weight basis using the following formula:

$$M.C. = S_1 + S_2 - \frac{(S_1 \times S_2)}{100}$$

where S_1 = % moisture lost in the first stage
S_2 = % moisture lost in the second stage
M.C. = final percent moisture content

GERMINATION TEST

According to the ISTA Rules (1976), the object of the germination test is to gain information with respect to the field planting value of the seed. In this experiment, the germinations were conducted in the laboratory in which the external conditions were controlled to give the most regular, rapid and complete germination of the seeds.

Determination was assessed from 3 replicates of 100 seeds using the rolled paper method. Samples were placed in wire baskets, covered with a polythene bag and germinated at 25°C. The seedling evaluation and percentage germination assessments were made as

prescribed in the ISTA Rules (1976) with the preliminary and final count on the 5th day and 8th day respectively.

TETRAZOLIUM TEST

Tetrazolium tests were conducted to assess seed viability and deterioration after 6 weeks storage. Fifty seeds from each treatment were preconditioned overnight in moist rolled towelling. The fully imbibed seeds were placed in plastic containers covered with 2, 3, 5, -triphenyl tetrazolium chloride solution (0.5%). Adequate staining was accomplished by adding sufficient staining solution to ensure coverage of all seeds which were kept in an oven maintained at 35^{o}C for 16 hours. When staining of the seed had been completed the tetrazolium solution was poured off and the seed rinsed and then held in tap water at a temperature of 5^{o}C until evaluation. To evaluate the staining pattern the seed coat was removed and seed was bisected between the cotyledons through the radicle-hypocotyl axis. The cut halves were examined with a hand lens for the presence of sound, weak and dead tissues. Strong, healthy tissues developed a normal red stain. Aged tissues revealed a pale or mottled stain. Dead tissues remained white. Seeds were classified as viable or non-viable according to their staining pattern as described in the Tetrazolium Testing Handbook prepared by the Association of Official Seed Analysts.

TEST FOR STORAGE FUNGI

Tests were made to detect storage fungi under different storage conditions. The tests were made after 8 and 12 weeks storage.

Soybean seeds were surface sterilised by soaking them in a 1% solution of mercuric chloride for 2 minutes. The seeds were then washed in running water for 2 minutes before placing them on Malt Salt Agar. The MSA plates were incubated at 35^{o}C to favour the growth of storage fungi. Pure cultures of all storage fungi present in the tested sample were obtained for identification.

3. 4 RESULTS

The effects of drying method, threshing treatment and storage condition on changes in the moisture content and viability of soybean seeds stored from 0 to 16 weeks will be presented.

3.4.1 Effect of Storage Conditions on Moisture Content

The initial moisture content of seed prior to storage is shown in Table 3.1. Changes in the moisture content of seeds stored at $20^{o}C$ - 40%RH and $35^{o}C$ - 90%RH for 16 weeks are shown in Figures 3.1 - 3.6, with statistical analysis in Table 3.2.

Irrespective of drying or threshing method, there were highly significant differences between the moisture content of seeds stored at $20^{o}C$ - 40%RH and at $35^{o}C$ - 90%RH. Under high relative humidity conditions seeds gained moisture until they reached equilibrium with the surrounding air. At $35^{o}C$ - 90%RH, seed moisture content rapidly increased to 14.8 - 16.2% after 2 weeks storage; to 14.8 - 17.9% after 4 weeks storage and to 16.4 - 18.6% after 6 weeks storage (Figures 3.1 - 3.6). Tests for moisture content were abandoned after 6 weeks storage since all seeds stored under $35^{o}C$ - 90%RH conditions were dead. The moisture content of seeds stored under $20^{o}C$ - 40%RH conditions was only slightly changed ($\pm$0.6%) by adsorption or desorption of water during the full 16 weeks storage period.

Table 3.1 Initial moisture content of seed prior to storage

Drying method	20°C - 40%RH		35°C - 90%RH	
	Hand Threshing	Beating Threshing	Hand Threshing	Beating Threshing
Dehumidification	8.1	8.1	8.0	8.2
Refrigeration	7.9	7.9	8.0	8.0
Ambient air	8.1	8.1	8.0	8.0
Heated air - 30°C	7.9	7.9	7.9	7.9
Heated air - 40°C	8.0	8.0	8.0	7.9
Heated air - 50°C	7.9	7.9	8.1	8.1

Table 3.2 Effect of storage conditions on seed moisture during 16 weeks storage (average over 6 drying methods and 2 threshing methods)

Storage period (weeks)	Moisture content (%)	
	20°C - 40%RH	35°C - 90%RH
2	7.9[a]	15.5[b]
4	7.8[a]	16.4[b]
6	7.6[a]	17.3[b]
8	7.7[a]	----
12	7.8[a]	----
16	7.6[a]	----

Values with a different letter are significantly different at the 1% level.

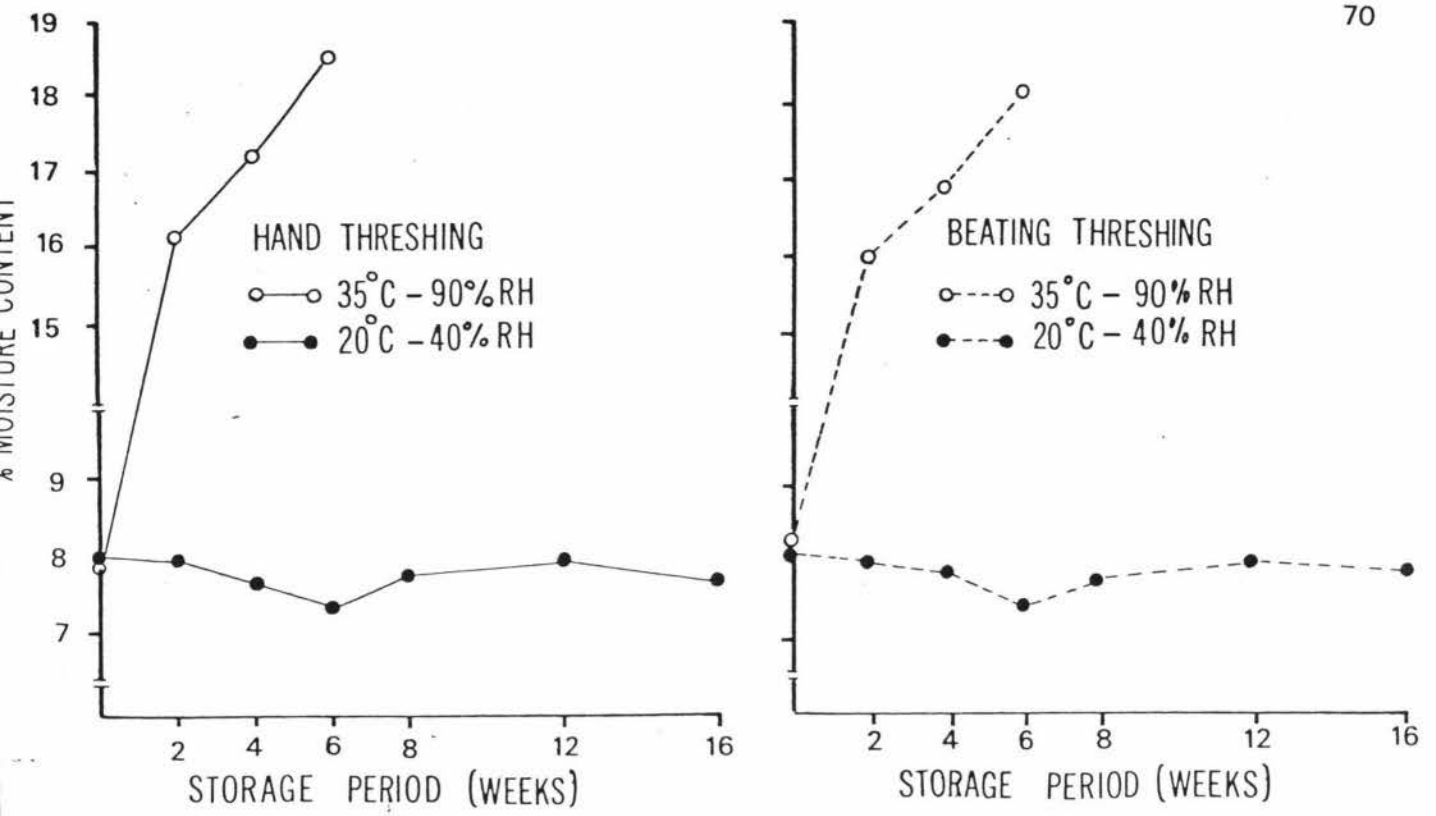


Figure 3.1 Changes in the seed moisture content of seeds previously dried by the dehumidification system and stored at 20°C - 40%RH or 35°C - 90%RH

