THE EFFECTS OF DRYING METHODS AND STORAGE CONDITIONS ON PEA SEED (*Pisum sativum* L.) QUALITY AND THE RELATIONSHIP BETWEEN HIGH TEMPERATURE DRYING AND MAIZE SEED (*Zea mays* L.) STRESS CRACKS.

This thesis presented in fulfilment of the requirements for the degree of Master of Applied Science (Agricultural Engineering) in the Institute of Technology and Engineering, Massey University, New Zealand

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Dedicated to my parents and my lovely children

ABSTRACT

High temperature and high relative humidity adversely affect the quality of seeds, and are features of tropical climate. Seed drying and storage are being used increasingly in developing countries to improve seed storage and quality. This study was undertaken to evaluate a range of seed drying methods and storage conditions with the view to selecting an appropriate method(s) for use in tropical countries.

Pea (*Pisum sativum* **L.**) seeds at three initial seed moisture content (m.c.) of 23.8, 18.0 and 14.5% were dried to 10% seed m.c. before storage. The performances of four different drying methods: artificial dryer (Kiwi Mini) set at 30°C or 45°C, natural sun drying, and in-bin natural ventilation drying were evaluated. Natural sun drying, and in-bin natural ventilation drying were conducted from March to May, 1997, when mean temperature and relative humidity during sunny days were 17°C and 60% respectively. The dried seeds were stored under two conditions: open storage at 20.5°C and 55% relative humidity (r.h.), and closed storage at 25°C and 90% r.h. for 20, 40, and 60 days.

Time and energy consumed for drying by the different methods were determined to compare the drying efficiency when combined with quality of the seed. Deterioration of the seed due to storage conditions and drying methods used was determined by assessing their effects on seed germination, abnormal seedlings, dead seed, hollow heart percentages, and conductivity.

Seed samples dried by the Kiwi Mini dryer set at 45°C took 7 hours and those set at 30°C took 17 hours. It took 54 hours with natural in-bin ventilation drying, while sun drying took 37 hours. However, energy consumed when drying seeds at 30°C was 17 kWh, which was more than twice that at 45°C. Seed germination was not significantly different between drying methods, but averaged only 75% because of

sprouting damage of the crop prior to harvest. Germinations after open and closed storage for 20 days did not differ, although some differences appeared after 40 days of storage. However, open and closed storage for 60 days significantly reduced seed germination to 54 and 33% respectively.

Because seeds are heat-sensitive, drying air temperature and drying rate are particularly important to avoid internal seed breakage, cracking and splitting, fungal growth, and loss of germination and vigour. Selected studies have shown that seed can be dried at high temperature for a short time, followed by tempering to re-distribute moisture and temperature inside the seed, thus reducing the percentage of cracking.

Thus, a second experiment was conducted with maize (*Zea mays* **L.**) to study the impact on seed viability of high temperature drying followed by tempering. Maize at 28.5% initial seed m.c. was dried at 60°C for short periods of 5, 10, 15, 20, or 25 minutes, followed by tempering for 45 minutes at either 30°C or 21°C. This cycle was repeated until maize seeds were dried to 13.0% m.c.. The percentage of cracked seeds, germination immediately after drying, and after an accelerated ageing test, did not differ between 30°C and 21°C tempering. Drying exposure times of upto 10 minutes per cycle at 60°C caused vertical cracks in up to 50% of seeds, but seed germination remained over 90% and seed vigour was also maintained. The percentage of seeds with stress cracks due to high temperature drying (5 - 25 minute cycles) at 60°C followed by tempering had polynomial relationships with seed germination and vigour. Seeds dried at the same temperature without tempering had their germination reduced from 99 to 20%.

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CHAPTER I

INTRODUCTION

All crops contain moisture at harvest and such moisture is one of the major factors contributing to the deterioration during storage of agro-products. There are many problems in agricultural production and productivity facing Vietnam, and South East Asia in general. Among these, the need to reduce postharvest losses has been accorded the highest priority. Currently annual postharvest losses for rice amount to 13 - 16% of total production. Drying problems account for approximately 2.0% of these losses, and storage problems account for another 3.5% (Dien, 1995).

Losses in grain quality are also significant. Mould infestations arising from improper storage conditions cause reductions in concentrations of amino acids in general, and of some essential amino acids in particular. Rodents and insects are other reasons causing losses.

Drying and storage methods for food grains in Vietnam and elsewhere in South East Asia are mainly traditional and involve manual handling, causing losses and inefficiencies throughout the postharvest system. In recent years, due to a relatively high rate of technology adoption in crop production, agricultural production in Vietnam has increased steadily, and further increases are expected. However, this has created problems. For example the use of natural sun and ventilation drying methods is difficult during the rainy season. Grain readily becomes affected by the growth of insects and moulds due to heating and high humidity, leading to losses during storage. Lack of appropriate mechanical drying facilities is also a severe impediment to maximisation of the benefits of increased production.

Drying of grain is fundamental for successful storage until it is used for sowing or processing. Thus, the primary function of a grain drying system is to dry high moisture content grain to a safe storage moisture content without a significant reduction in grain quality.

Seeds must be stored dry if they are to retain their viability and therefore the ability to germinate when planted. High moisture content tends to shorten seed life by increasing respiration rate, encouraging mould growth and insect attack. The purpose of seed drying and storage is to preserve and maintain the high germination capacity with high vigour of seed from harvest to planting time. Therefore, grain drying and storage occupies a vital place in the economies of both developed and developing countries.

Drying has been the most common method of preserving grain, and proper drying is a precondition for safe storage and delivery. Since grain drying is an energy intensive process, increasing its efficiency has important economic consequences for both grain producers and consumers. A large body of data exists describing the drying process, explaining design parameters for different drying methods, drying time, drying energy and safe drying conditions.

This project was designed to compare various drying methods and techniques and study their impact on quality of pea seed after drying, and after storage under different conditions. In addition, the effect of high drying temperature and tempering conditions on maize seed quality were also determined.

CHAPTER II

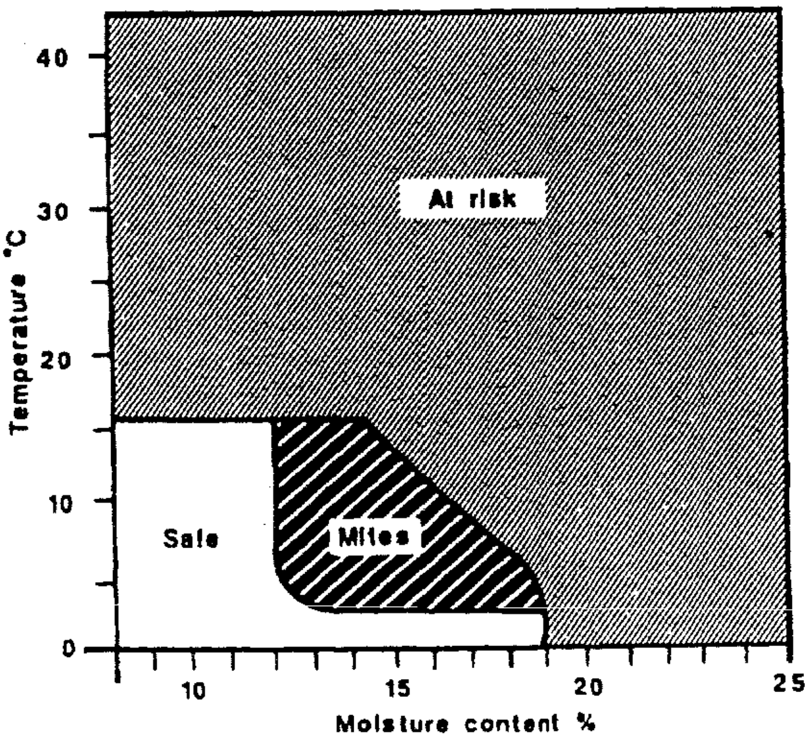
LITERATURE REVIEW

2.1. Importance of grain and seed drying and storage

In most countries grains are among the most important staple food. However, grains are often produced on a seasonal basis, and in many ecosystems there is only one harvest a year, which itself may be subject to failure. On the other hand, in many ecosystems with a benign climate, cereals are surplus to domestic requirements and are offered for export. In order to feed the world's population, most of the global production of grains must be held in storage for periods varying from one month up to more than a year. In addition, the proper storage of grain for seed is necessary to ensure adequate field germination and vigour for the crop cycles to come.

After harvest, the management objective during the storage period is to reduce grain metabolic activity to such a low level that the grain mass is sufficiently stable to survive with minimal deterioration. However, most grain after harvest contains moisture, which if not reduced to a level suitable for safe storage is the cause of metabolic activity, resulting in heating, and hence deterioration and damage because of mould and insect attack. There are direct economic losses resulting from poor management of postharvest systems. Losses directly caused during drying and storage stages are significant, with an annual average of 3 to 11% (Coulter and Magrath, 1994).

In order to store grains effectively, it is necessary to carry out drying to lower the freshly harvested grains' moisture content to a "safe level", which is combined with good storage conditions to protect grain from risks of mould development, mite and insect attack, and germination loss (Fig. 2.1). Drying is the phase of the postharvest system during which the product is rapidly dried until it reaches the "safe-moisture" level. The maximum moisture content for safe storage is normally described as that at which the rate of respiration is low enough to prevent an accumulation of heat and consequent crop deterioration (Muckle and Stirling, 1971).



Source: McLean (1989)

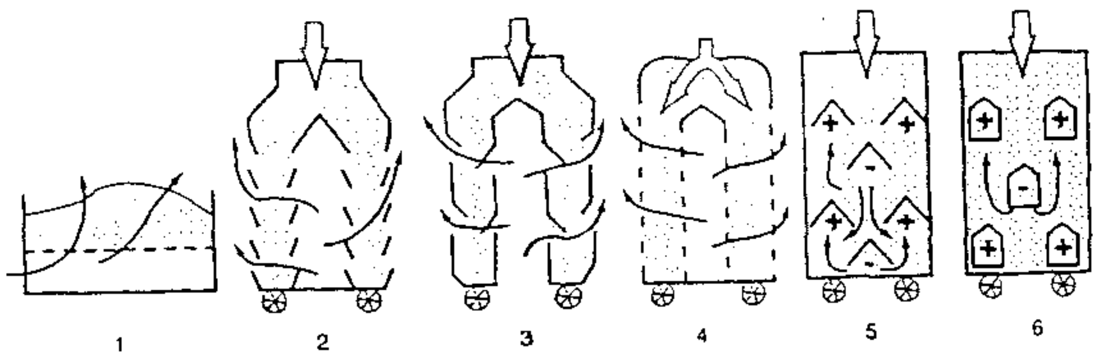
Fig. 2.1. Safe conditions for storage.

The aim of drying is to lower the moisture content in order to guarantee conditions favourable for storage or for further processing of the product. Drying permits a reduction of losses during storage caused by premature and unseasonable germination of the grain, development of moulds, or proliferation of insects. The goal for all the procedures during seed processing should be to maintain quality by delaying the inevitable process of deterioration (Hampton, 1994). Drying, therefore, is an essential part of the postharvest process, and it increases longevity of seeds in a predictable way.

2.2. Status of grain drying and storage in Vietnam

There are many drying systems used in Vietnam. These generally use two drying processes: sun drying and/or artificial drying.

Sun drying is often carried out as a family activity in the farmer's yard over a period of days in the dry season, although actual drying time for a batch of grain may be approximately 3 days. The grains are considered dry when they give a solid cracking sound when broken between teeth. The grains are manually turned over to obtain uniform drying. However, sun drying is dependent on weather, and it is difficult to carry out during the rainy season. In such case farmers often sell their grain immediately after harvest (Hien, 1995; Hien et al., 1996).

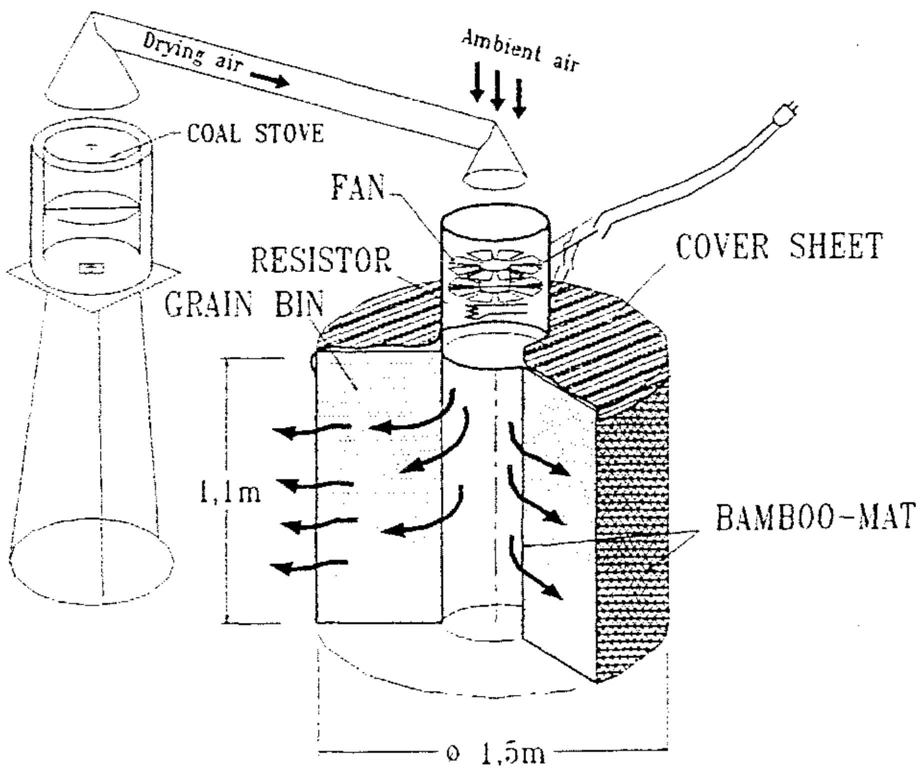


Source: Hien (1995)

Fig. 2.2. Selected types of mechanical dryers: 1) Flat-bed forced air, 2) Grain circulating with shutter, 3) Grain circulating with baffle, 4) Upright screen forced air, 5) Grain circulating with inverted troughs, 6) Grain circulating with multiple air duct.