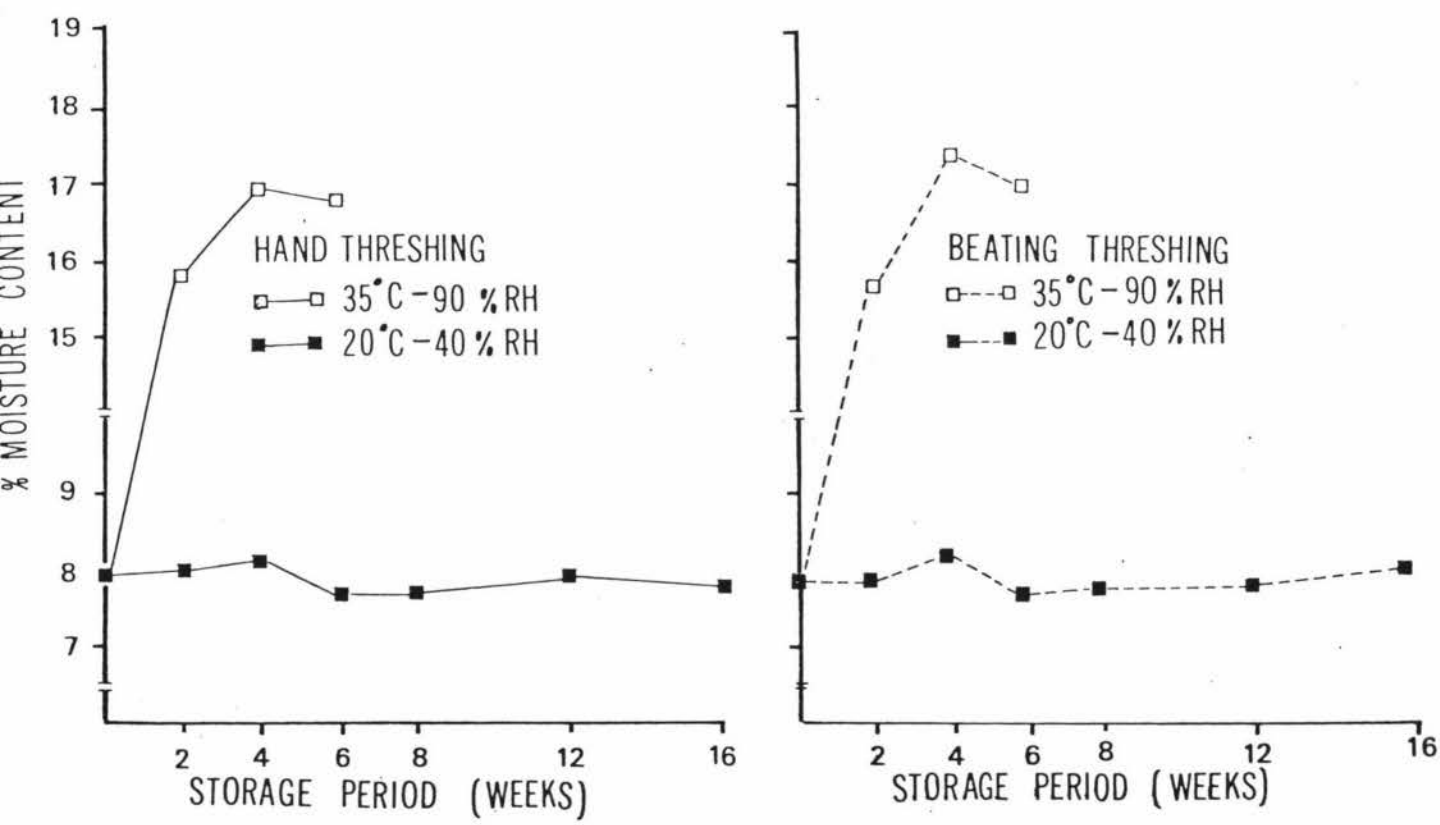


Figure 3.2 Changes in the seed moisture content of seeds previously dried by the refrigeration system and stored at 20°C - 40%RH or 35°C - 90%RH

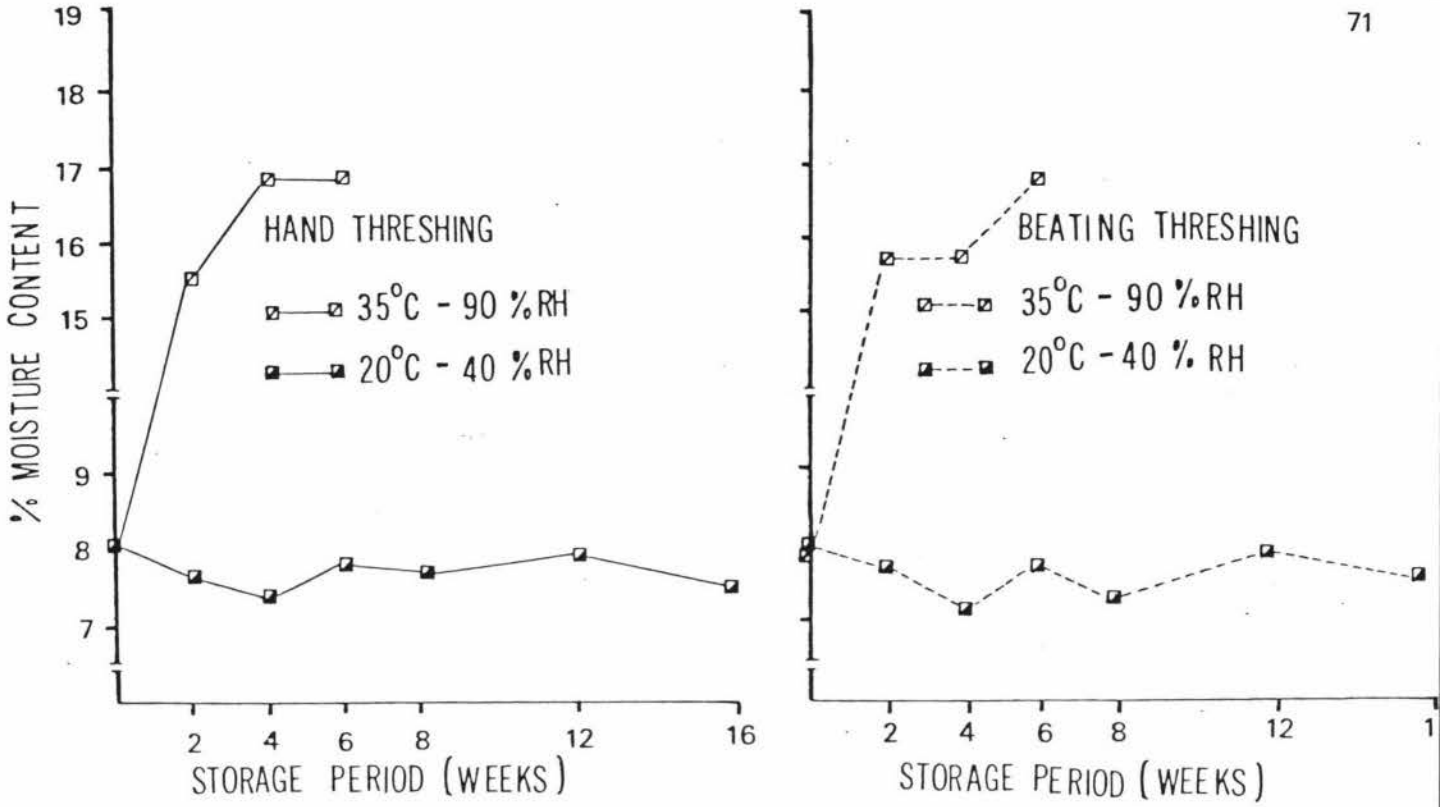


Figure 3.3 Changes in the seed moisture content of seeds previously dried by the ambient air system and stored at 20°C - 40%RH or 35°C - 90%RH

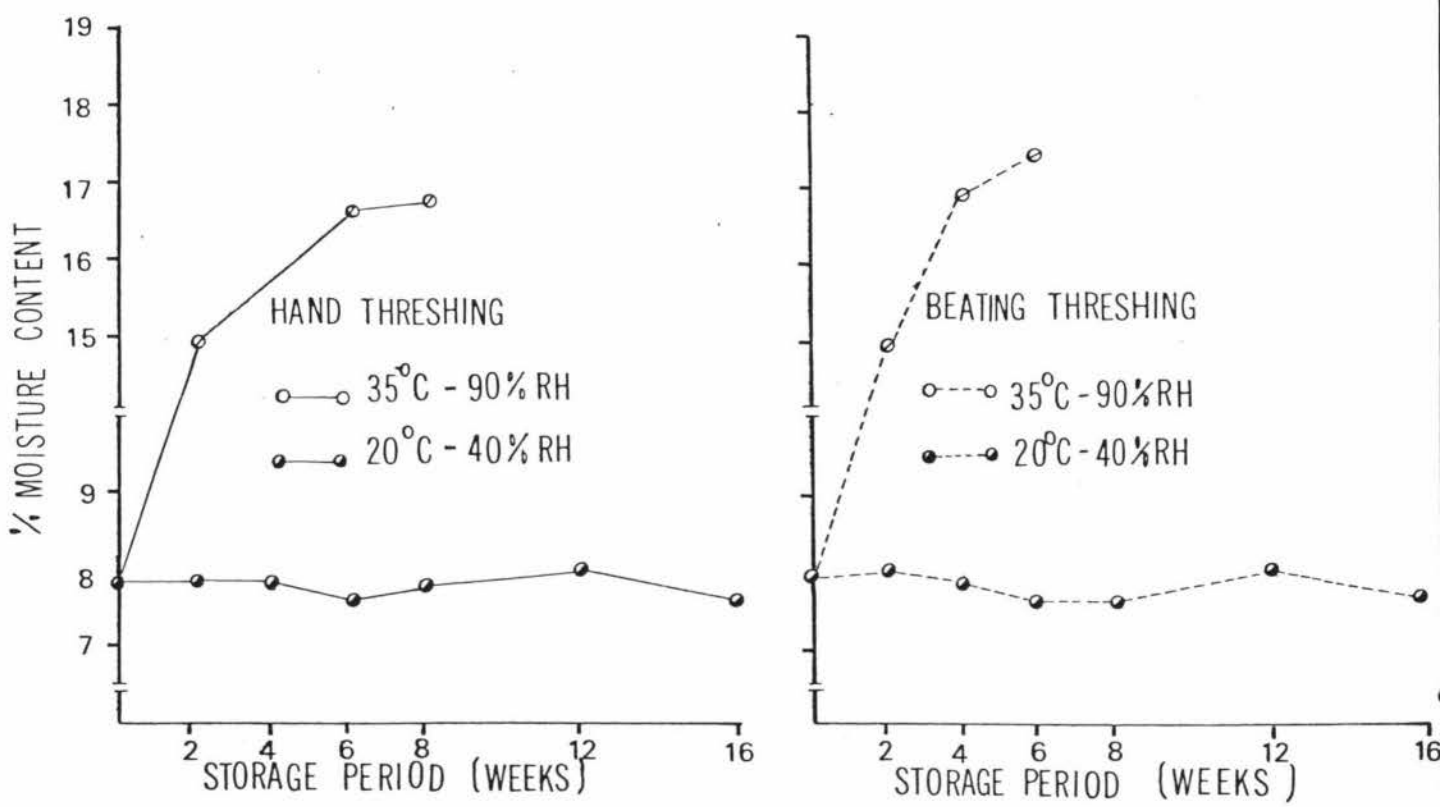


Figure 3.4 Changes in the seed moisture content of seeds previously dried by the 30°C heated air system and stored at 20°C - 40%RH or 35°C - 90%RH

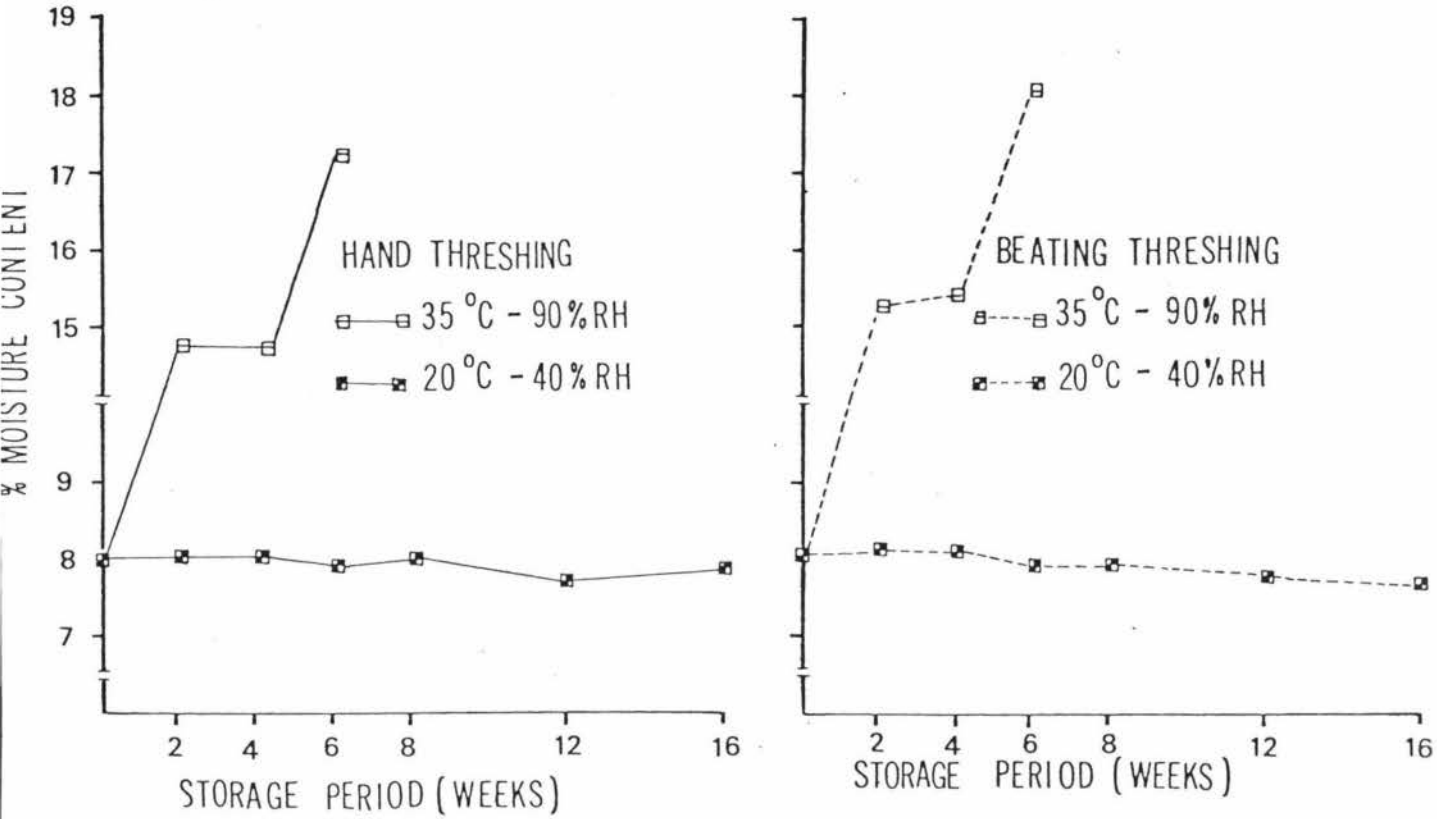


Figure 3.5 Changes in the seed moisture content of seeds previously dried by the 40°C heated air system and stored at 20°C - 40%RH or 35°C - 90%RH

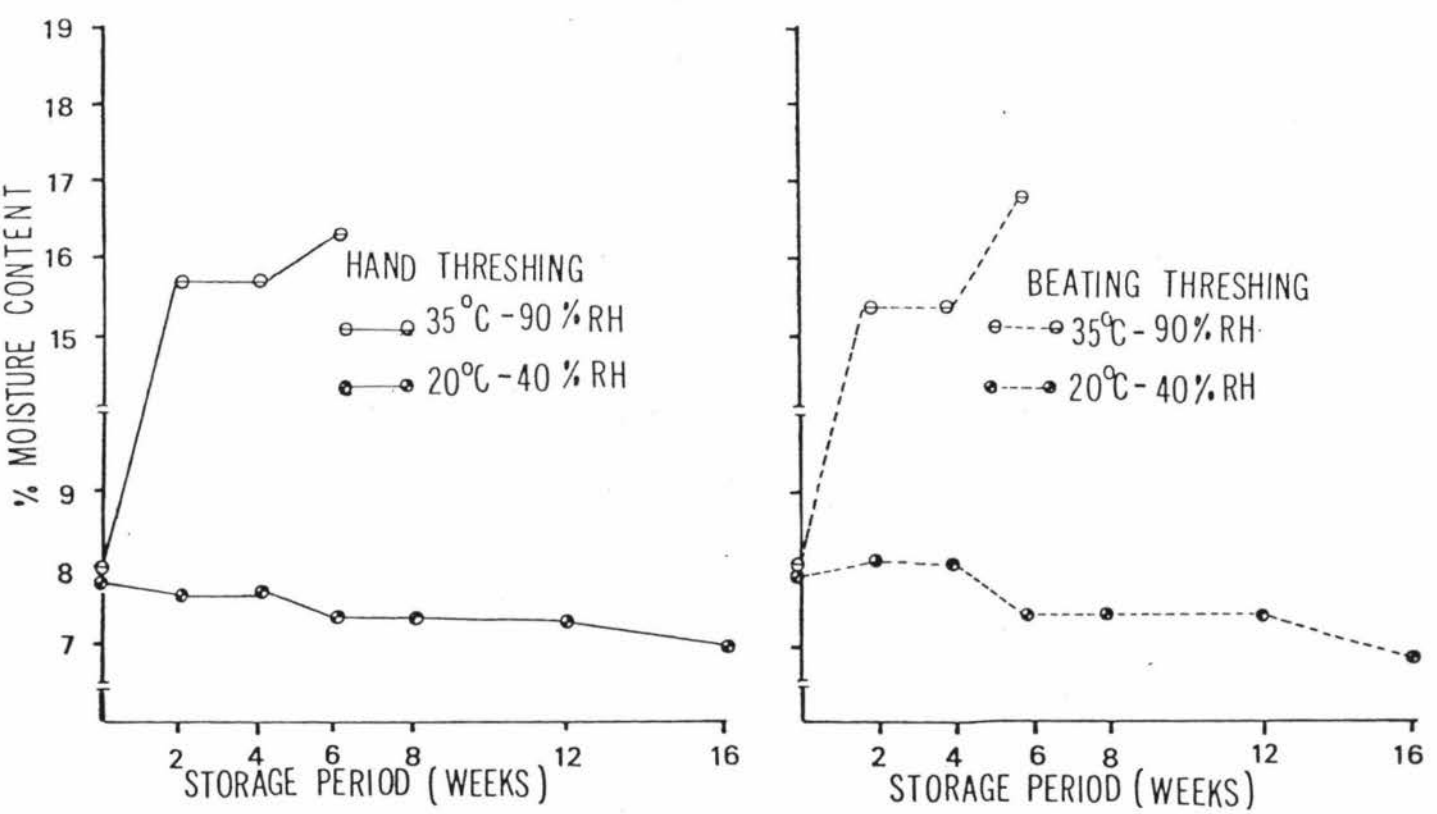


Figure 3.6 Changes in the seed moisture content of seeds previously dried by the 50°C heated air system and stored at 20°C - 40%RH or 35°C - 90%RH

GERMINATION

Experimental data on the viability of soybean seeds from different drying and threshing treatments which were stored at $20^{o}C$ - 40%RH or $35^{o}C$ - 90%RH are presented in Appendices 3.1 - 3.4.

3.4.2 Effect of Threshing on Normal Germination

Under $20^{o}C$ - 40%RH storage conditions at each sampling, the hand threshed seeds had a significantly higher germination when compared to beaten seeds, although the results were non significant at 12 weeks storage (Table 3.3). The germinability of hand-threshed seeds was also significantly higher than that of beating-threshed seeds when seeds were stored under $35^{o}C$ - 90%RH conditions after 2 weeks. Although seed from both sources was dead after 4 weeks storage, these results showed that threshing method influenced seed viability and that adverse effect of the beating threshing method occurred irrespective of storage conditions. Beating damage to seeds was revealed in tetrazolium tests where the staining pattern clearly showed damage due to fractures and/or bruising. Tetrazolium staining intensity in sound tissues tended to develop a lighter colour (Plate 3.1) than tissues that were bruised, aged or deteriorated (Plate 3.2). Although deterioration occurred in both hand threshed seeds and beating threshed seeds, a comparison of tetrazolium test staining patterns, clearly showed that beating-threshed seeds (Plate 3.3) had deteriorated further than hand-threshed seed (Plate 3.4). There were also more fractured or bruised seeds in beating-threshed seed samples. These seeds upon deterioration developed large areas of necrotic tissue(Plate 3.2).

Table 3.3 Mean percentage of normal germination (mean of 6 drying methods) as affected by threshing method and storage at 20°C - 40%RH

	WEEKS AFTER STORAGE					
	2	4	6	8	12	16
Hand threshing	74[a]	75[a]	74[a]	74[a]	74[a]	69[a]
Beating threshing	70[b]	68[b]	68[b]	70[b]	71[a]	63[b]

Means comparison with columns with different letters are significantly different at the 5% level

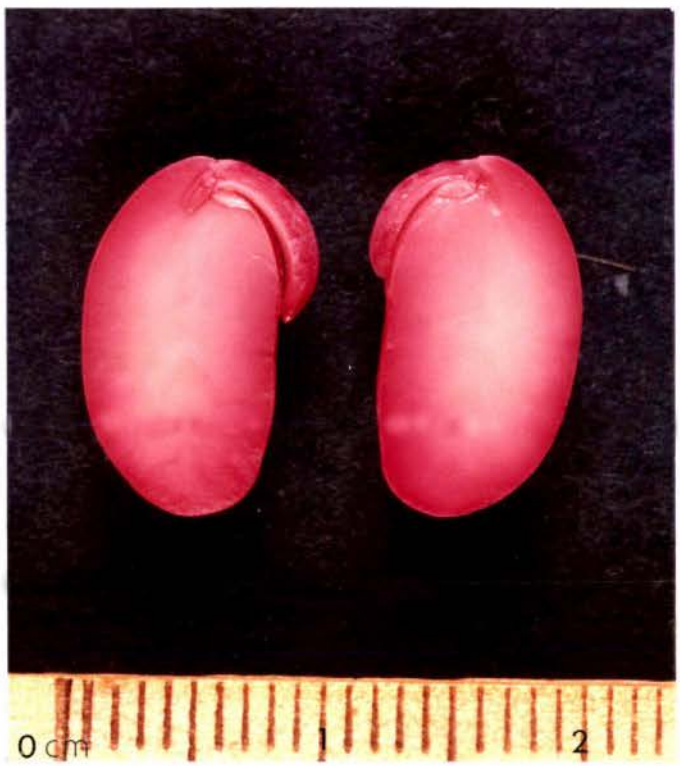
Table 3.4 Mean percentage of normal germination (mean of 6 drying methods) affected by threshing method and storage at 35°C - 90%RH

	WEEKS AFTER STORAGE					
	2	4	6	8	12	16
Hand threshing	70[a]	4	0	0	0	0
Beating threshing	65[b]	1	0	0	0	0

Means comparision with columns with different letters are significantly different at the 5% level

Plate 3.1 Tetrazolium staining pattern on sound seed.