Mechanical dryers have been introduced for drying food grains in Vietnam. Some of these dryers have been imported from developed countries, and some have been manufactured by local industry (Fig. 2.2) (Hien, 1995).

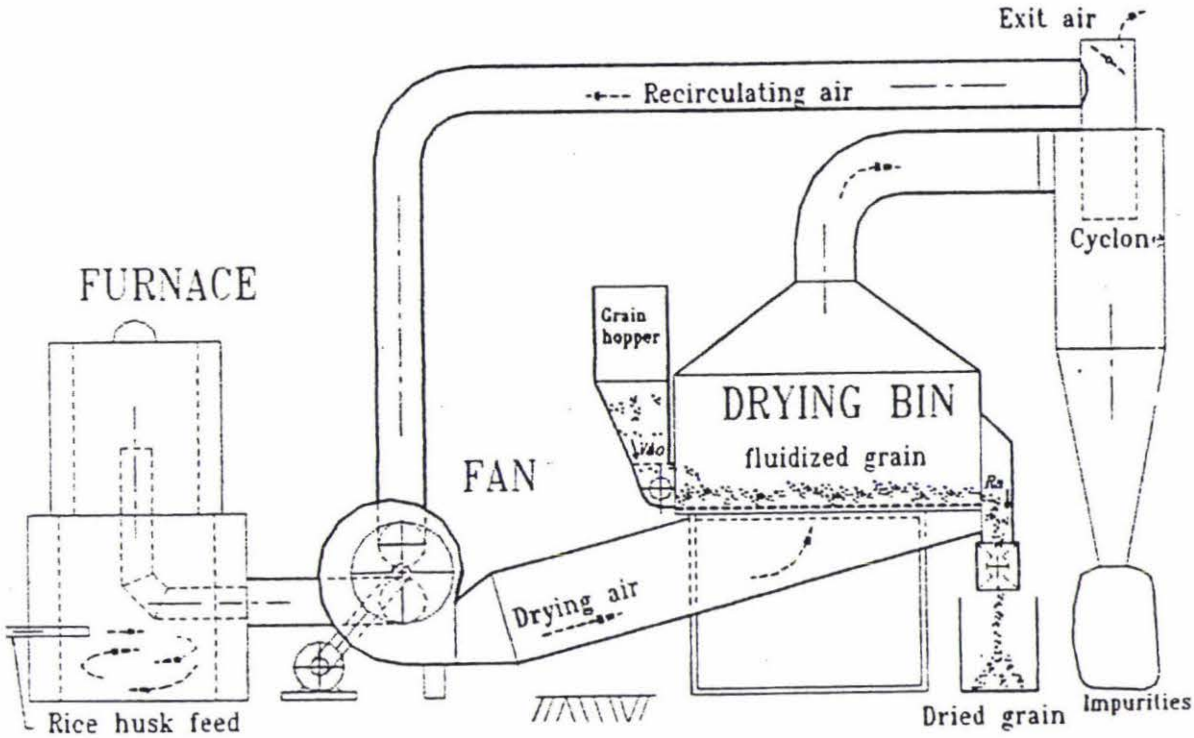
Several manual grain drying techniques developed in Vietnam involve the use of the family cooking stove. These dryers are simple, available locally during rainy periods, and their drying rate and grain quality are higher than those achieved by natural sun drying. These dryers can use a resistor to heat the air for drying if cooking stove is not available. Therefore, these dryers (Fig. 2.3) are easily adapted by farmers, although drying is uneven between the interior and exterior layers of grain (Hien, 1996).



Source: Hien (1996)

Fig. 2.3. Schematic drawing of a manual grain dryer using a cooking stove as the heat source.

Vietnam has also developed furnaces for drying grain, which use rice husk for burning as the heat source (Hien, 1995; Hien, 1996; Xuan, et al., 1996). These medium scale dryers (Fig. 2.4) have been installed and operated in some areas for grain maize drying. The drying cost is low because of the use of rice husk as the heat source, which is abundantly and freely available at rice mills.



Source: Hien (1996)

Fig. 2.4. Schematic drawing of a bed dryer with pneumatic-fed rice husk furnace.

Dry paddy is generally stored in wooden boxes with capacities ranging from 500 to 1,000 kg. However, there are two modern and well equipped silos of 10,000 and 48,000 tonne capacity each (Dien, 1995), which have made a significant contribution to maintaining the quality of rice for local consumption and for export.

There has been some research on techniques for pest management during grain storage in Vietnam. One method was developed by Thanh and Ho in the 1970s (Ho, 1995) and uses rice husk to cover the surface of bulk stored paddy to prevent insect contamination. This method has proved technically very effective for storage but economically impractical because of high labour costs. This is because the warehouses must be dry, clean, free from pest, insects and treated with pesticide before loading, and that involves high labour input.

Two-stage in-store drying technology was introduced in Southern Vietnam (Hung, et al., 1995). In the first stage, freshly harvested grain is quickly dried to about 18% moisture content (w.b.) by sun drying, flat-bed drying or continuous drying. During the second stage, in-store grains are dried down to 14 - 15% moisture content (w.b.) using slightly higher than the ambient temperatures at a low airflow rate. This is achieved by heating the ambient air by conductivity through exposing it onto the body of an operating diesel engine. This method provided high quality dried grain at low operating costs.

2.3. Status of drying and storage in New Zealand

New Zealand is a developed country with advanced agricultural engineering technologies. Artificial drying is commonly used for drying grain. Artificial drying systems are classified into three groups which use either low, medium or high temperatures.

Drying operations in New Zealand are often controlled by large companies such as Hodder & Tolley and Wrightsons Ltd. Such private enterprises have developed expertise for large scale dehydration of crops such as peas, beans, maize and other cereals. However, in the South Island many cropping farmers do their own drying at their farms. Although drying and storage techniques used are modern and advanced, they are often high fossil fuel energy consuming operations. Grain drying in New Zealand during the 1978-1979 season consumed about 4 million litres of diesel (Sims et al., 1983), which is equivalent to approximately 40 million kWh. Therefore, there is a dire need to reduce energy used in the drying and storage industry.

The potential for energy savings in the drying of foods in New Zealand is seen to fall into three main areas. They are: 1) improving the efficiency of existing equipment; 2) conversion of existing equipment to alternative energy sources; and 3) introduction of "new technologies". Improved control of dryers, especially by way of microprocessor- and computer-based strategies can yield energy savings of up to 20%, and even simple temperature control equipment can save 10% (Barnett and Earle, 1985).

2.4. Grain quality

Grain quality restrictions are often dependent on end usage. The quality factors of grains that are of interest to end users include (1) moisture content, (2) damaged kernels (3) breakage susceptibility, (4) milling quality, (5) seed viability, (6) nutritive value, (7) mould and carcinogen content and, (8) insect damage (Brooker et al., 1992).

Quality of seed is an essential requirement for agricultural and horticultural production. It is well known that not every seed is in fact suitable for sowing because inside the seed there are hidden properties which are decisive for the development of the seedlings. Esbo (1980) defined seed quality as a collection of seed properties including purity, freedom from weeds, uniformity, moisture content, germination capacity and vigour, which are considered to be of importance for assessment of the value of the seed for planting. The results of these assessments are widely used for determining the price and value for sowing purposes. Therefore, in the simplest form, seed quality assessment should at least be able to distinguish between good and bad seed lots. In the most sophisticated form, seed quality assessment should be able to predict seed performance in the field and detect when things have gone wrong in the seed production and processing system (Hill, 1996).

When drying, grain and seed quality components can be affected by the dryer construction, operational procedures, initial and final grain moisture contents, drying air temperature, air flow rates, and grain cooling procedures after drying. The relationship of these parameters to grain quality and the economic value of the dried grain must be considered in designing any dryer or in selecting a drying system (Loewer et al., 1994).

2.5. Grain properties

Seed is hygroscopic, so water losses during drying depend on the moisture content of the surrounding air. Several major physical properties of grain used in drying and storage are: 1) bulk density; 2) 1000-grain weight; 3) porosity; 4) specific heat; 5) thermal conductivity; and 6) specific surface area. These properties vary for various grain species. Each property has a significant effect on the drying rate (Chung and Lee, 1986 & 1996; Brooker et al., 1992).

- Grain bulk density and 1000-grain weight determine capacity of the dryer and the bin volume required to store a certain mass of grain.
- The porosity is the void space in a mass of grain, and is used to represent the resistance of bulk grain to airflow.
- The specific heat is the energy required by a unit mass of grain to increase temperature by a unit degree.
- Thermal conductivity is defined as the rate of heat flow by conduction through an individual grain kernel. The higher the conductivity in the grain,

the faster the drying because the thermal gradients in the kernels disapear more rapidly.

- The specific surface area is a total surface area of seeds per unit volume of grain that exchanges energy and moisture with the drying air. Hence, for equal volumes of grain, with equal heat and air supplied, species with a higher specific surface area will be dried faster. This property is related to the size and shape of the grain.

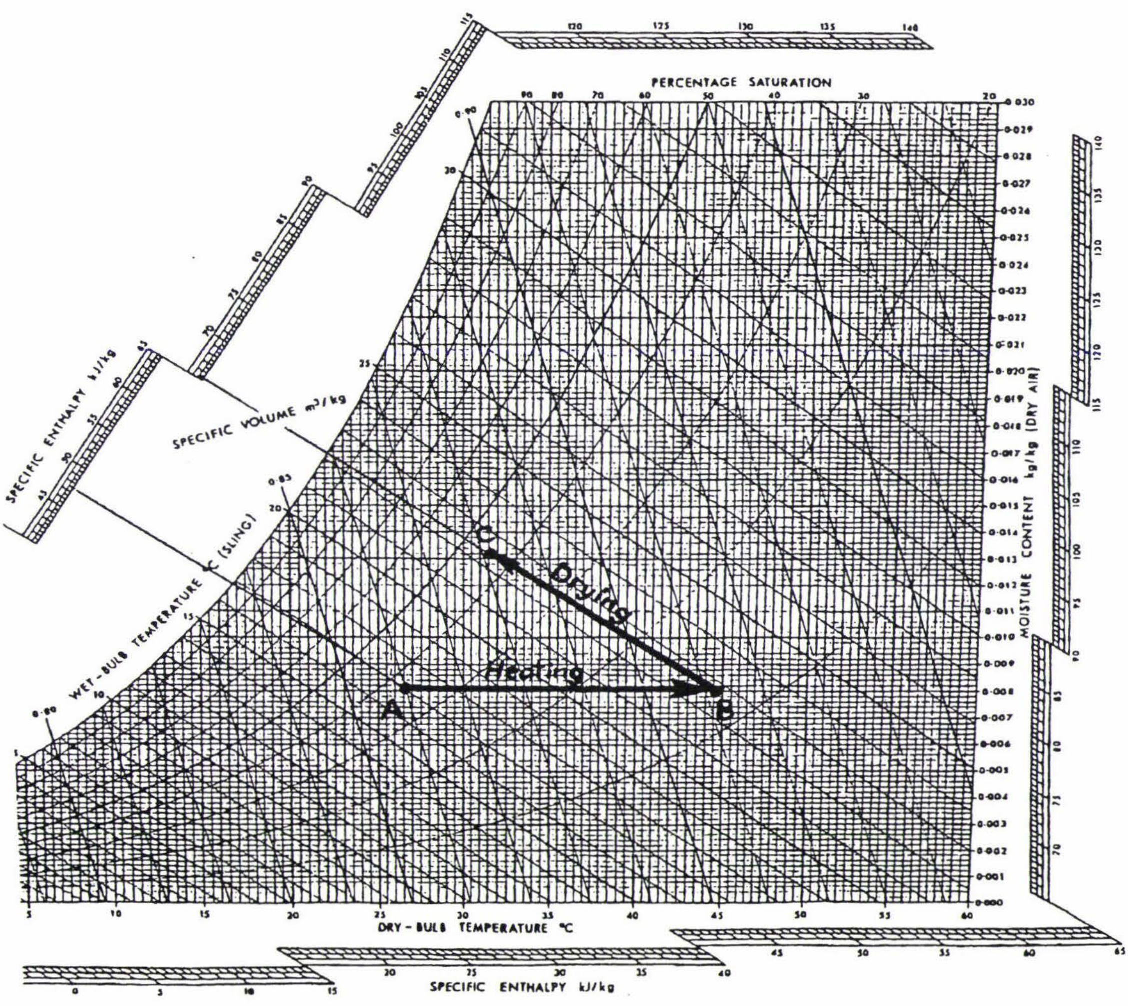
2.6. Theory of drying

Drying requires a heat transfer. Heat transfer may be accomplished by contaction, convection or radiation. Most grain drying is based on transfering heat by convection. Air at varying degrees of heat is circulated through a mass of grain.

As the air moves, it imparts heat to the grain while absorbing the humidity of the outermost layers of the grain. The exchange of heat and humidity between the air and the product to be dried is explained in the following phenomena:

- heating of the grain, accompanied by a cooling of the drying air,
- reduction in the moisture content of the grain, accompanied by an increase in the relative humidity of the drying air.

The principle of convection drying is to use the exchange of heat between grain and air to remove moisture from grains by evaporation. Evaporation occurs because some of the molecules of water contain sufficient energy to enable them to ovecome the attraction of their neighbours on the grain and escape from the grain. If the grain is heated, more molecules of water will absorb enough energy to escape and the rate of evaporation will increase (McLean, 1989). The water molecules move in all directions during evaporation, some even re-entering the grain. This movement creates vapour pressure in the air, and a state of equilibrium is reached when the number of water molecules leaving the grain equals the number which are re-entering the grain. At this moment, the vapour pressure exerted by the water remaining in the grain is equal to that in the air, and the moisture content of the grain reaches its equilibrium moisture content at this drying air condition.