Plate 3.2 Tetrazolium staining pattern on deteriorated seed.


0 cm
1
2

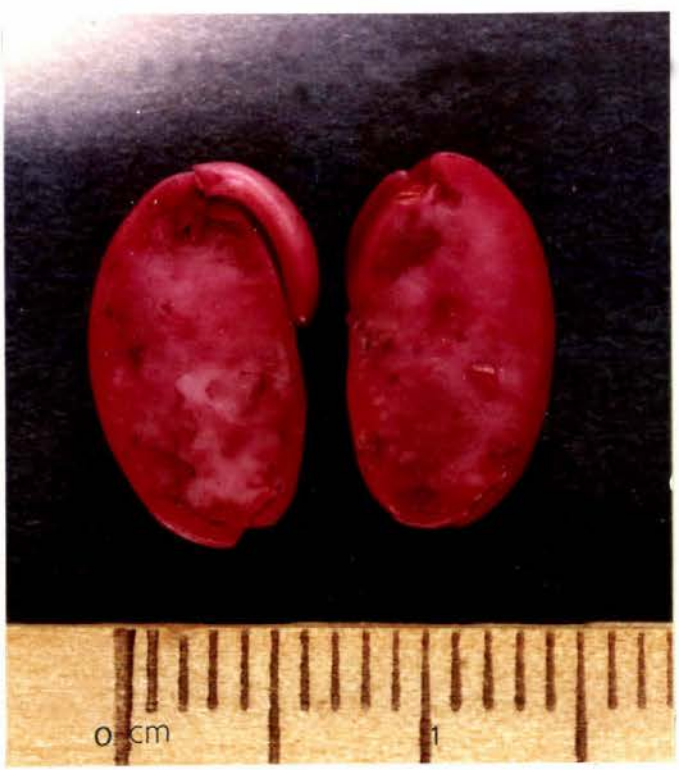
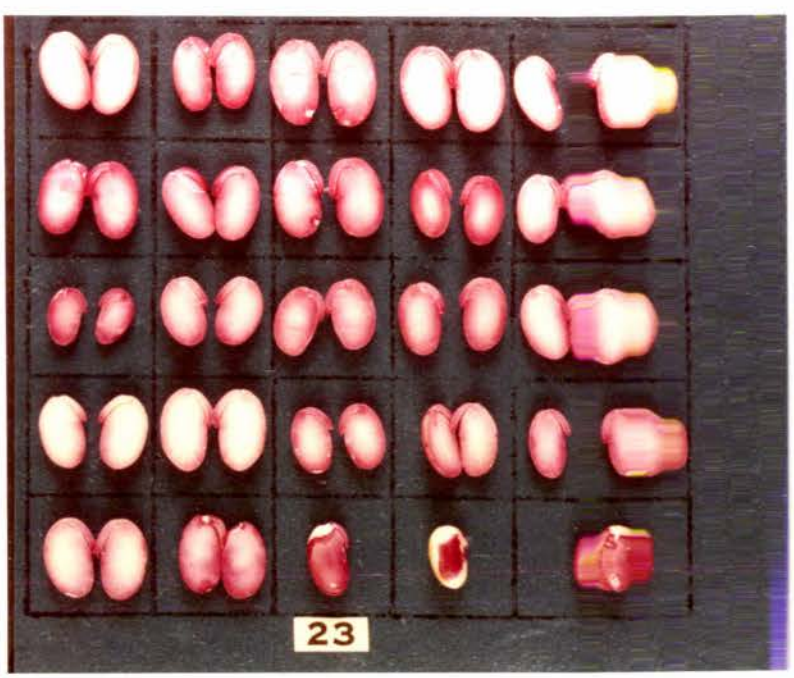

0 cm
1

Plate 3.3 Tetrazolium staining patterns on beaten-threshed seeds.

Plate 3.4 Tetrazolium staining patterns of hand-threshed seeds.


26


23

3.4.3 Effect of Drying on Germinability of Soybean Seeds Stored at 20°C - 40%RH

The germination percentages of seed following drying and before storage (Chapter 2 and Table 2.1) showed that there were no significant differences in the germinability of seeds dried by different drying methods.

The effect of previous drying treatments on seed viability when seeds had been stored under 20°C - 40%RH conditions for 16 weeks, and the analysis of variance are shown in Tables 3.5 and 3.6. The results in Table 3.5 show that hand threshed seeds when stored under 20°C - 40%RH generally showed that there was no difference between the germination percentages of seeds by different drying methods. The only significant difference in seed germination occurred at 4, 6 and 8 weeks in seeds dried by the refrigeration method. However, this effect was not consistent throughout the entire storage period, variability being due to the low initial seed quality of seeds obtained from this drying treatment.

The beating threshed seeds showed similar results to hand threshed seeds when stored under identical conditions (Table 3.6).

3.4.4 Effect of Drying on Germinability of Soybean Seeds Stored at 35°C - 90%RH

Seeds which had been dried using different drying methods when stored under 35°C - 90%RH conditions showed a vastly different storage performance compared to seeds stored under 20°C - 40%RH conditions. In seed dried using heated air drying temperatures of 40°C and 50°C seriously reduced seed storability in both hand-threshed and beaten seeds (Table 3.7 and Table 3.8). Drying seeds with heated air at 30°C and by the use of dehumidification resulted in the best subsequent storage performance. However, the drying effects of ambient and refrigerated air drying systems on storability of hand-threshed was poor. This situation followed a similar trend in beaten-threshed seeds although seeds from the refrigeration drying treatment was superior to that

obtained using the same drying method and hand threshing. In both hand threshed and beating threshed seed samples there was evidence that seed longevity was increased to more than 4 weeks in the case of seed samples which had been dried using heated air methods involving air temperatures of 30°C or 40°C. This effect was not evident in seed dried with heated air at 50°C, or in ambient air, refrigeration or dehumidification drying treatments. Seeds in these latter categories were all dead at 4 weeks storage.

These results emphasise the importance of storage conditions as a main factor affecting viability. In addition they show the superiority of storage environments involving lower temperature and RH combination compared with seed performance under storage conditions which are warm and humid.

Table 3.5 Percentage of normal germination of soybean seeds dried by 6 drying methods, hand threshed and stored at 20°C - 40%RH.

DRYING METHOD	% GERMINATION (MEAN)					
	2	4	6	8	12	16(wks)
Dehumidification	74[a]	78[a]	81[a]	75[a]	73[a]	69[a]
Refrigeration	69[a]	66[b]	69[b]	62[b]	69[a]	66[a]
Ambient air	73[a]	74[a]	78[a]	77[a]	77[a]	69[a]
Heated air 30°C	77[a]	77[a]	79[a]	79[a]	79[a]	71[a]
Heated air 40°C	74[a]	78[a]	74[a]	76[a]	75[a]	68[a]
Heated air 50°C	76[a]	77[a]	69[b]	78[a]	71[a]	72[a]

Values with the same letter do not differ at 5% level within column

Table 3.6 Percentage of normal germination of soybean seeds dried by 6 drying methods, beaten threshed and stored at 20°C - 40%RH.

DRYING METHOD	% GERMINATION (MEAN)					
	2	4	6	8	12	16(wks)
Dehumidification	72[a]	68[a]	70[a]	77[a]	71[a]	69[a]
Refrigeration	66[a]	66[a]	65[a]	67[a]	63[b]	60[a]
Ambient air	65[a]	73[a]	69[a]	73[a]	75[a]	68[a]
Heated air 30°C	77[a]	74[a]	75[a]	73[a]	74[a]	66[a]
Heated air 40°C	77[a]	63[a]	66[a]	67[a]	73[a]	59[a]
Heated air 50°C	66[a]	68[a]	65[a]	67[a]	70[a]	61[a]

Values within column with the same letter do not differ at 5% level

Table 3.7 Percentage of normal germination of soybean seeds dried by 6 drying methods, hand threshed and stored at 35°C - 90%RH

DRYING METHODS	% GERMINATION (MEAN)					
	2	4	6	8	12	16(wks)
Dehumidification	77[a]	-	-	-	-	-
Refrigeration	64[b]	-	-	-	-	-
Ambient air	62[b]	-	-	-	-	-
Heated air 30°C	86[a]	7	-	-	-	-
Heated air 40°C	66[b]	19	-	-	-	-
Heated air 50°C	63[b]	-	-	-	-	-

Values within column with the same letter do not differ at 5% level

Table 3.8 Percentage of normal germination of soybean seeds dried by 6 drying methods, beaten-threshed and stored at 35°C - 90%RH

DRYING METHOD	% GERMINATION (MEAN)					
	2	4	6	8	12	16(wks)
Dehumidification	65[b]	-	-	-	-	-
Refrigeration	68[a]	-	-	-	-	-
Ambient air	57[b]	-	-	-	-	-
Heated air 30°C	79[a]	3	-	-	-	-
Heated air 40°C	64[b]	4	-	-	-	-
Heated air 50°C	57[b]	-	-	-	-	-