Source: McLean (1989)

Fig. 2.5. Psychrometric chart and heating-drying processes.

Therefore, for drying to happen, the vapour pressure of the air shoud be lower than that in the grain. In practice, it is not feasible to measure the vapour pressure exerted by water in the grain and of the air. Alternative measures of relative quantities of moisture of the grain and relative humidity of the air are used. Relative humidity of the air must be reduced to a level at which moisture moves from the grain surface into the surrounding air.

A difference in heat temperature between the inside and surface of the grain then causes diffusion of internal water to the surface. These processes continue until the grain moisture content and the level of moisture in the air reach a balance (Muckle and Stirling, 1971; Hill, 1996).

The physical and thermal characteristics of drying air are diagrammatically represented by psychrometric charts (Fig. 2.5). The psychrometric properties include: 1) dry-bulk temperature; 2) wet-bulk temperature; 3) moisture content of the air; 4) relative humidity; 5) specific volume; 6) specific enthalpy; and 7) dew-point temperature (McLean, 1989; Brooker et al., 1992). Any state point on the chart can be created by any two psychrometric properties. Hence, if one point is existing, all other properties can be determined.

2.7. Methods of drying

There are many drying systems based on the two basic drying methods: natural and artificial drying (Muckle and Stirling, 1971). Natural drying takes place with the atmospheric air moving naturally around wet seed spread on trays, floors, yards etc. Artificial drying uses heated or unheated air that is mechanically forced through or over the seed mass. Both methods have certain advantages and disadvantages.

2.7.1. Natural drying

Natural drying in the open air is a method commonly used in developing countries. After harvesting, grain is sun- and ventilation-dried over several days depending on the wind run and intensity of sun.

2.7.1.1. Natural Sun drying:

Grain is spread out on a concrete or brick floor under the sun and is manually turned to obtain uniform drying. However, losses in quantity because of birds, losses in quality due to sudden rain and hygiene issues often occur. Sun drying is labour intensive and requires extensive space, particularly in the case of large scale operations. Thus, the total expense of sun drying is considerable when the costs of quantity and quality losses are taken into account.

2.7.1.2. Natural In-Bin Ventilation:

Ventilation is a more convenient method based on blowing heated or unheated air through the seed bulk. Unheated air is quite effective if the relative humidity of the air is lower than the equilibrium moisture content of the seed to be dried. However, sufficient air flow must be used to ensure fairly rapid drying, otherwise storage fungi can invade the seed while the seed moisture content remains high.

The grain is taken in when its moisture content is 13 - 14% (w.b.) or lower, which is considered to be safe for storage. These methods are cheap because they do not consume fossil fuel energy, but are labour-intensive. In addition, as windrowing and sun drying are highly dependent on field conditions and weather, natural drying is difficult or impossible during the rainy season.

2.7.2. Artificial drying

The moisture content of food grains is about 17-18% when they are delivered to storage silos. Therefore, spoilage of grain is unavoidable if the storage facility does not have a dryer. For safe storage and to prevent quantitative and qualitative losses, the first priority is to reduce the excess moisture content of grain. In this circumstance, an artificial drying method is mostly used.

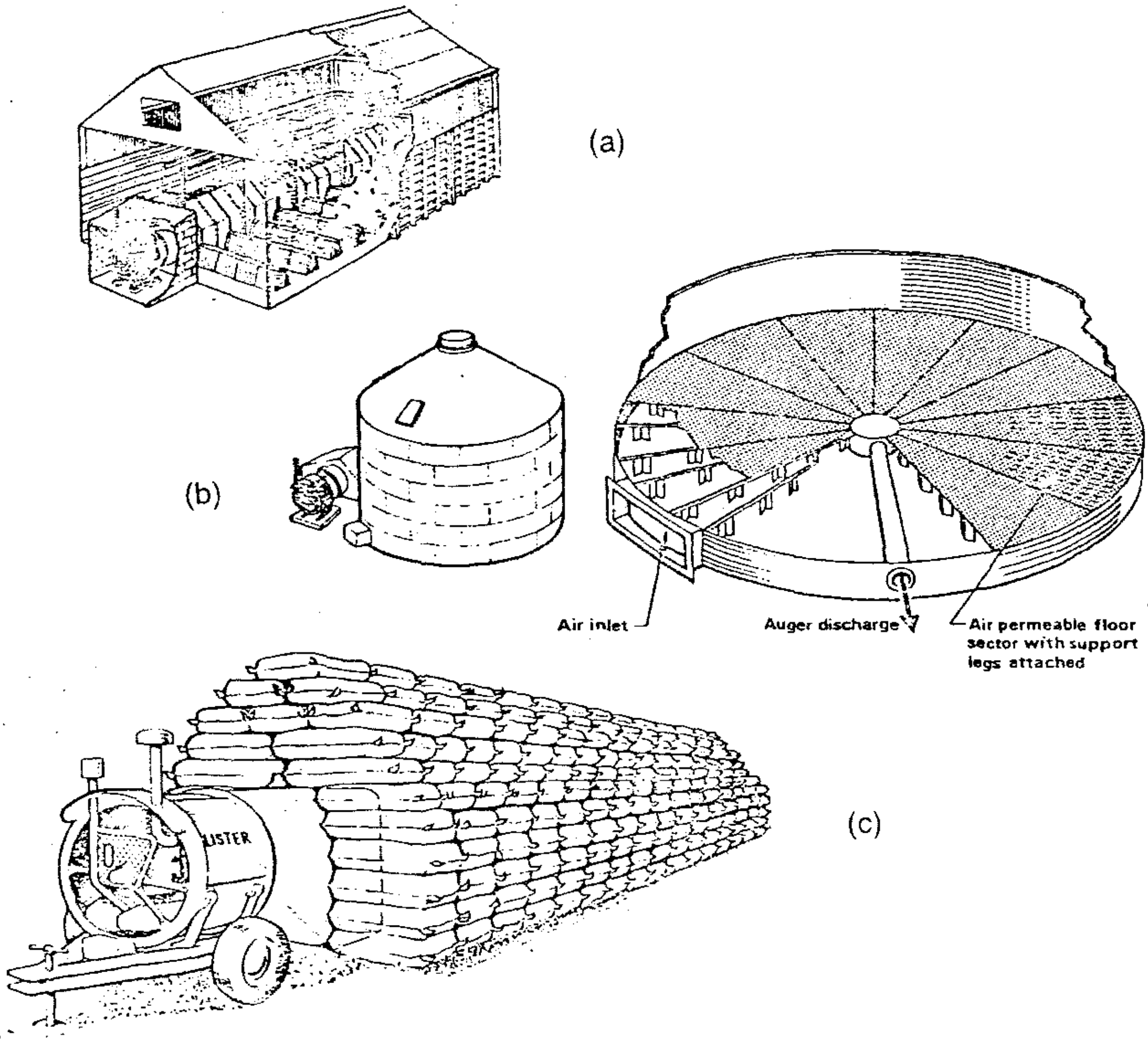
In artificial drying, either ambient air at lower relative humidity than that of the grain is forced through the grain bulk, or air heated by various sources is used to reduce air relative humidity prior to passing over the grain.

2.7.2.1 Classifying levels of drying temperature

Artificial drying systems can be divided into three groups: low, medium and high temperature depending on the end-use of grains (Muckle and Stirling, 1971).

a. Low temperature drying:

This is the simplest artificial drying arrangement. It consists of passing the airflow through the grain bulk by means of a fan. The ambient air, which is at a lower relative humidity than the grain, dries the grain until the grain gradually reaches an equilibrium moisture content. Low temperature dryers include on-the-floor dryers, in-bin dryers and tunnel drying (Fig. 2.6).

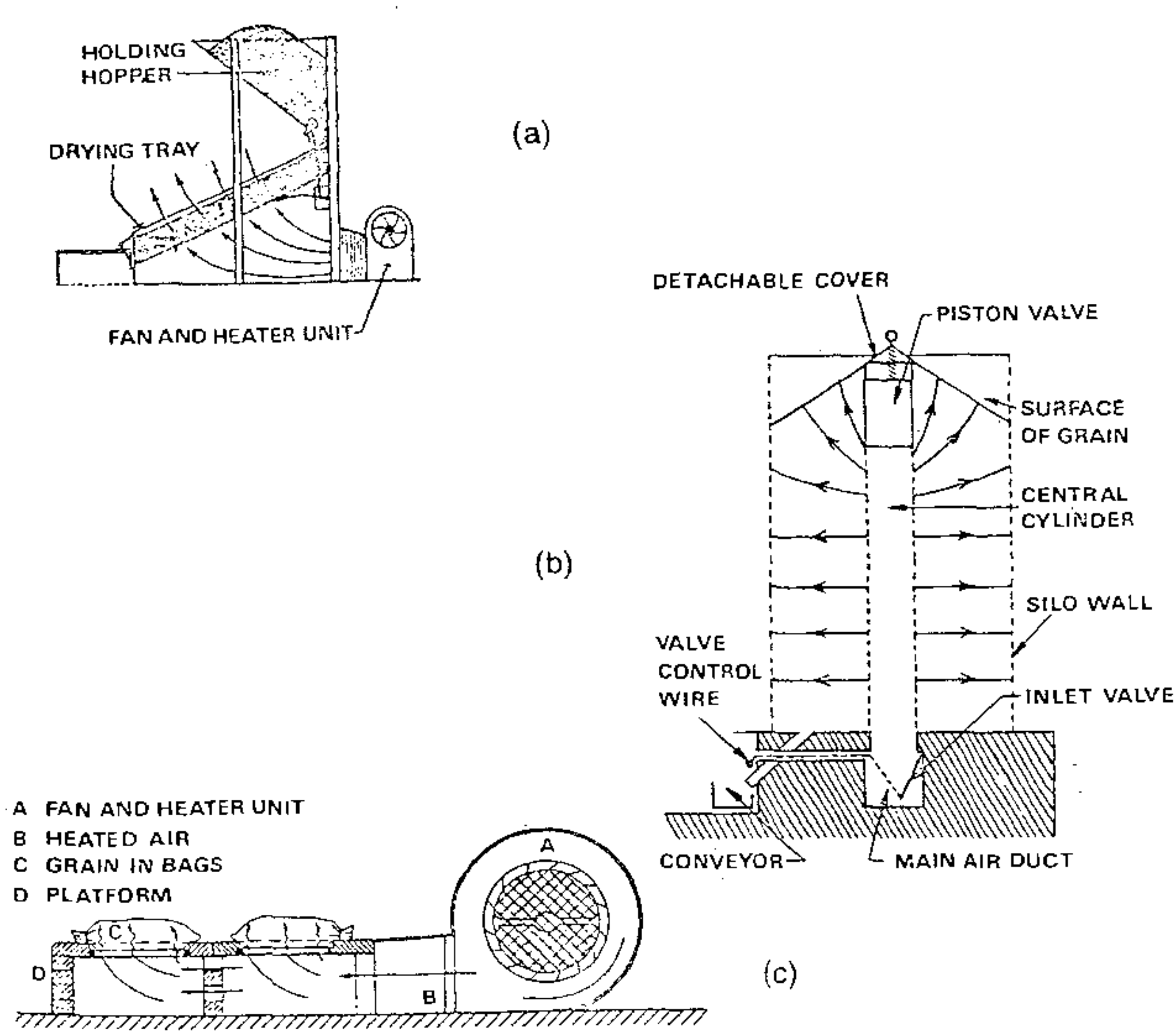


Source: Muckle and Stirling (1971)

Fig. 2.6. Schematic diagram of (a) On-floor dryer, (b) In-bin dryer, and (c) Tunnel drying.

b. Medium temperature drying:

This method is used in situations where higher moisture extraction rates are required. The principle of these dryers is based on warmed air blown through a bed of grain. Dryers of this type include tray dryers, radial flow dryers, and sack dryers. The principles of their operation are shown in Fig. 2.7.



Source: Hill (1996)

Fig. 2.7. Schematic diagram of (a) Tray dryer, (b) Radial flow dryer, and (c) Sack dryer.

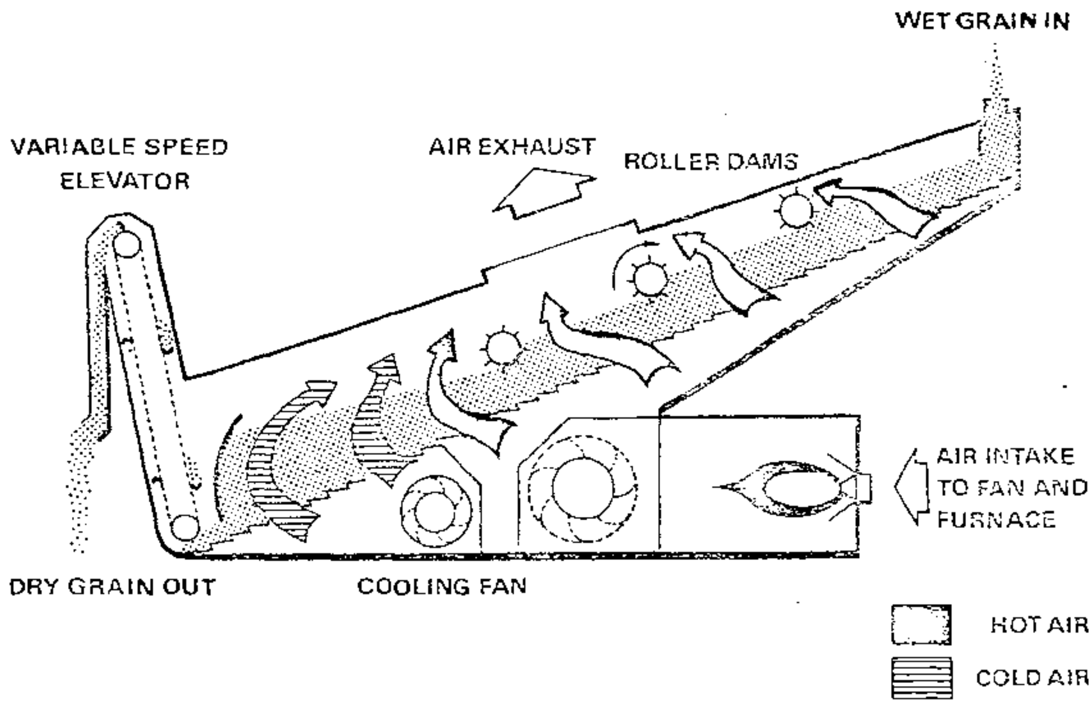
c. High temperature drying:

High temperature drying is used to reduce the time required for drying (Fig. 2.8). However, if the moisture gradient is too great, internal stresses may cause cracking, resulting in losses in storage and processing quality. Table 2.1 shows the maximum air temperatures for safe drying used for various grains, and in relation to the purpose of use (Muckle and Stirling, 1971).