Values within column with the same letter do not differ at 5% level

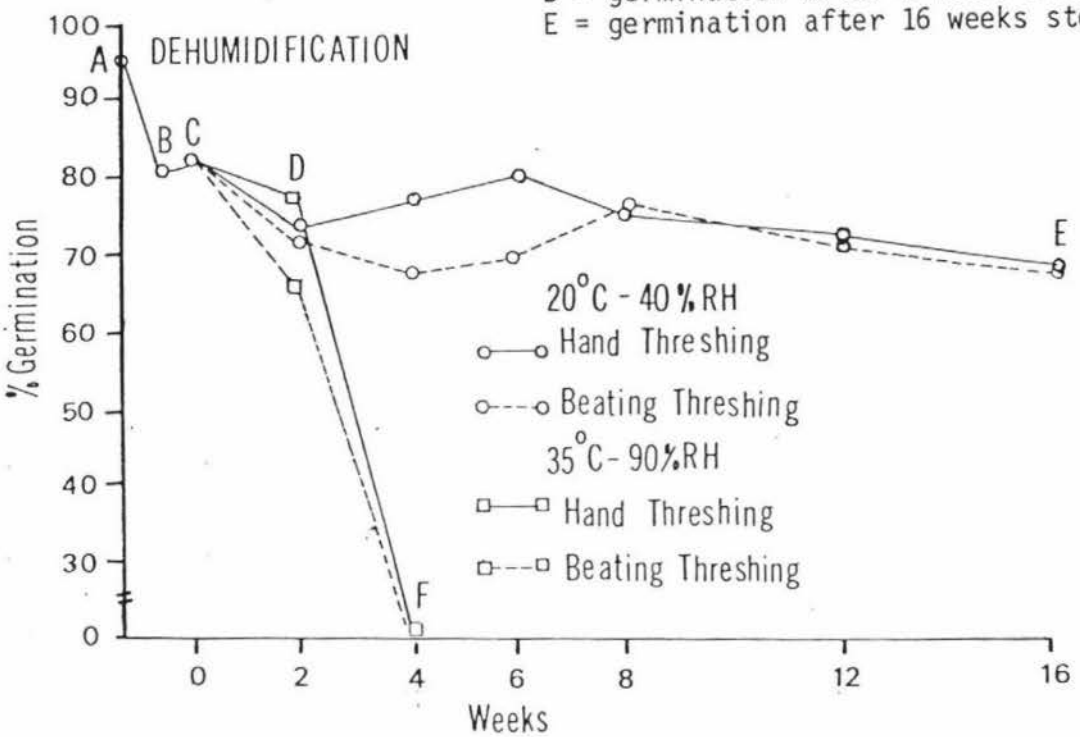
3.4.5 Changes in Seed Germinability after Harvest, Drying and Storage

Changes in the germination percentage of seed after harvest and during different drying processes is previously discussed in Chapter 2. The subsequent germination performance of seeds during storage for up to 16 weeks is summarised in Figure 3.7

The results show that during the drying process and during storage under 20°C - 40%RH conditions there was no serious decline in seed germination even though seed germinability had been shown to decline to various extents immediately after harvest. This latter effect was due to high moisture levels in seed at the time of harvest to time between harvest and the commencement of drying. This delay resulted in the development of storage fungi, particularly in seedlots which were later used in the refrigeration and 50°C heated air drying systems. Although there was some reduction in the germinability of seeds stored under 20°C - 40%RH conditions after 16 weeks storage this storage environment was vastly superior to 35°C - 90%RH conditions. In the latter environment all seed was dead after 6 weeks storage. Beating-threshing was shown to result in more seed damage and in faster seed deterioration in storage than hand-threshing.

Figure 3.7 Changes in seed germination of soybean seeds after harvest, during drying and storage at 20°C - 40%RH and 35°C - 90%RH for up to 16 weeks

A = germination at harvest
B = germination at commencement of drying
C = germination at conclusion of drying
D = germination after 2 weeks storage
E = germination after 16 weeks storage



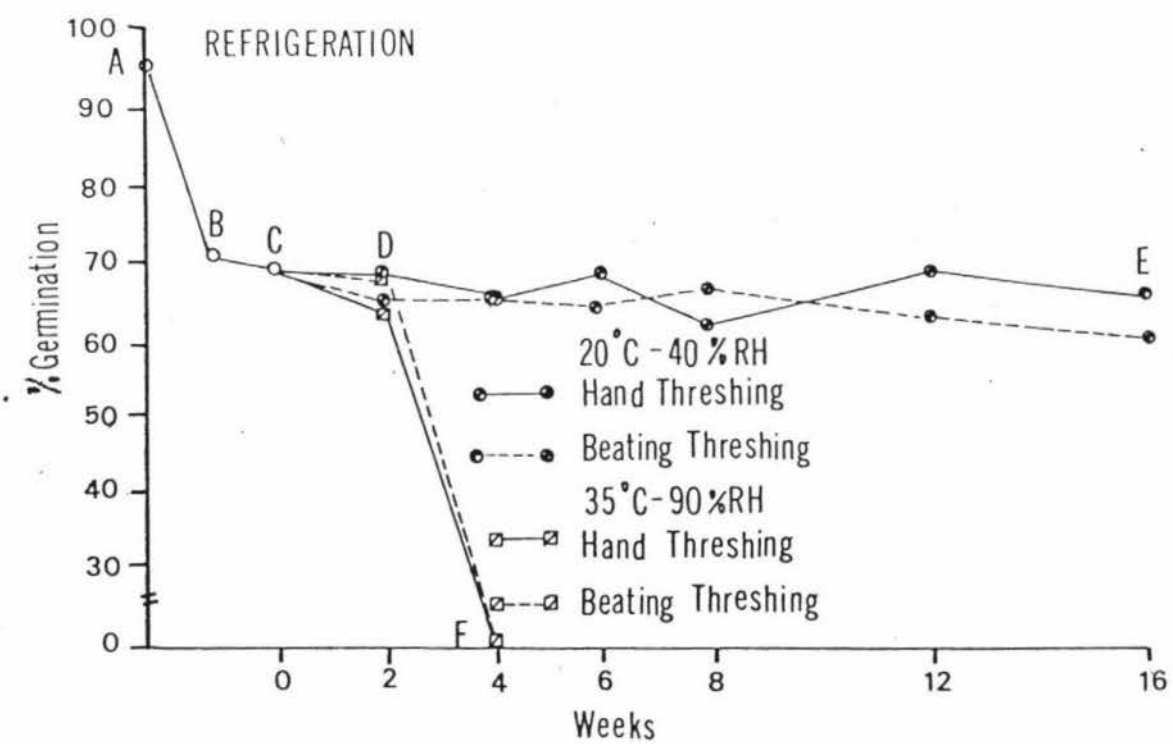


Figure 3.7 continued

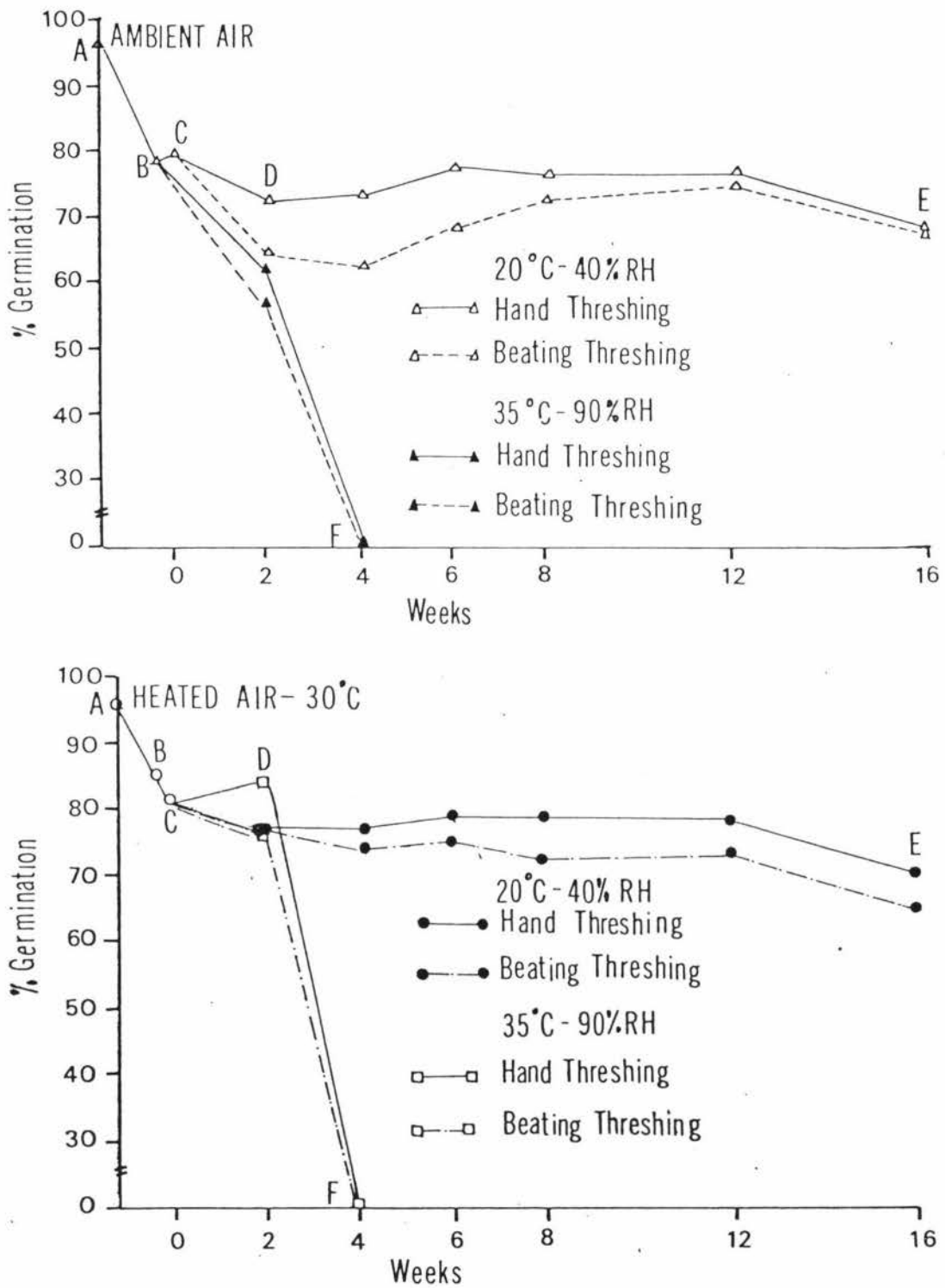
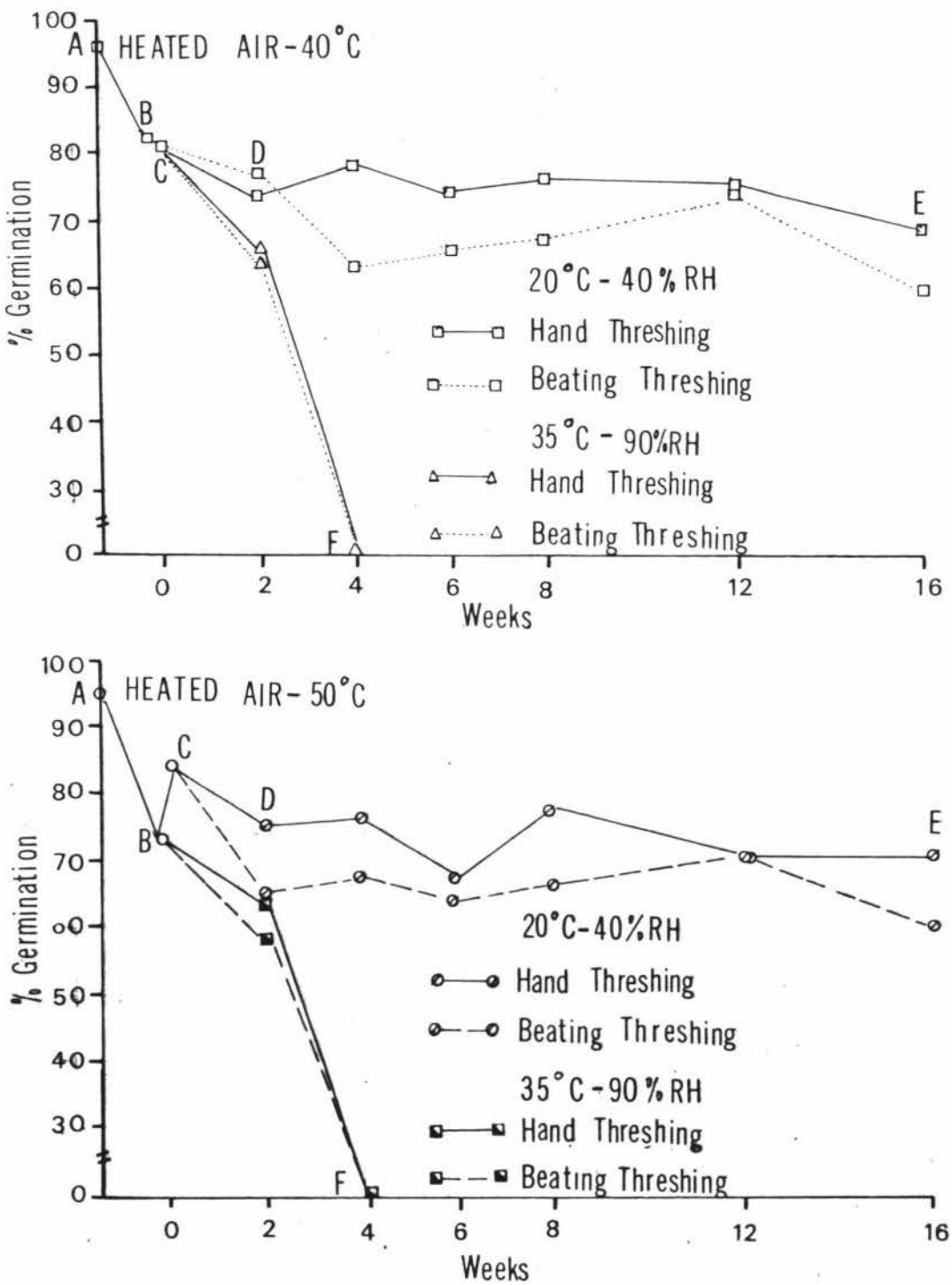


Figure 3.7 continued



3.4.6 Storage Fungi

Although only a relatively small number of seeds were used in tests for storage fungi, the results show the importance of storage environment in influencing the extent of fungal development and the types of fungi present. A number of different colonies were detected from seeds stored under 35°C - 90%RH storage conditions. These were identified as *Aspergillus glaucus, A. flavus, A. orchraceus, A. niger and Penicillium spp*. Despite the widespread occurrence of these species in the 35°C - 90%RH storage treatment after only 4 weeks none of these species were found in seeds which had been stored at 20°C - 40%RH. In this latter case only colonies of field fungi such as *Helminthosporium, Alternaria and Stemphylium spp.* were detected.

3.4.7 Abnormal Seedlings

The recording of abnormal seedling percentages and categories is important since it needs to be considered in conjunction with changes in dead seed and normal seedling percentages to obtain a clear understanding of gross treatment effects. The categories of abnormal seedlings are illustrated in Plates 3.5 - 3.10. The main types of abnormal seedlings in all treatments were those exhibiting weak, unbalanced growth and completely shattered seedlings (Plate 3.8 and 3.9). The rate of occurrence of these two main categories of abnormal seedlings was found to be significantly higher than other types of abnormal seedlings (Appendix 3.5). The unbalanced growth category was found in all treatments irrespective of storage condition or threshing method. However, completely shattered seedlings were found as a more pronounced feature in seed samples which had been beating threshed(Figure 3.8). The percentage of abnormal seedlings in beating-threshed seedlots was significantly higher than in hand-threshed seed (Table 3.9 and 3.10).

Plate 3.5 Abnormal seedling - hypocotyl short and thick or twisted or curled over.

Plate 3.6 Abnormal seedlings - more than half the total cotyledonary area broken off.

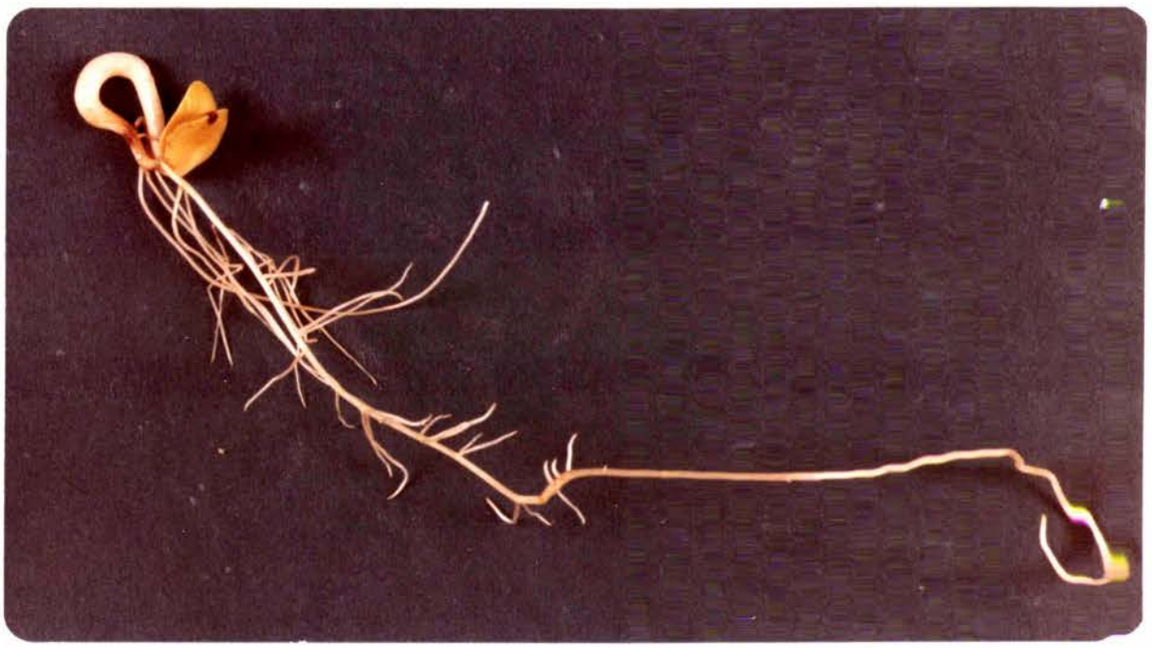
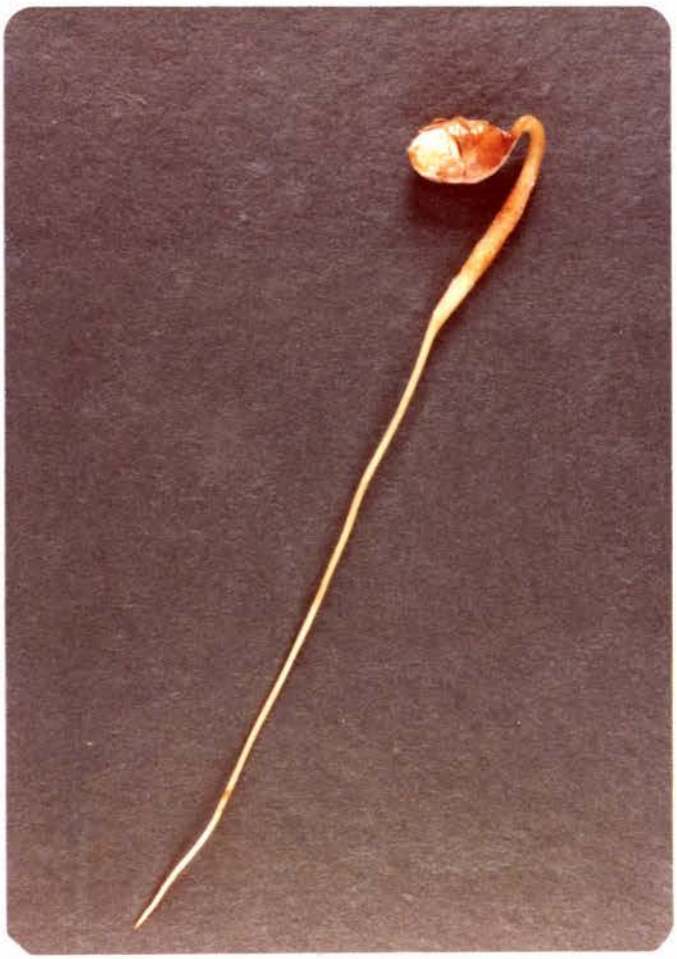


Plate 3.7 Abnormal seedling - decayed.

Plate 3.8 Abnormal seedlings showing weak, unbalanced growth.



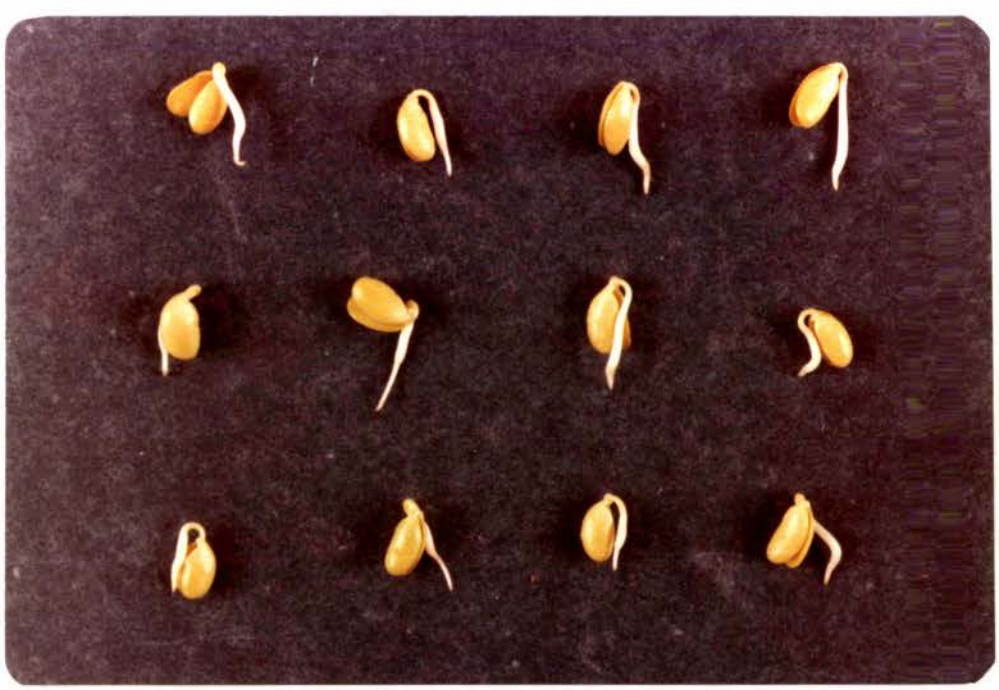


Plate 3.9 Abnormal seedlings - completely shattered.