Table 2.1. Maximum air temperature for drying various cereals and legumes.

	Commodity	Purpose	Maximum drying air temperature, °C
Cereals	Maize	Seed	44
		Starch	55
		Animal feed	82
	Paddy	Up to 20% m.c.	44
		Over 20% m.c.	40
	Sorghum	Seed	44
		Starch	60
		Animal feed	82
	Millet	Seed	44
		Feed	65
	Wheat	Seed up to 24% m.c.	49
		Seed over 24% m.c.	44
		Milling	66
Legumes	Beans	Seed	38
		Animal feed	45
	Cowpeas	Seed	38
	Soybeans	Seed	38
		Manufacture	48
	Groundnuts	Seed	37

Source: Muckle and Stirling (1971).



Source: Muckle and Stirling (1971)

Fig. 2.8. Schematic diagram of high temperature continuous dryer.

2.7.2.2. Dryer design types.

There are three main design types.

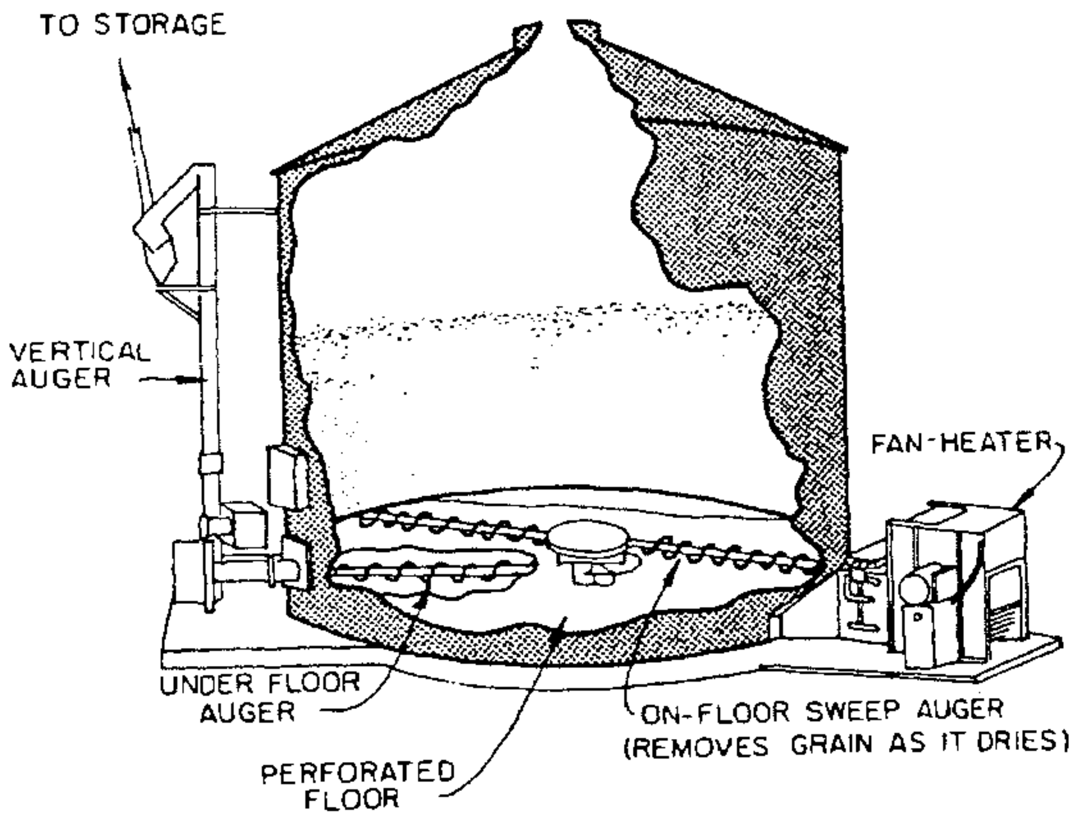
a. In-bin drying systems:

Low temperature drying

This system uses natural air. Wet grain is placed in a bin to a depth of 2.5 to 5.0 meters and slowly dried using external fan-blown air. This system can produce high quality grain. The airflow rates used may vary depending on farmers' enterprise and throughput. This in-bin storage and drying may be a combined operation. This drying system generally has a low capacity, but is energy-efficient, and can produce excellent quality grain when operated properly (Paulsen, 1989).

Continuous counter-flow drying

This is a relatively new method and consists of two bins (Fig. 2.9). One is a heated air in-bin counter-flow dryer and the other is a natural air in-bin dryer at lower temperature. Wet grains are loaded into the first bin and then dried. The partially dried, hot grain is moved to a second bin for slow final drying and cooling.

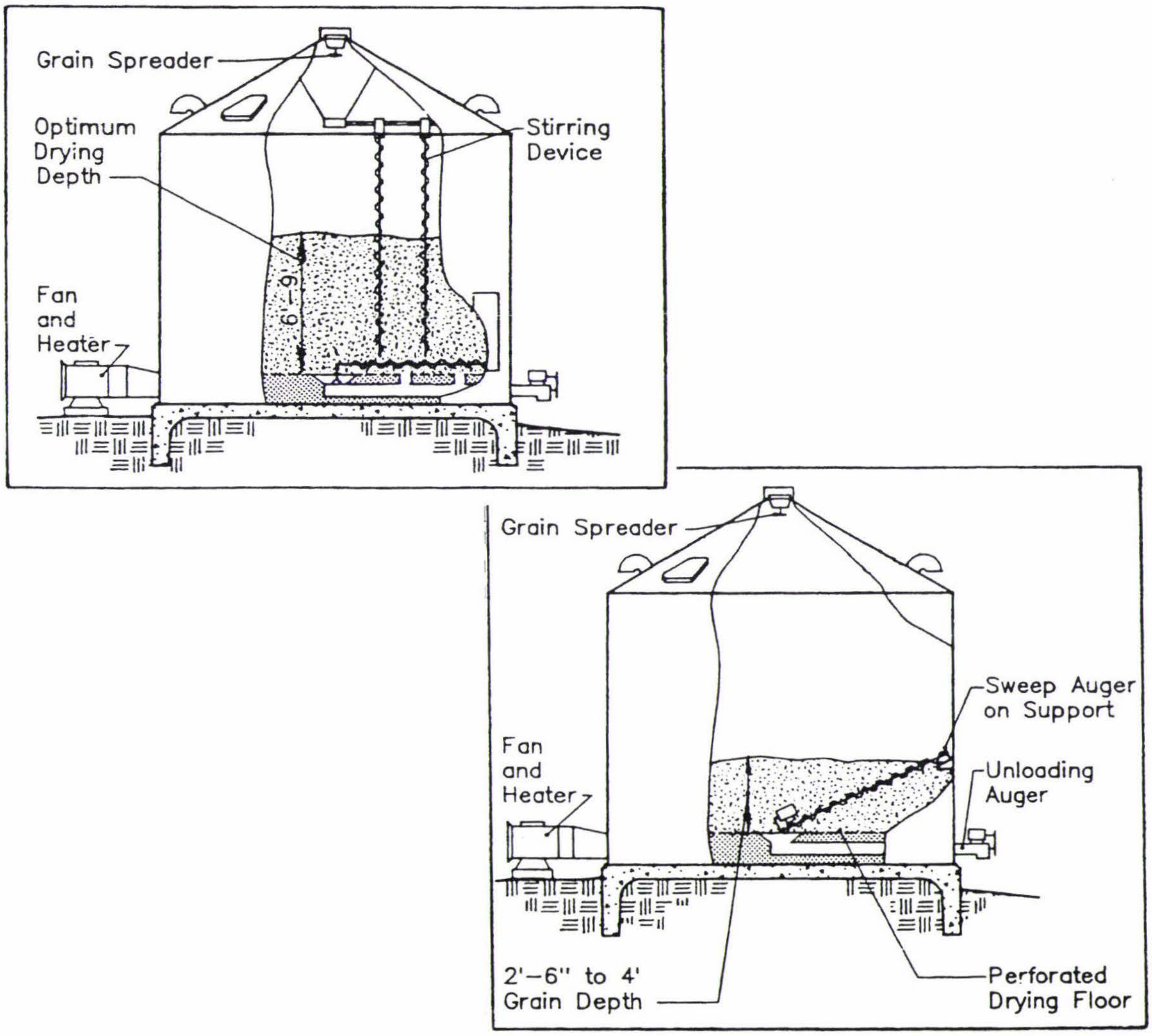


Source: Brooker et al. (1992)

Fig. 2.9. Schematic diagram of an in-bin continuous counter-flow system

Batch-in-bin dryers

These differ from in-bin counter-flow dryers in that they are not equipped with the second drying and cooling bin (Fig. 2.10). Airflow rates and drying temperature are similar to those for in-bin counter-flow dryers, but the energy efficiency as well as the grain quality is poorer (Paulsen, 1989).



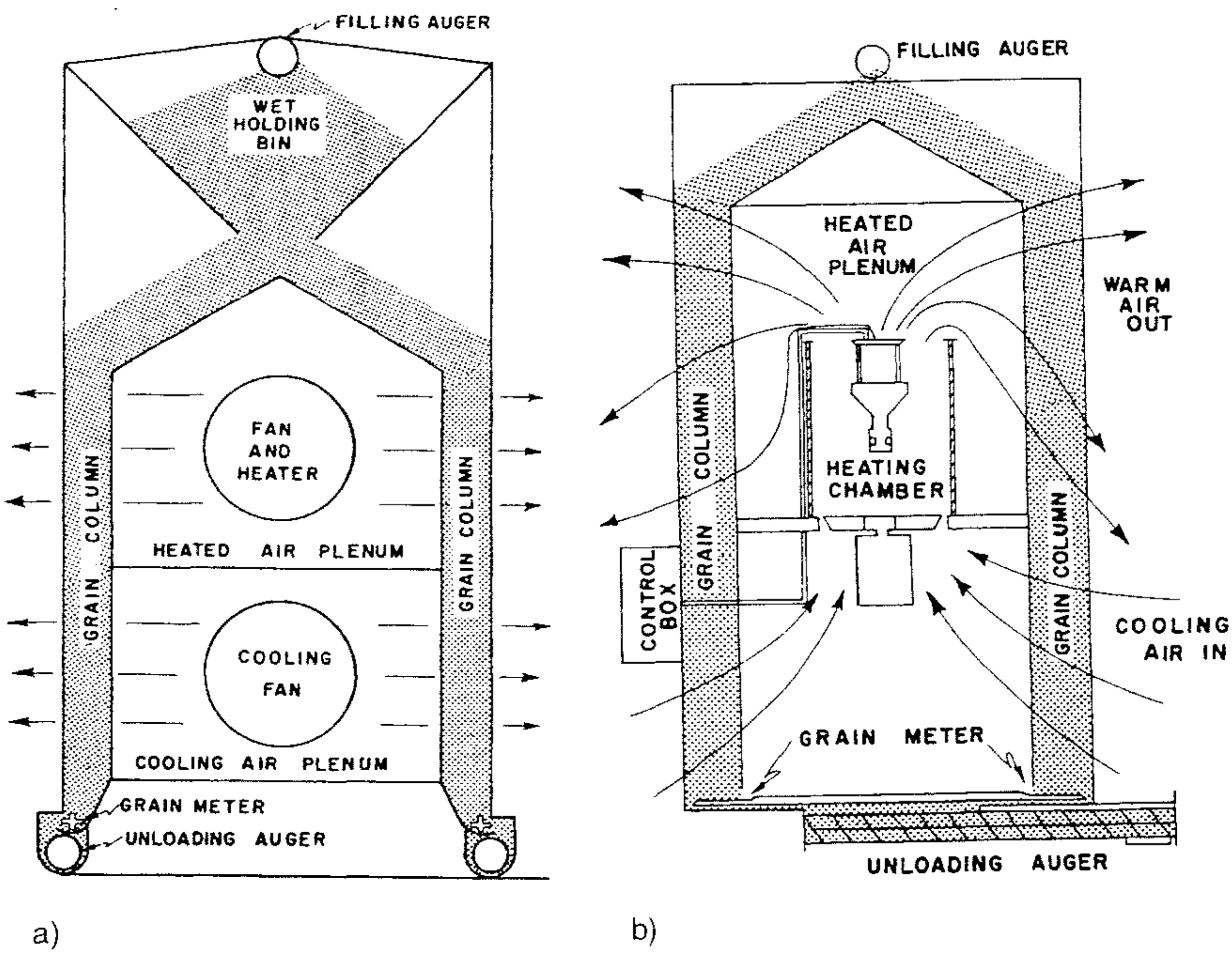
Source: Brooker et al. (1992)

Fig. 2.10. Schematic diagram of on-floor in-bin batch drying system

b. Off-farm drying systems

Grain dryers located off-farm in commercial handling facilities are termed off-farm dryers. Three types of such dryers are: cross-flow, mixed-flow, and concurrent-flow.

Cross-flow dryers

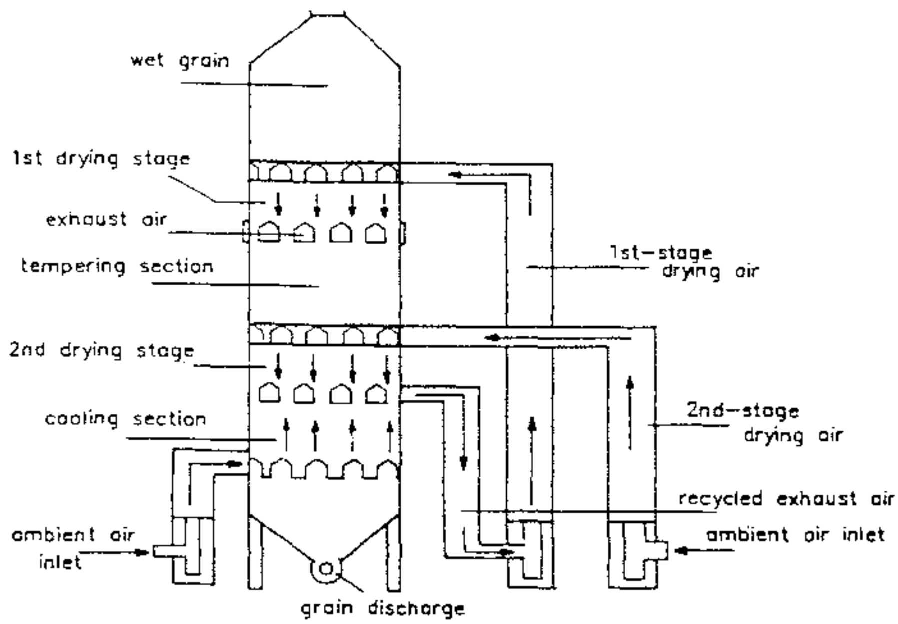


Source: Brooker et al. (1992)

Fig. 2.11. a) Conventional cross-flow dryer with forced-air drying and cooling; b) Modified cross-flow dryer with reverse-airflow cooling

This model has a perpendicular direction of the grain and air flows (Fig. 2.11), which results in non-uniform drying. Cross-flow dryers without reversal of air, or grain flow inverters develop moisture gradients across the drying column as large as 20%, and have grain breakage as high as 50%. Cross-flow dryers do not dry grain uniformly because of the existance of a large moisture gradient across the grain. The grain near the air inlet side of the grain columns often gets overdried, which results in increased breakage susceptibility, compared with the rest of grain column (Brooker et al., 1992).

Concurrent-flow dryers

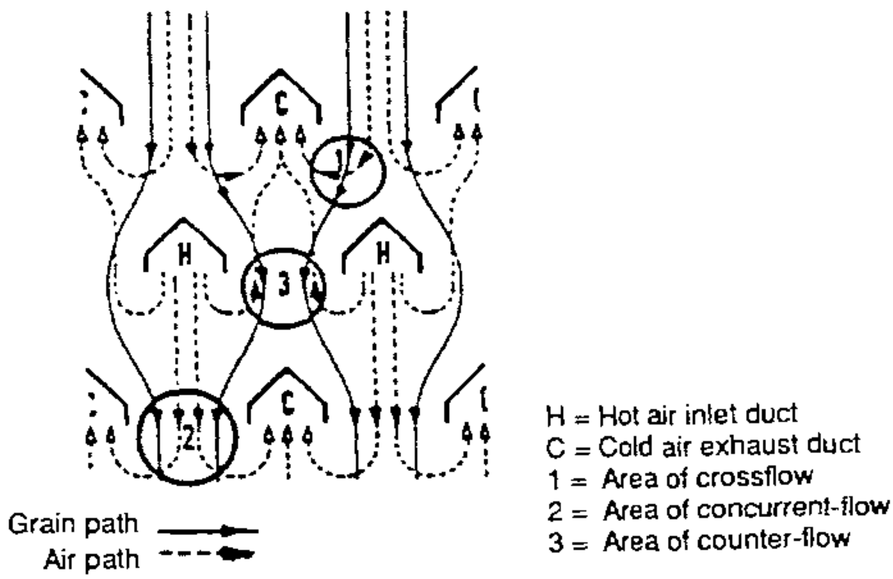


Source: Brooker et al. (1992)

Fig. 2.12. Two-stage concurrent-flow dryer with counter-flow cooler, tempering section

In concurrent-flow dryers the grain and drying air flow are in the same direction (vertically) as shown in Fig. 2.12. Cooling occurs in a concurrent-flow cooler in which the grain and air flows are in the opposite direction. The most distinguishing advantage of these dryers is the uniformity of the grain quality. Every kernel undergoes the same heating, drying, and cooling process, unlike in crossflow and mixed-flow dryers. The drying-air temperature is much higher than in other dryers because the wet grain is subjected to the hot drying for a few seconds only. Thus, the grain temperature does not approach the drying air temperature, and susceptibility to breakage in concurrent-flow dryers is half that of mixed-flow and one fourth that of cross-flow dried maize (Thompson et al., 1968; McLean, 1989; Paulsen, 1989).

Mixed-flow dryers



Source: Brooker et al. (1992)

Fig. 2.13. Schematic diagram of a mixed-flow grain dryer

Mixed-flow dryers are also called cascade or rack-type dryers. Grains are dried by a mixture of cross-flow, concurrent-flow and counter-flow drying processes (Fig. 2.13). The grain flows over a series of alternate inlets and exhaust air ducts. This results in fairly uniform drying, uniform grain moisture content and quality. The drying temperature in mixed-flow dryers is higher than that in cross-flow dryers because the grains are not subjected to the high temperature for a long period. Mixed-flow dryers are more expensive to manufacture (Thompson et al., 1968; McLean, 1989; Paulsen, 1989).

c. On-farm drying systems

The dryers shown in Fig. 2.11 are also used for on-farm drying. When they are operated as continuous units, the operation and operating characteristics are the same as those for off-farm dryers. For on-farm use, they are smaller than those of off-farm dryers in capacity (ordinary $\leq$ 12.5 tonnes per hour) (Brooker et al., 1992). Dryers of this size can be mounted on a wheeled chassis to facilitate easy movement within the farm.

2.7.3. Microwave drying

Energy may be supplied from various sources of electromagnetic radiation, whose wavelengths range from those of solar radiation (about 0.2 m) to those of microwaves (about 0.2 μm) (Keey, 1972).

Characteristics of microwaves include reflection, transmission and absorption. They behave in the same manner as infra red and light waves. Decareau (1992) suggested that microwaves in themselves are not heat. The materials that absorb microwaves convert the energy to heat. Products that have bi-polar molecules, for most part interact with microwaves to produce heat. Water in the product is the most common polar molecule. The water molecule is called a polar molecule because it has a negative and a positive end (a North and a South pole), and in the presence of a microwave electric field it attempts to line up with the field of a magnet.

Since the microwave field reverses its polarity millions of times each second, considerable kinetic enegy is extracted from the microwave field, and heating occurs. The phenomenon is similar to the heating of the products when exposed to the Sun. Energy in the form of infra-red rays from the Sun is not heat until it is absorbed by the product, and the polar molecules in the surface layers of the product convert it into heat (Decareau, 1992).

The main difference between microwave heating and other heating methods is that microwaves penetrate deeply into product materials and are converted to heat as they penetrate.

Since microwaves penetrate the product, they produce a pressure gradient that pumps out the moisture. This property can be used to advantage to speed up the drying process and produce a superior product at the same time, and this has significant advantage over conventional drying (Adu et al., 1994).

Although microwave heating is not generally considered a new technology, its use for drying large quantities of hygroscopic materials has not been exploited (Hall, 1992).

2.8. Effect of drying temperature

The quality factors of the grain as stated in section 2.4 are affected by drying methods. Drying air temperature and drying rate are particularly important to avoid internal grain breakage, cracking and splitting, sprouting, fungal growth, and loss of germination and vigour. Cereal grains reach physiological maturity at different moisture contents depending on the crop. These grains must have their moisture contents dried down to 10 - 14% to achieve a high quality storage product.

In fact, the water in the outer layers of grain evaporates much faster and more easily than that of the internal layers. Drying with high temperature permits quicker and more complete drying, and is especially useful for grain harvested in rainy seasons in humid tropical regions. However, grains are heat-sensitive, and the use of high temperature for drying wet grain for seed is particularly injurious (Hill and Johnstone, 1985). It would be a mistake to think that grain can be rapidly dried at high temperature because such drying conditions create internal tensions which produce tiny cracks that can lead to rupture of the grain during subsequent treatments. This is particularly true for rice.

When drying grain, moisture is initially removed from the outer layers, resulting in a moisture gradient from the centre to the periphery. If the drying temperature supplied is too high, the moisture gradient is too great, and internal stresses will cause cracking (Hampton, 1992). This creates favourable conditions for insect attack, and contributes to decreasing quality during storage. In addition, if grains are used for seed, high temperatures would likely kill the embryo, and thus reduce seed quality.

Boxall and Calverley (1986) stated that damage to the grain may arise if drying is carried out at too high a temperature or too fast. Excessive drying can result in developing seed abnormalities (Nutile, 1964). Thus, the drying process itself may adversely affects grain quality unless the drying system is selected and operated with care. No single temperature can be quoted which is safe for seed during drying, because many factors are involved, such as the type of seed, initial seed m.c., and drying rate. The maximum safe grain drying temperature depends on the m.c. of the kernel and the length of time it is maintained at that temperature. The drying temperature recommended by seed scientists ranges from 38 to 43°C (Copeland and McDonald, 1985).

A low temperature drying regime is safe for grain since it is unlikely to cause heat damage when drying. However, low temperature causes a slow drying rate, and therefore may allow deterioration to occur due to mould development before the seed is dry enough for storage. Brooker et al. (1992) suggested that if the rate of moisture removal decreases in the drying process, the drying time will increase accordingly.

2.8.1. Quality of grain used for human consumption

The baking and milling qualities of grain are also seriously impaired by excessive kernel temperatures. However, grain to be used for baking and milling can withstand somewhat higher temperatures than seed grain. Excessively high kernel temperatures in maize cause increased breakage, stress cracking, and kernel discolouration, and lead to a decrease in starch separation and oil recovery as well as protein quality. High kernel temperatures in wheat will damage its baking qualities (Brooker et al., 1974).

Table 2.2. Critical temperatures (°C) used in drying wheat

Moisture content, %	Seed	Baking
27	48	49
25	51	52
23	52	54
21	54	57
19	57	59
17	59	63
15	62	67

Source: McLean (1989)

The maximum allowable grain temperature depends not only on the end-use and the type of grain, but also on the moisture of the grain. Table 2.2 shows the critical temperatures for drying wheat as a function of grain m.c. and end-use for seed and for baking. The higher the initial m.c., the lower the allowable drying-air temperature (Brooker et al., 1974), so that the grain coat does not harden, which retards the evaporation from the grain kernel.

Excessive drying rates, or high temperatures for drying, may cause both physical and chemical damage to the product. Table 2.3 shows the maximum drying temperature for grains used for various purposes without becoming detrimental to quality. These recommendations have remained unchanged in the United Kingdom for many years and were originally discribed as 'maximum safe drying air temperatures' (McLean, 1989).

Table 2.3. Maximum safe drying temperatures

Grain and its use purpose	Moisture content %	Maximum grain temperature, °C
Malting barley and seed grain	below 24	49
	above 24	43
Milling wheat	below 25	66
	above 25	60
Grain for stock feed		82 - 104
Oily seeds		46

Source: McLean (1989)

Foster (1973) and Boxall and Calverley (1986) indicated that maize kernels used in the wet milling process should not be heated above 60 - 65°C, because above these temperatures, gluten becomes hardened or toughened and clings to the starch. This leads to reduced starch yield (Table 2.4). Wheat used for milling if dried at high temperature becomes case-hardened, and is more difficult to mill than normal wheat. In addition, the baking quality may be impaired if temperatures of over 80°C are used for grain drying.

Table 2.4. Drying temperature and starch yield in maize

Drying air temperature, °C	Starch yield, (% of dry weight)
23	62.2
60	61.2
86	60.2
114	57.5
141	48.8

Source: Foster, 1973

The discolouration of grain due to drying is another important factor to estimate the marketable grain quality. Heat damage caused by high temperature drying turns maize grains to "glassy" in appearance, which is similar to an appearance brought about by mould activity. Rapid drying at 147°C caused visible discolouration in ear maize (Hukill, 1954). When ear maize was dried at temperatures ranging from 87°C to 92°C, no damage was visible. However, the shelled maize when dried at the same temperature range showed the germ ends of the kernels to be shriveled and discoloured. The brittleness in grain which arises as a result of rapid drying at high temperatures is particularly noticeable due to cracks caused by stress in the kernels. Paddy, soybean and maize are prone to such internal cracking if dried too rapidly and subsequent handling will cause the kernels to break up (Boxall and Calverley, 1986).

For sorghum, Illyas and Birewar (1977) recommended that for continuous-flow dryers, air temperature should be within the 60 to 70°C range with an air flow rate of 45 to 60 m^3 per minute per ton of grain. On the other hand, the air temperature should be 40 to 45°C and air flow rate 30 to 40 m^3 per minute per ton of grains if drying in-bin, because drying by continuous-flow dryers creates more uniform drying than by in-bin dryers.

Drying peas cannot be satisfactorily carried out over a short period in a high temperature regime. Temperatures above 49°C may cause excessive toughening of the skin, and above 57°C the grain may be cracked, thus reducing cooking quality. Drying peas for human consumption by continuous-flow driers should involve a temperature which is not greater than 43°C if the m.c. of grain is over 24%. If the m.c. is below 24%, the drying temperature used should not exceed 49°C (Gane et al., 1984).