Plate 3.10 Abnormal seedlings showing damage with evidence of damage to the shoop apex.

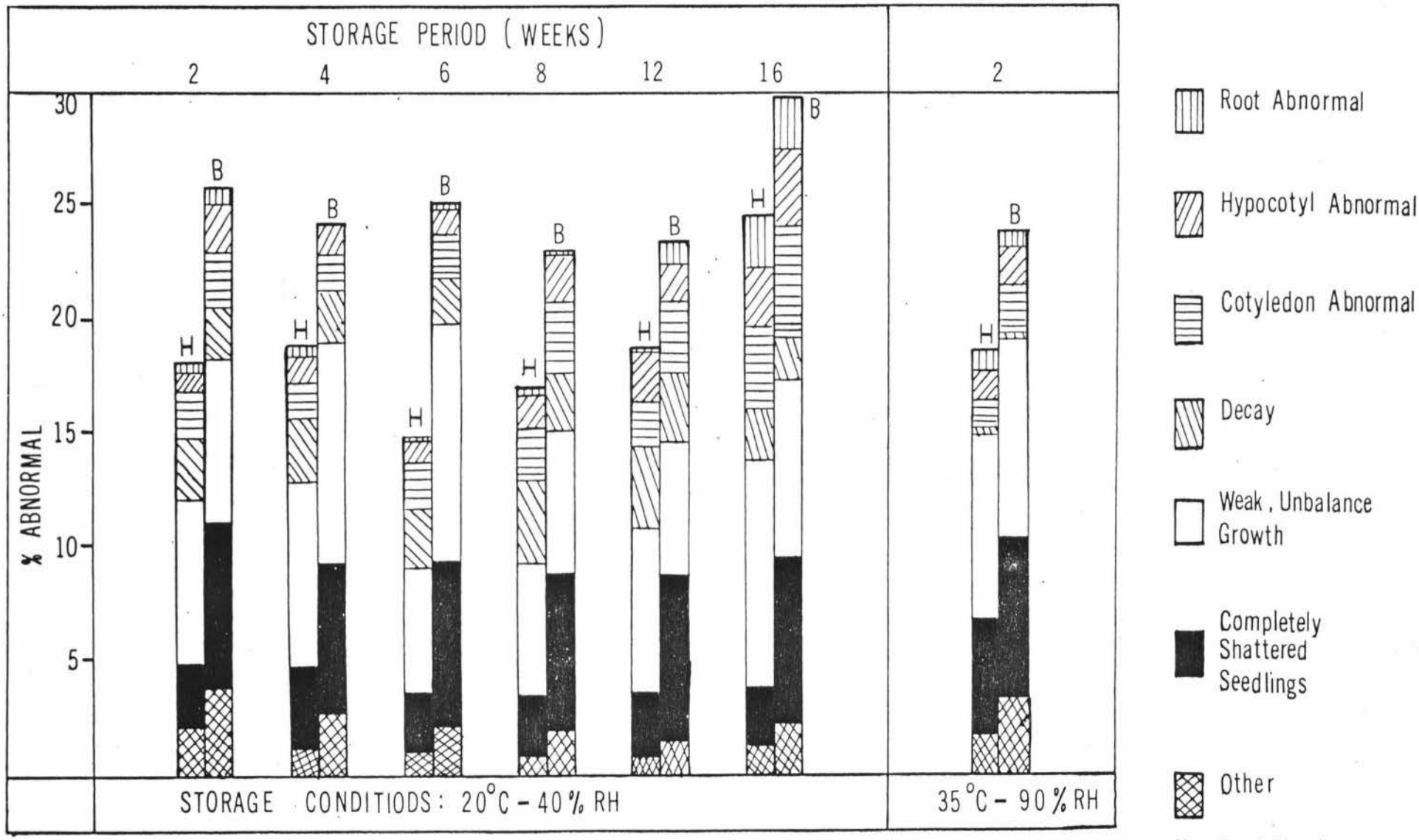


Figure 3.8 Effect of threshing method on the type of abnormality in soybean seed during 16 weeks storage (average over 6 drying treatments)

Table 3.9 Effect of threshing method on the percentage of abnormal seedlings produced by seeds stored at 20°C - 40%RH for up to 16 weeks (average over all drying methods)

	STORAGE PERIOD (WEEKS)					
	2	4	6	8	12	16
Hand threshing	18[a]	19[a]	18[a]	19[a]	19[a]	25[a]
Beating threshed	23[b]	26[b]	26[b]	23[b]	24[b]	29[b]

Values within column showing the same letter do not differ at the 1% level

Table 3.10 Effect of threshing method on the percentage of abnormal seedlings produced by seeds stored at 35°C - 90%RH for up to 16 weeks (average over all drying methods)

	STORAGE PERIOD (WEEKS)	
	2	4
Hand threshing	21[a]	0[a]
Beating threshed	25[b]	0[a]

Values within column showing the same letter do not differ at the 1% level

3.5 DISCUSSION

Abdul-Baki and Anderson (1972) reported that many physiological manifestations of seed deterioration may occur. These included changes in seed colour, delayed germination, lowered tolerance to adverse storage conditions and reduced growth of seedlings. However, they pointed out that reduced germinability of seedlings is the most widely accepted single criterion of seed deterioration.

In the previous chaptor factors affecting seed viability soon after harvesting until drying were discussed. The threshing operation is frequently a further factor involved in reducing seed longevity in subsequent storage. Cobb and Jones (1960) and Douglas et al (1965) agree that mechanical damage is greatly responsible for germination failure. The present experimental results show that threshing damage can affect seed viability. Irrespective of storage conditions, viability in beating threshed seeds showed greater damage than hand-threshed seeds.

The deterioration in injured seed is clearly revealed in the tetrazolium test. The work by Grabe (1970) is supported in the present study since sound tissues were shown to absorb tetrazolium more slowly and tended to develop a lighter colour than tissue which had been bruised aged or disturbed in other ways. The comparatively lower germination recorded for beating threshed seeds was a direct consequence of the threshing process as shown by an increase in the percentage of abnormal seedlings categorised as shattered seedlings. The effect of mechanical injuries on seed viability may not necessarily be serious immediately but will become more critical and severe during storage as has been pointed out by Moore (1972).

The effect of drying temperature on seed viability was prominent when seeds were stored under adverse storage conditions. The evidence was clearly seen in comparative % germination results of seeds dried by heated air at $30^{o}C$ and seeds dried at $40^{o}C$ and $50^{o}C$. Seeds dried using $30^{o}C$ heated air maintained their germinability after 2 weeks storage whereas seed stored for the same period following drying at

40°C or 50°C showed a loss in germinability of between 15 - 17% and 22 - 28% respectively. This reduction in germinability was a direct result of the combined effects of drying and poor storage conditions. However, drying temperature have no obvious or deleterious effect on seed viability when seeds were stored under good storage conditions. In this study the major causes of rapid deterioration of seed and the consequent complete loss of viability was due to adverse storage conditions of high temperature and high relative humidity. These results support the very considerable body of published literature which has shown that humidity and temperature have a major responsibility for the maintenance of seed quality in storage in a wide range of crops (Toole et al 1949, Barton 1961, James et al 1967, Delouche 1968 and Harrington 1972a). Moore (1963) and Grabe (1972) regareded moisture and temperature as the most common factors that influence the general drying rate of seed. In the present study seeds stored under 35°C - 90%RH conditions completely lost germinability after 4 weeks. The high relative humidities had a direct effect on seed moisture content. Since seeds are hygroscopic they will absorb moisture from the surrounding air until they reach equilibrium with the surrounding air. In this case, the moisture content of seeds was 14.8 - 16.2% after 2 weeks storage and 16.4 - 18.6% after 6 weeks storage. The high moisture content in seeds, particularly when combined with high temperature in the storage environment, greatly favoured the growth of storage fungi which were responsible for an increased rate of seed deterioration. Christensen (1973) reported that storage conditions of 30°C - 35°C and 65 - 90%RH are favourable for the establishment amd multiplication of storage fungi. Loss of vitality has been shown to occur as a result of exhaustion of stored foods, degeneration of enzymes, accumulation of digestion of substances toxic to the seed (Sherman 1921).

In this study, the results showed that the germinability of seeds stored under low temperature and low relative humidity (20°C - 40%RH) conditions was significantly higher than that of seed stored under high temperature and high relative humidity. These results have been supported by Delouche (1968) and Harrington (1972a) who have shown that the longevity of seed in storage increased as the temperature and

relative humidity decreased. Grabe (1965) reported that the temperature of the storage environment and within the seed mass also has a profound effect on the maintenance of seed quality. In most instances temperature and seed moisture content (or relative humidity) interact closely in their effects on the longevity of seed. Under $20^{o}C$ - 40%RH storage conditions soybean seeds maintained their moisture content at approximately 8%. These conditions were not suitable for the growth of storage fungi. Therefore, the storability of seeds stored under $20^{o}C$ - 40%RH was highly superior to seeds stored under $35^{o}C$ - 90%RH conditions.

Helmer et al (1962) have suggested that proper harvesting, drying and storage will not imporve the quality of seeds. However, they will slow the rate of deterioration in seeds by maintaining the quality as close as possible to the highest level attained at the beginning of harvest maturity. In the present study two main aspects of the post harvest system were responsible for seed deterioration i.e. the period between harvest and the commencement of drying and the storage environment. Surprisingly the influences of threshing and drying method were only of major importance when they were associated with poor storage environment. The major influence of drying method was caused by high temperature drying with air temperatures of $40^{o}C$ or $50^{o}C$. These seed temperatures are common in sun drying systems in the tropics. The findings in this present study help to explain some of the reasons why soybeans produced by local farmers in Thailand is often of low keeping quality. With sun drying, seed temperatures are often high enough to harm seed viability as a result of heat damage and rapid seed drying rate.