2.8.2. Quality of grain used for animal feed

It is known that at grain drying temperature above 92°C excessive stress-cracking occurs, resulting in increased breakage and greater susceptibility to mould during storage. For these reasons, it is recommended that feed grains should be dried at temperatures below 87°C (Brooker et al., 1974).

The nutritive value of maize for livestock feed is not normally reduced unless drying temperatures exceed 60 - 65°C. When maize is dried at high temperatures of up to 140°C, the loss in nutritive value has been shown to be relatively little (Foster, 1973).

Each of the nutritional components such as carbohydrates, proteins and vitamins reacts very differently to temperature treatment. Cabell et al. (1958) pointed out that protein nutritive value is more sensitive to heat than other nutritional factors. To this extent, a maximum temperature of 82°C for animal feed has been recommended (Muckle and Stirling, 1971; Salunkhe et al., 1985).

2.8.3. Oily seed quality.

Problems in drying oilseeds are very similar to problems in drying cereal grains except that oilseeds differ in indices of quality of the final product. Quality of the extracted oil can be reduced by improper drying temperature because heat-damaged seeds give an oil that is more susceptible to oxidation. Therefore, oilseed must be dried under conditions that do not reduce the grain quality and their products.

Moysey (1973) indicated that oilseed viability can be destroyed by prolonged exposure to temperature as low as 46°C. Temperatures higher than 40°C during artificial drying may affect oily seed viability. However, the temperature limit also depends on species and the end use (Muckle and Stirling, 1971; Hill, 1996), and on initial m.c. of the seed to be dried, as the seed is more sensitive to increases in temperature when the seed m.c. is high.

For soybean, the temperature of the drying air should not exceed about 30°C. Cold air should preferably be used for artificial drying in humid conditions. If hot air dryers are used, temperatures below 40°C must be maintained to prevent seed damage (Salunkhe and Desai, 1986).

2.8.3. Quality of seed

Seed requires a high germination percentage. Therefore, it is necessary to avoid loss of germination and vigour. If grains are dried too severely, they will crack, or the seed coat may become hard, retarding the germination because of reduced moisture permeability.

High seed temperatures will kill the embryo. At the initial stages of drying, when the m.c. of the seed is high, high levels of moisture evaporate from the surface. When the seed m.c. decreases following evaporation, this enhances seed temperature, causing death of the embryo. Drying temperature has an upper limit for individual seed species. In order to ensure the viability of seeds, Justice and Bass (1978) have recommended that the seed temperature during drying should not exceed 40 - 43°C, particularly for seed maize. Thus seed should not be dried under high temperature conditions. The maximum temperatures suitable for drying seeds of various crops are shown in Table 2.1.

Trim and Robinson (1994) also reported that seed must be dried in a manner that preserves the viability of the seed. Seed embryos are killed by temperatures greater than 40 - 42°C, and therefore, low temperature drying regimes must be used. Muckle and Stirling (1971) and Salunkhe et al. (1985) showed that drying temperatures of 44°C and higher will destroy the embryo of the seed.

However, the effects on germination also depends on initial seed m.c. (Hukill, 1974). When seeds are at a high initial moisture, the drying temperature should be lower. This is because when seed is dried at high temperature the high evaporation rate leads to moisture removal only from the coat. However, internal moisture of seed remains high, which leads to mould growth during storage. High temperature drying, or drying too quickly or excessively, can dramatically reduce viability (Bewley and Black, 1986) and vigour (Hampton, 1990). Drying too rapidly causes case-hardening whereby the surface of the grain dries out rapidly, sealing the moisture within the inner layers (Abe et al., 1992). This retards germination, and in some legumes increases the number of hard seeds.

Tanner and Hume (1978) indicated that a resultant feature of rapid removal of moisture at high temperatures was stress effects on seedcoats, resulting in cracking. Soybean seeds were dried at four temperatures by Sangakkara (1988) to observe damage caused to the seedcoats. The author suggested that the number of seed with cracks on the seed coat decreased significantly from 36.5 to 9.8% with hand-threshed seeds, and from 59.7 to 14.3% with machine-threshed seeds, when drying temperature was decreased from 60°C to 30°C respectively. His observation also indicated that high drying temperatures may allow earlier fungal infections because cracks developed act as points of fungal entry.

Mian (1983) demonstrated that drying sweet corn seed at 50°C produced internal cracks in 16% of seeds, whereas at a temperature of 30°C, no seed cracks were found.

Obviously, while high temperature increases drying rate, it also reduces seed quality. For best quality, seed drying temperature should not exceed 43°C for grain seeds and 32°C for vegetable seeds. Therefore, in order to reduce the risk of damage, Hill (1996) recommended that drying temperature should be lower than the maximum whenever possible.

2.9. High temperature drying followed by tempering

High temperature in drying was seen as the main cause of stress cracking in seeds and high dead seed percentage by many seed scientists. Peplinski et al. (1975) reported that maize seed of 24% initial seed m.c. after drying to 12% seed m.c. at a temperature of 32°C retained 92% germination whereas seed of 25% initial m.c. dried at 49°C to 12 % seed m.c. had germination reduced to 84%.

Rapid drying produces a steep moisture gradient in the grain. Ban (1971) found that the cracking in rice did not occur during rapid drying. The cracks appeared and increased for the next 48 hours after the drying process. White et al. (1982)

suggested the development of stress cracks in popcorn was caused by a redistribution of moisture after popcorn grain had been removed from the dryer. Stermer and Kunze (1990) developed an acoustical detection device to record the development of the cracks in rice during moisture adsorption. Hampton (1992) has suggested that during drying, moisture is initially removed from the outer layers, creating a moisture gradient from the centre to the periphery. This gradient is too great if too high a drying temperature is used, causing stresses between the interior and exterior layers, so that the grain develops stress cracks.

Kunze (1996) stated that cracks do not develop until the drying has ceased, when the moisture gradient within the grain is relaxing. Since cracks originate at the centre of the grain, they will develop while the centre is losing moisture to the drier outer layers.

Aziz (1985) studied the impact of drying temperature range on the cracking of shelled maize seed. He observed that when maize was dried from an initial seed m.c. of 20-22% to below 10% final seed m.c. using temperatures of 20, 30, 40 and 50°C, seed cracking occurred at all drying temperatures except 20°C. The highest percentage of stress cracked seeds was 29.2% with drying at 50°C, while it was 10 and 5.1% at 40 and 30°C respectively. This author further observed that cracking did not affect the germination immediately after drying but was the point of infestation of storage fungi and insects, that led to reduced storability. These drying temperatures had no significant effect on the germination after an accelerated ageing test. However, the trend in results showed an increase in reduction of germination with increasing drying temperature.

The recommendations for temperature limitations to avoid deleterious effects are usually stated on the basis of drying air temperatures. Various reports have shown that air temperatures above 43°C are detrimental to the viability of maize seed, especially if the seed m.c. is relatively high at the start of the drying process.

The usefulness of tempering has been known for a decade. Drying in association with the tempering process allows the relieving of some of the stresses within the grain (Escasinas, 1986). Grain, after having been dried to moisture levels two to three percent higher than the desired final m.c., is transferred to the tempering bin with a temperature of 50-70^{0}C (Brooker et al., 1992). Thompson and Forster (1963) showed that reducing moisture extraction of maize during drying with high temperature by 4 to 5% per drying pass will decrease the development of stress cracks. Watson (1987) stated that stress cracking of maize is further prevented by limiting the rate of drying. Kato and Yamashita (1979) stated that high storage temperatures would help to reduce the development of cracks when they temporarily stored rice at 60°C after drying.

Abe et al. (1992) dried rough rice from an initial m.c. of 27.1% to a final m.c. of 15% (w.b.) with a procedure of intermittent drying-tempering. After the grains were dried for a certain time, they were removed from the drier to an incubator of lower temperature to temper for a certain time. This process was repeated for each drying cycle until the grain m.c. reached the desired level. They suggested that recycling procedures of drying at 45 to 55°C for 5 to 10 minutes and tempering at 25°C for 45 minutes were appropriate for reducing the percentage of cracked rough rice during drying and caused no loss in value. These authors achieved the highest germination of 98% when they conducted experiments with either drying at 40°C for 5 to 10 minutes with tempering at 25 and 35°C for 45 minutes, or 50°C drying temperature for 3 minutes with a 35°C tempering temperature for 45 minutes. These studies suggested that high temperature drying for short periods followed by tempering at lower temperature may give energy use efficiencies while retaining seed viability.

2.10. Storage

Storage is a phase of the postharvest system. The main objectives of storage are to permit different uses of the agricultural products harvested and ensure availability of seeds for the crop cycles to come. In addition, grain storage also maintains regular and continuous supplies of materials for processing industries, and balances the supply and demand of agricultural products, stabilizing market prices.

In order to attain these general objectives, it is obviously necessary to adopt measures aimed at preserving the quality and quantity of the stored products over time.

To conserve the quality of products over long-term storage, degradation processes must be slowed down or even stopped. The factors which influence seed deterioration during storage are environment conditions and seed quality before being stored. Degradation of grain during storage depends principally on a combination of environmental factors, such as temperature, moisture and oxygen content. During storage, as during other phases of the postharvest system, the combined effects of these environmental factors can sometimes cause severe losses. Temperature and moisture have a direct influence on the speed of development of insects and micro-organisms (moulds, yeasts and bacteria), and on the premature and unseasonal germination of grain.

The moisture content of seeds to be stored is a factor of initial seed quality affecting seed longevity. The thickness, structure and chemical composition of the seed coat affect the rate of water absorption and retention (Justice and Bass, 1978). However, drying to a safe level for storage is not enough for successful storage because grain m.c. will come to an equilibrium with the surrounding air during storage. Therefore, the temperature and the relative humidity of the storage environment are the most important factors affecting the maintenance of seed quality. There is a relationship between relative humidity and grain m.c. Relative humidity reflects the amount of moisture actually in the air as a percentage of the amount of moisture that the air is capable of holding.

The best storage atmosphere is dry and cold. This helps retain the viability and vigour of many seed types. After drying and placing in storage, seed moisture content still may change depending upon the fluctuation of temperature and relative humidity of the surrounding air. Temperature and humidity of the storage atmosphere should be kept relatively low to minimize seed deterioration. A rule of thumb suggested by Harrington (1973) is that the numerical sum of air temperature (in degrees F) and the relative humidity (in percent) should not exceed 100.

The relative humidity of the store and seed m.c. tend to reach an equilibrium, hence, the relative humidity should be kept no higher than that in equilibrium with the desired seed moisture content. Table 2.5 shows the equilibrium m.c. of some grain seeds at 25°C and various relative humidities. Relative humidity of the storage environment affects directly the seed m.c. that indirectly affects seed quality by the activity of storage fungi. Harrington (1972) stated that in the seed moisture range of 18 - 20%, heating can occur as a result of the respiration of seed and of fungi and bacteria inside or on the seed coat.

Prolonging seed storage as long as possible is the best way of preserving plant genetic resources (Côme, 1983). The main factors affecting seed longevity during storage are temperature and seed m.c. In most cases, the lower the seed m.c. and storage temperature, the longer the viability. Harrington (1973) reported that seed longevity doubled when seed m.c. was reduced by 1%, or when temperature was lowered by 5°C, when seed m.c. was between 5 and 14%. However, according to Roberts and Ellis (1977), longevity would double when seed m.c. was reduced by 2.5% and temperature by 6°C.

Table 2.5. Equilibrium moisture content (%) of grain seeds at 25°C and various relative humidities.

Grains	Relative humidity (%)						
	15	30	45	60	75	90	100
Barley	6.0	8.4	10.0	12.1	14.4	19.5	26.8
Maize Shelled	6.6	8.4	10.4	12.9	14.7	18.9	24.6
Rice	5.9	8.6	10.7	12.8	14.6	18.4	_
Oats	5.7	8.0	9.6	11.8	13.8	18.5	24.1
Pea[a]	_	8.6	10.1	11.9	15.0	22.0	26.0
Broad bean[a]	_	7.2	9.3	11.1	14.5	22.6	27.5

Sources: American Society of Agricultural Engineering. (ASAE, 1972)

a. Data compiled by Hill (1996)

There are basically two methods of storage: in bags and in bulk. Bags can be stored in the open air or in warehouses; bulk grain is stored in bins or silos of various capacities. The choice between these methods and the degree of technological sophistication of the storage buildings depend on many technical, economic and socio-cultural considerations. However, in any method chosen, the storage environment must be firstly considered.

2.11. Research objectives

The general objectives were five-fold:

1. Assess the suitability of natural ventilation, sun drying, and Kiwi Mini dryers for drying pea seeds.

2. Assess the effect of selected drying methods and initial seed moisture content on time and energy consumption.

3. Evaluate the main changes in pea seed quality (germination, vigour) as affected by drying techniques and drying parameters and storage conditions (temperature, relative humidity).

4. Determine whether tempering would allow seed maize to be dried at high temperature without affecting quality.

CHAPTER III

MATERIALS AND METHODOLOGY

This chapter presents details of the materials and methodology used to achieve the objectives stated in the previous chapter. The experiments were conducted in the Department of Agricultural Engineering (now part of the Institute of Technology and Engineering), and Seed Technology Centre (now part of the Institute of Natural Resources), at Massey University Turitea Campus, New Zealand.

Experiment 1: COMPARISON OF PEA SEED DRYING METHODS

3.1. Field growing of seed grain

Gane et al. (1984) have reported that harvesting pea seeds in the UK at around 25% seed m.c. minimised harvest damage and produced higher quality seed than when the crop was harvested at 15% seed m.c. In New Zealand, pea seeds are normally harvested at 14 to 16% m.c. (Rae, 1986). Delays in harvesting may lead to shattering or quality loss due to bleaching (Hampton, 1994). However, earlier harvest will result in energy costs involved with drying the seed to a safe seed m.c. for storage.

Peas were harvested from a crop grown at Massey University which had been sown in early December 1996. The original intention was to harvest peas at three seed moisture levels, 24.0, 18.0 and 14.0% for drying experiments. Before seed moisture content reached the first level of 24.0%, moisture content tests were regularly conducted to decide the first harvest day. These tests began on 20^{th} of February, and then were conducted every 5 days. Twenty five pea pods (about 80 g of seeds) were picked randomly from the field. Seeds were taken out of the pods by hand, and seed m.c. was determined (section 3.4.1). However, because of wet weather during February, 1997, peas began to sprout in the pods, and all the pea seeds had to be harvested immediately at 28.0% moisture content. The harvest was conducted by hand, which took 2 days, because most of the plants had lodged. The whole plants were picked and brought to the machinery hall. Pea plants were immediately spread on the indoor concrete floor to avoid further deterioration before being threshed at 24.0% m.c. All the seeds were threshed using a 'Seed Master' thresher with a drum speed of 680 rpm and cleaned by spiral separation.

After cleaning, seeds were tested for purity. The minimum weight of working sample for *Pisum sativum* L. is 900 g (ISTA, 1993a). Therefore, two half samples of at least 450 g of seeds were individually drawn and weighed to 1 decimal place. Seeds were sorted into three components: pure seeds, other seeds and inert matter. The harvested seed lot had a purity of 68%, and the impure seed consisted mostly of sprouted seeds.

3.2. Seed preparation

After threshing and cleaning, seed was mixed by hand and divided into three lots. Lot 1 with an initial m.c. of 23.8% was dried immediately (section 3.3). Lots 2 and 3 were spread on a floor in a large shed at a depth of 5 cm for 3 and 10 days with regular turning using a plastic spade to allow m.c. to reduce to 18.0% and 14.5% respectively.

Before seed lots were used for drying, pure seeds of each lot was tested for germination (section 3.4.2), moisture content (section 3.4.1) and conductivity (section 3.4.3). A pilot test was conducted with microwave treatment to test if the seeds retained their quality (section 3.3.1). However, because the quality was thoroughly lost while seeds were not dry enough, the microwave treatment was rejected. Every seed lot was then divided by hand into 7 sub-lots of 3,000 g to be dried under 7 different conditions (Appendix 1).

3.3. Experimental treatments

3.3.1. Microwave drying

A 650 W microwave ('National' brand) with a frequency of 2450 Hz was used.

Preliminary tests were conducted to detect the time needed to dry seed from initial moisture contents of 23.8, 18.0 and 14.5% to 10%. The germinability of the seed after microwave drying was also determined.

Table 3.1. Microwave drying test results

Exposure time (min.)	Moisture content (%)	Germination (%)
0	23.8	82
20 mins, 325 W	17.0	2
30 mins, 195 W	17.4	0

However, when seeds at 23.8% m.c. were placed in a single layer in the microwave oven for 20 minutes at medium power of 325 W and for 30 minutes at low power of 195 W, seed moisture was still high at around 17%, while the seeds had completely lost their germination capacity (Table 3.1).

Based on these test results, further experiments with microwave drying were discarded.

3.3.2. Natural sun drying

Pea seeds were spread in a thin layer (around 2.5 cm) on a concrete floor in the open using an area of $0.69 \text{ m} \times 0.40 \text{ m} = 0.276 \text{ m}^2$. Every 4 hours, a sample was taken to test if the seeds had reached 10% m.c. A thermometer was placed at ground level to measure wet bulb and dry bulb temperatures of the air. If it rained or if relative humidity of the natural air (determined by using a psychrometric chart based on air temperatures) would have resulted in a pea seed equilibrium m.c. (Table 2.5) higher than the present m.c. (4 hourly determination), the seed lot was collected, placed in a plastic bag which was placed in a sealed plastic box to prevent drying or rewetting during this time. Seeds were continually exposed to the sun for further drying each day until they reached the desired m.c. This method was used twice (see Fig. 4.3).

Fig. 3.1. Pea seed drying under natural sun condition.

3.3.3. In-bin natural ventilation drying

A wooden box 0.69 m long × 0.40 m wide × 0.30 m high (Fig. 3.2) was constructed to dry pea seed by natural air ventilation. Pea seeds were spread in a shallow layer of 2.5 cm, which was similar to that of Natural Sun Drying, in the box within an area of $0.69 \times 0.40 = 0.276$ m^2. The difference in size between the intake and outlet forced air to circulate within the box, and therefore removed moisture from the seeds. Every 4 hours, a sample was taken to test if the seeds had reached 10% m.c. Because this box was put outside to get natural air for drying, when it rained, or when the relative humidity of the natural air would have produced an equilibrium m.c. higher than the present m.c. of the seeds, the seed lot was collected, placed in a plastic bag which was then placed in a sealed plastic box to prevent further drying or rewetting. Seeds were continually in-bin dried until the desired seed m.c. was reached.

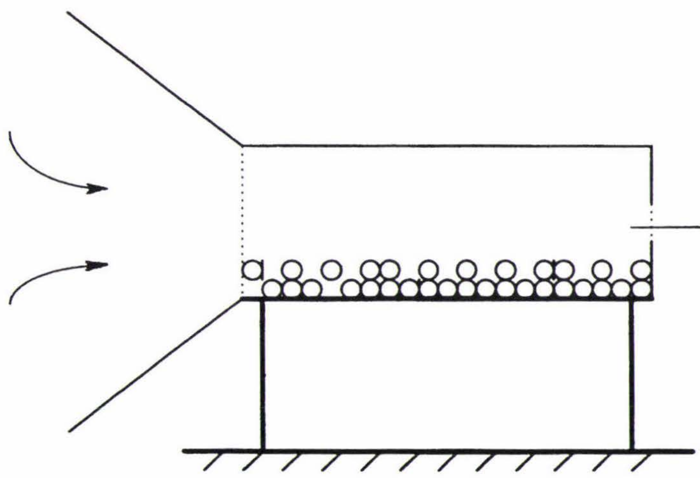


Fig. 3.2. Grain drying bin with large funnel exposed to natural wind direction and a small opening in the rear wall.

3.3.4. Artificial drying

Kiwi Mini dryers, developed at the Seed Technology Centre (Fig. 3.3) were used for these experiments. A built-in fan was used to force ambient air through an electrical heater, and blow heated air through the seeds. With these dryers, an anemometer and thermometer were used to measure air speeds and temperature respectively of the air entering and leaving the seed bulk.

Two drying temperatures, 30°C and 45°C, were set for drying to compare the effect of temperature on quality of the seed and efficiency of drying. Two different dryers were used at each temperature.

Every two hours during drying, the seed mass was weighed to find if the moisture of the seed had reached the desired final m.c. The final weight was calculated as follows:

Supposing that initial wet seed of M_o moisture content has a weight of W_o, the formula for determining moisture content is:

$$M_0 = \frac{W_0 - W_d}{W_0} \tag{3.1}$$

where, W_d is weight of the completely dry seed mass.

After drying to final moisture of M_f , the seed mass has the weight of W_f.

$$M_f = \frac{W_f - W_d}{W_f} \tag{3.2}$$

From (4.1) and (4.2) the final weight of the seed mass is:

$$W_f = W_0 \frac{(1 - M_0)}{(1 - M_f)} \tag{3.3}$$

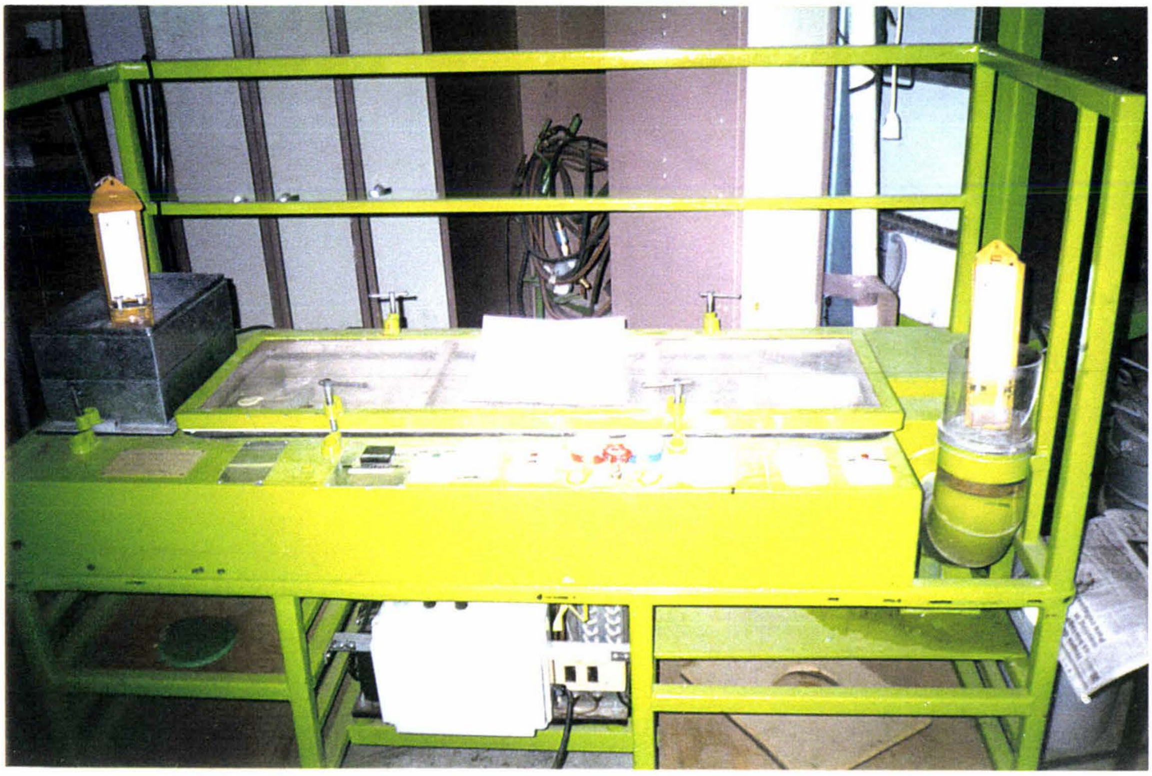


Fig. 3.3. Kiwi Mini Dryer and equipment for drying.

3.4. Parameters and measurement procedures

3.4.1. Seed moisture content

Seed m.c. was determined by using an air oven method. For seed samples with a m.c. higher than 17%, seed m.c. was determined in two stages.

At the first stage, two seed sub-samples of at least 25 g each (W_{o1}) were placed for 30 minutes into a oven set at 130°C, and then kept exposed separately in a laboratory room for 2 hours (ISTA, 1993a), by which time the seed m.c. had reduced to less than 17%, and it's weight was denoted as W_{11}. The seed moisture loss at this stage was then determined:

$$S_1 = \frac{W_{01} - W_{11}}{W_{01}} \qquad (3.4)$$

For the second stage, these two sub-samples were separately ground so that more than 50% of the particles were less than 4 mm (ISTA, 1993a). Sub-samples of less than 10 grams of ground seed (W_{02}) were taken, and placed into a 130°C oven for 1 hour as suggested by ISTA (1993a) for pea. After removal from the oven, the sub-samples were placed in a desiccator for 15 minutes, and then reweighed (W_{12}). This stage was also used to determine the m.c. of any pea seed lots with a m.c. less than 17%. The seed m.c. loss at this stage was calculated as follows:

$$S_2 = \frac{W_{02} - W_{12}}{W_{02}} \qquad (3.5)$$

The final seed moisture content(s) when using two-stage drying, was calculated as follows:

$$S = S_1 + S_2 - \frac{S_1 \times S_2}{100} \qquad (3.6)$$

If the difference in m.c. between two subsamples exceeded 0.2%, the determination was repeated.

3.4.2. Seed germination

Normal germination is defined as the emergence and development of the seedling to a stage where its essential structures show that the seedling is able to develop further into a plant under favourable conditions in soil.

The between paper (BP) method was used in the germination test for pea (ISTA, 1993a). Four replicates of 50 seeds for each seed sample were spread on two sheets of damp paper using a counting board. Another sheet of damp paper was placed on top. Sheets of paper with pea seeds inside were rolled up and put upright in a wire basket. The basket was then put into a plastic bag to prevent water evaporation, and placed in a 20°C room (Fig. 3.4).

An interim count of normal seedlings was made after 5 days (ISTA, 1993a), and the final count of normal and abnormal seedlings and remaining seeds was made after 8 days (ISTA, 1993a).

Pea seeds belong to group A 2.2.2.2 (ISTA, 1993b). The symbols in order indicate that pea is an agricultural and horticultural species and its systematic class is dicotyledons. Its germination mode is hypogeal and shoot characteristics are epicotyl elongation. Secondary roots are taken into account when assessing germination.

Therefore, a pea seedling was classed as normal if it satisfied all the conditions below:

- the primary root was intact or with slightly discoloured or necrotic spots. If the primary root was defective, but the secondary roots were sufficient and normally developed, the root system was defined as normal.
- the cotyledons were intact or with slight defects, the epycotyl was intact or with slightly discoloured or necrotic spots,
- the primary leaves were intact or with slight defects, and the terminal bud was intact

A pea seedling was defined as abnormal if it contained one or more of the following:

- the primary root was either stunted or retarded, missing, broken, trapped in the seed coat, glassy, but insufficient normal secondary roots,
- the cotyledons were more than 50% damaged or deformed, separate or missing, discoloured or necrotic,
- the epicotyl was either short or missing, deeply crached, broken, glassy

- the primary leaves were either separate or missing, damaged, deformed, discoloured or necrotic,
- the terminal bud was missing or defective

Fig. 3.4. Germination rolls in the germination room.