The traditional threshing method used in Thailand is a beating-threshing system. The use of this method in the present study was shown to have a deleterious effect on seed viability. In Thailand seeds are stored in jute sacks under ambient conditions, resulting in seeds being directly affected by prevailing high temperatures and high relative humidities. Because of this poor post harvest handling and storage system the planting value of soybean is often poor even in situations where the carryover period to the next planting season

is only 3-4 months. The present study therefore stresses the need for an improved understanding by farmers of those aspects of the post-harvest production of soybeans which play a vital role in ensuring the maintenance of high seed quality.

3.6 CONCLUSION

The main reduction in seed viability of all treatments occurred after harvest and before the commencement of drying. Further reduction in germinability was also caused by beating threshing.

Under identical storage conditions damaged seeds deteriorated more rapidly than undamaged seeds. Drying method had no effect on seed viability when seed was subsequently stored under good storage conditions ($20^{o}C$ - 40%RH). However, when seeds were stored under $35^{o}C$ - 90%RH conditions, those seedlots which had been previously dried using $40^{o}C$ or $50^{o}C$ heated air methods showed a serious loss in seed viability compared with seeds dried with heated air at $30^{o}C$. However, the drying effect was not as important as storage condition since all seeds stored under $35^{o}C$ - 90%RH completely lost viability after 6 weeks storage. Seeds stored under $35^{o}C$ - 90%RH conditions gained a relatively high moisture content. These storage conditions of high temperature and high relative humidity accelerated the deterioration rate in seeds and also favoured the growth of storage fungi. The storage conditions of $20^{o}C$ - 40%RH prolonged the storage life of soybean seeds by slowing down the ageing processes that occurred.

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Appendix 3.1

Experimental data of soybean seeds from different drying and hand threshing treatments, stored under 20°C - 40%RH conditions for 16 weeks.

```
COMMENT NORMAL GERM 2 WEEKS STORAGE 1
DATA 70 75 78
     68 72 66
     72 71 76
     80 75 75
     72 73 77
     79 79 70
COMMENT NORMAL GERM 4 WEEKS STORAGE 1
DATA 78 79 78
     66 65 66
     76 71 74
     75 76 81
     84 80 69
     79 77 75
COMMENT NORMAL GERM 6 WEEKS STORAGE 1
DATA 80 84 78
     73 66 69
     80 77 76
     81 78 77
     72 79 71
     69 67 71
COMMENT NORMAL GERM 8 WEEKS STORAGE 1
DATA 74 76 75
     66 53 67
     80 73 76
     72 80 84
     76 71 80
     78 75 80
COMMENT NORMAL GERM 12 WEEKS STORAGE 1
DATA 74 68 76
     67 80 61
     77 83 72
     80 80 77
     84 70 71
     68 66 78
COMMENT NORMAL GERM 16 WEEKS STORAGE 1
DATA 75 71 60
     54 77 66
     67 70 70
     70 77 66
     63 67 73
     72 71 74
```

Appendix 3.2

Experimental data of soybean seeds from different drying and beating threshing treatments, stored under 20°C - 40%RH conditions for 16 weeks.

```
COMMENT NORMAL GERM 2 WEEKS STORAGE1
DATA 78 72 66
     63 71 64
     63 70 63
     77 70 69
     77 75 78
     69 59 73
COMMENT NORMAL GERM 4 WEEKS STORAGE 1
DATA 68 66 69
     70 63 64
     77 77 65
     67 81 74
     58 63 67
     66 68 71
COMMENT NORMAL GERM 6 WEEKS STORAGE 1
DATA 66 79 64
     64 67 62
     71 72 65
     73 83 73
     63 65 69
     65 69 61
COMMENT NORMAL GERM 8 WEEKS STORAGE 1
DATA 80 73 69
     63 65 72
     74 76 68
     71 72 75
     66 73 61
     65 70 60
COMMENT NORMAL GERM 12 WEEKS STORAGE 1
DATA 74 71 68
     58 61 69
     79 77 70
     73 77 72
     73 74 71
     66 73 70
COMMENT NORMAL GERM 16 WEEKS STORAGE1
DATA 70 59 77
     60 62 58
     61 71 73
     67 65 66
     63 59 55
     56 65 62
```

Appendix 3.3

Experimental data of soybean seeds from different drying and hand threshing methods, stored under 35°C - 90%RH conditions for 16 weeks.

```
COMMENT NORMAL GERM 2 WEEKS STORAGE 2
DATA 69 77 84
     67 62 63
     68 62 56
     83 89 86
     69 68 61
     59 69 61
COMMENT NORMAL GERM 4 WEEKS STORAGE 4
DATA  0  0  0
      0  0  0
      0  0  0
      0 23  0
     24 24 10
      0  0  0
ALL SEEDS WERE DEAD AFTER 6 WEEKS STORAGE
```

Appendix 3.4

Experimental data of soybean seeds from different drying and beatend threshing methods, stored under 35°C - 90%RH conditions for 16 weeks.

```
COMMENT NORMAL GERM 2 WEEKS STORAGE 2
DATA 64 64 68
     74 62 68
     69 42 60
     78 81 79
     59 69 66
     59 59 54
COMMENT NORMAL GERM 4 WEEKS STORAGE 4
DATA  0  0  0
      0  0  0
      1  0  0
      2  6  1
      4  3  6
      0  0  0
ALL SEEDS WERE DEAD AFTER 6 WEEKS STORAGE
```

Appendix 3.5

Analysis of variance of abnormal seedling categories of seed samples at 2 weeks storage

FACTOR C

	MEAN	MS	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	0.7500	1.13888889	1.06716737	0.12576924	0.29774408
2	1.5417	2.16666667	1.47196014	0.17347217	0.29774408
3	1.8056	2.19444444	1.48136574	0.17458063	0.29774408
4	1.6806	2.34722222	1.53206469	0.18055556	0.29774408
5	7.7778	16.20833333	4.02595744	0.47446363	0.29774408
6	5.8472	12.22222222	3.49602949	0.41201103	0.29774408
7	2.8611	8.40277778	2.89875452	0.34162150	0.29774408

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?

BARTLETT'S TEST M/C = 143.61141, P = 0.000000, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

C	1	2	4	3	7	6	5
P = 0.05	-------						

P = 0.01	----------						

Appendix 3.5 continued

Analysis of variance of abnormal seedling categories of seed samples at 4 weeks storage

FACTOR C

	MEAN	MS	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	0.2917	0.33333333	0.57735027	0.06804138	0.22432045
2	0.6667	0.62500000	0.79056942	0.09316950	0.22432045
3	0.9583	1.23611111	1.11180534	0.13102752	0.22432045
4	1.4722	1.90277778	1.37941211	0.16256528	0.22432045
5	5.6389	9.33333333	3.05505046	0.36004115	0.22432045
6	3.9306	9.75000000	3.12249900	0.36799004	0.22432045
7	1.1111	2.18055556	1.47667043	0.17402728	0.22432045

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?
BARTLETT'S TEST M/C = 211.15003, P = 0.000000, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

	C	1	2	3	7	4	6	5
P = 0.05		-------						

P = 0.01		----------						

Appendix 3.5 continued

Analysis of variance of abnormal seedling categories of seed samples at 6 weeks storage

FACTOR C

	MEAN	M3	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	0.1111	0.11111111	0.33333333	0.03928371	0.14875600
2	0.5694	0.66666667	0.81649658	0.09622504	0.14875600
3	1.0000	1.18055556	1.08653373	0.12804923	0.14875600
4	1.1667	1.16666667	1.08012345	0.12729377	0.14875600
5	4.7083	4.34722222	2.08499933	0.24571953	0.14875600
6	2.5417	2.68055556	1.63724023	0.19295061	0.14875600
7	0.7917	1.00000000	1.00000000	0.11785113	0.14875600

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?

BARTLETT'S TEST M/C = 147.03030, P = 0.000000, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

C.	1	2	7	3	4	6	5
P = 0.05		---	---				
			---	---			
P = 0.01		---					
		---	---				
			---	---			

Appendix 3.5 continued

Analysis of variance of abnormal seedling categories of seed samples at 8 weeks storage

FACTOR C

	MEAN	MS	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	0.1528	0.08333333	0.28867513	0.03402069	0.14745414
2	0.6750	0.45833333	0.67700320	0.07978559	0.14745414
3	1.3611	1.50000000	1.22474487	0.14433757	0.14745414
4	1.5694	2.81944444	1.67912014	0.19788621	0.14745414
5	3.2778	2.65277778	1.62873502	0.19194826	0.14745414
6	2.4583	2.79166667	1.67082814	0.19690898	0.14745414
7	0.6806	0.65277778	0.80794664	0.09521743	0.14745414

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?

BARTLETT'S TEST M/C = 161.18458, P = 0.000000, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

	C	1	7	2	3	4	6	5
P = 0.05			-------		-------			
P = 0.01		-------						

Appendix 3.5 continued

Analysis of variance of abnormal seedling categories of seed samples at 12 weeks storage

FACTOR C

	MEAN	MS	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	0.3056	0.40277778	0.63464776	0.07479396	0.14995590
2	1.0278	1.23611111	1.11180534	0.13102752	0.14995590
3	1.2500	1.76388889	1.32011479	0.15651983	0.14995590
4	1.7222	2.54166667	1.59426054	0.18788541	0.14995590
5	3.3611	2.59722222	1.61156997	0.18992770	0.14995590
6	2.3889	1.94444444	1.39443338	0.16433555	0.14995590
7	0.6528	0.84722222	0.92044675	0.10847569	0.14995590

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?

BARTLETT'S TEST M/C = 53.160448, P = 0.000000, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

	C	1	7	2	3	4	6	5
P = 0.05		-------						

P = 0.01		-------						

Appendix 3.5 continued

Analysis of variance of abnormal seedling categories of seed samples at 16 weeks storage

FACTOR C

	MEAN	MS	SD	SE OF MEAN VARYING ERROR	SE OF MEAN CONSTANT ERROR
C1	1.1667	1.08055556	1.29630243	0.15277778	0.18890931
2	1.2361	1.75000000	1.32287566	0.15590239	0.18890931
3	2.1806	1.76388889	1.32811479	0.15651983	0.18890931
4	1.1111	1.55555556	1.24721913	0.14698618	0.18890931
5	4.4306	5.98611111	2.44665304	0.28834063	0.18890931
6	2.4722	3.09722222	1.75988267	0.20740534	0.18890931
7	0.9444	2.15277778	1.46723474	0.17291527	0.18890931

DO THE 7 LEVELS HAVE DIFFERENT ERROR VARIANCE ?

BARTLETT'S TEST M/C = 39.575225, P = 0.000001, SIGNIFICANT

DUNCAN'S NEW MULTIPLE RANGE TEST

	C	7	4	1	2	3	6	5
P = 0.05		----------	----------	----------		-------		
P = 0.01		----------	----------	----------		-------		