3.4.3. Conductivity of the seed

The conductivity of the samples was measured using a conductivity meter Model CDM-83. This meter gives a direct readout of the conductivity of the sample in micro-Siemens (μS). The mesurement method as stipulated by Hampton and TeKrony (1995) was used. This included:

Four replicates each consisting of 50 seeds from each seed lot were weighed to 2 decimal places and each replicate was placed in a flask containing 250 ml deionized water. The flask was then covered by parafilm foil to reduce evaporation and dust contamination, and kept at 20°C for a 24-hour soaking time. A control flask containing 250 ml deionized water without seed was set up with each test run.

After the soaking, the flask of seeds was gently swirled for 10-15 seconds, and the conductivity was then determined by immersing the dip cell in the solution. After each reading the dip cell was thoroughly rinsed in deionized water to avoid any errors in the next reading. All the readings were conducted in a 20°C room (Fig. 3.5).

Fig. 3.5. The Conductivity meter with the flasks of peas.

The reading of the control flask was subtracted from each reading. This corrected value was then divided by the weight (in grams) of the 50 seeds for each replicate, so that the result was expressed as $\mu S.cm^{-1}.g^{-1}$.

3.4.4. Hollow heart

During the germination test, in the first and final counts, every normal seedling was split in half and checked for symptoms of hollow heart that may vary from a small shallow depression to a large cavity as suggested by Castillo (1992). The number of normal seedlings that had this symptom was used for determining the percentage of hollow heart.

3.4.5. Expected field emergence

An assessment of expected field emergence (EFE, %) is successfully applied for peas to determine the planting value (Hampton,1994). From this EFE, the required sowing rate, which is recommended to growers to meet a target plant population, is easily determined. The EFE is calculated by using the results of the standard germination test (Std.G, %), conductivity test (C, $\mu S.cm^{-1}.g^{-1}$) and hollow heart (HH, %) (Hampton and Scott, 1982).

$$EFE = 26.8 + 0.7 \times Std.G - 0.34 \times HH - 0.23 \times C \qquad (3.7)$$

3.4.6. Air velocity.

An anemometer manufactured by Davis Instrument Mfg. Co., Inc. was used in this experiment (Fig. 3.6). The air velocity was recorded every two hours during drying. Anemometer readings were timed for 1 minute. Because the readings from this anemometer were given in feet per minute (V_1), the results were transferred to meters per second (V_2) using the following formula:

$$V_2 = \frac{0.3048 \times V_1}{60} \quad (3.8)$$

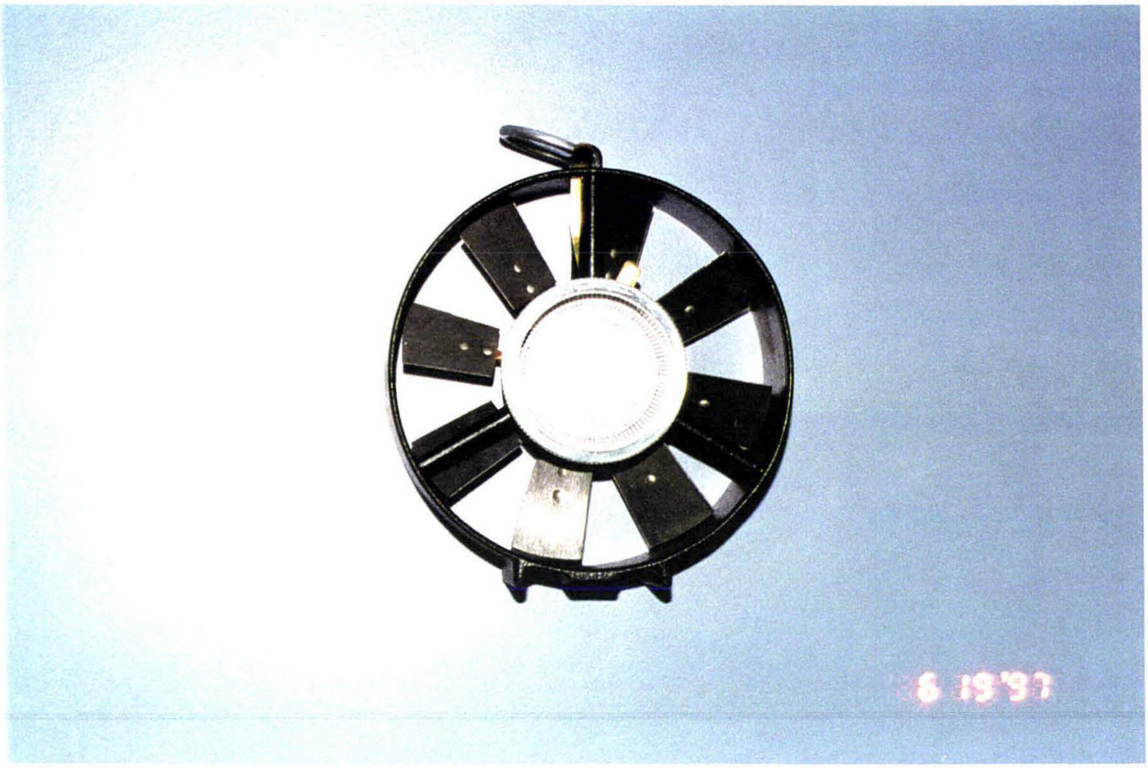


Fig. 3.6. Davis anemometer

3.4.7. Temperature

In seed drying, the temperature needs to be measured to define the environment to which the seed is exposed. Temperature is a very important parameter because of its effect on drying rate, quality of the seed after drying and seed storage life.

Three thermometers were put into each dryer. The first one was to measure ambient air temperature and ambient relative humidity (r.h.) was determined by using psychrometric chart based on wet bulb and dry bulb temperatures. The second one was to measure drying air temperature and r.h. after heating, and the third one was to measure exhaust air temperature and r.h. after drying the seed (Fig. 3.3). The readings were recorded every two hours throughout the drying process.

3.4.8. Weather data

Intensity of sun radiation (I_r, $W.m^{-2}$) data measured by the Horticultural Research Institute every 30 minutes each day at the meteorological site of the Massey University Research Orchard, which is about 2 km away from the drying place were used.

3.4.9. Determination of energy consumption

A psychrometric chart was used to determine energy consumption. The diagram as shown in Fig. 3.7 can be used for tracing the changes in the state of the air. The drying process consists of taking air at initial condition A. This air is heated to condition B without addition of water. The heated air then passes through the grain bulk to condition C to pick water up without changes in heat (Teter, 1987; Brooker et al., 1992). These three air conditions A, B and C are similar to air conditions at points A, B and C in Fig. 3.8. The changes in air conditions from A to B involve a change of heat without change in moisture, while changes in air conditions from B to C involve a change in moisture without a change in heat. The change from A to B is the heating process, and the adiabatic change from B to C is the drying process.

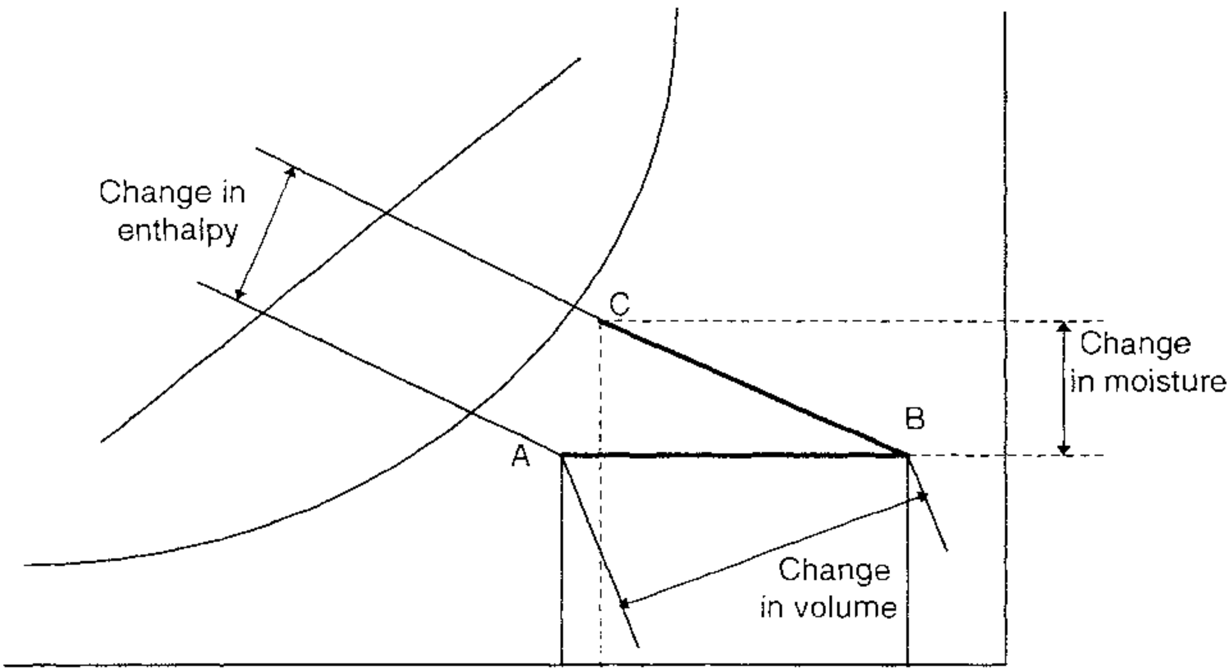


Fig. 3.7. Schematic diagram of drying air circulation: A- Ambient air, B- Heated air; and C- Discharged air.

3.4.9.1. Artificial drying

Energy consumed (EC) in kWh for drying by the artificial dryer was determined as follows:

$$EC = Q.(D_2.q_2 - D_1.q_1).t \quad (3.9)$$

where, Q = the air volume passing through seed bulk per second, ($m^3.s^{-1}$)

D_1, D_2 = the air densities before and after heating, ($kg.m^{-3}$)

q_1, q_2 = the specific enthalpies of the air before and after heating, ($kJ.kg^{-1}$)

t = the drying time, (h).

The air volume (Q, $m^3.s^{-1}$) is obtained by multiplying the area (S, m^2) and air velocity (V, $m.s^{-1}$) measured at the inlet. The air densities (D_1, D_2) and the specific enthalpies (q_1, q_2) of the air before and after heating were measured from the psychrometric chart, based on the ambient temperature and temperature of the air after heating.

Therefore,

$$EC = V.S.(D_2.q_2 - D_1.q_1).t \qquad (3.10)$$

Kiwi Mini dryers have an inlet diameter of 0.14 m. Hence, the inlet area is:

$$S = \frac{\pi.d^2}{4} = \frac{\pi \times 0.14^2}{4} = 0.0154 \ \text{m}^2 \qquad (3.11)$$

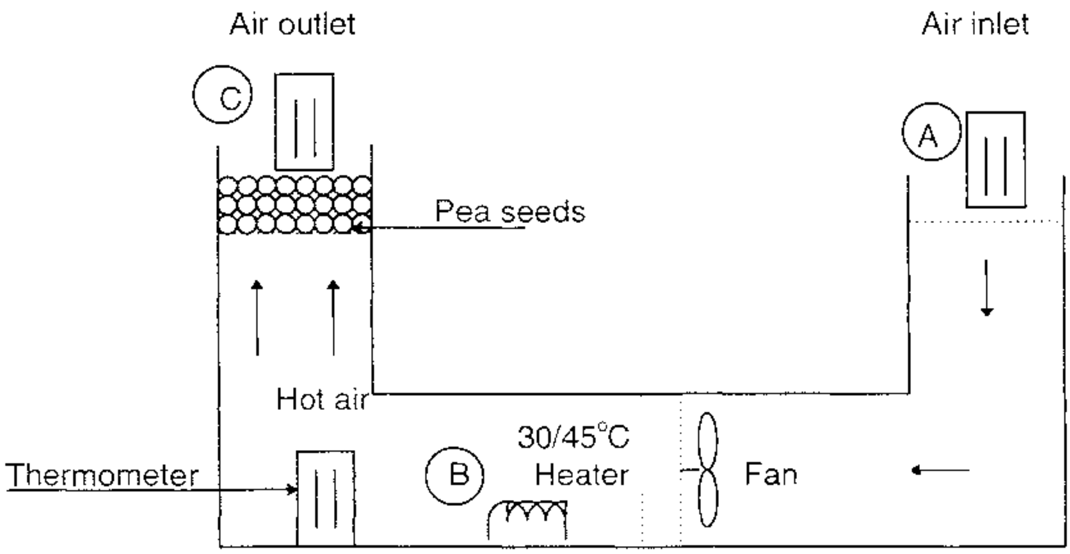


Fig. 3.8. Schematic diagram of air circulation in Kiwi Mini dryer

3.4.9.2. Natural sun drying

The energy from the sun is presented as intensity of radiation. The energy absorbed by drying from natural resources was determined using the formula:

$$E_s = I_r . S_d . t_d . 10^3 \qquad (3.12)$$

where: E_s (kWh) = Energy absorbed when drying by natural sun radiation;

I_r ($W.m^{-2}$) = Intensity of radiation from the sun. Mean radiation data collected when the seed lot was exposed to the sun;

S_d (m^2) = The area of the concrete drying floor used for spreading seeds under the sun for drying. In this experement, all the seed lots were exposed to the same area of S_d = 0.276 m^2;

t_d (h) = Time consumed for drying.

3.4.9.3. In-bin natural ventilation drying

The bin for natural ventilation drying was essentially similar to the artificial dryer design concept, the main difference being that the ambient air passing through the bin had not been artificially heated. Its enthalpy is absorbed by moist seeds to bring the moisture content of the seed to an equilibrium at this air condition.

The air after passing through the bin of seed had a lower temperature than that of natural air. It was therefore assumed that this air was 'heated' by the sun to ambient temperature to supply the heat for drying (Fig. 3.9). Therefore, the energy consumed for this 'heating' process is equal to the energy absorbed by moist seeds for drying, and is calculated as follow:

$$E_v = V.S.(D_1.q_1 - D_2.q_2).t \qquad (3.13)$$

where,

E_v (kWh) = The energy absorbed by moist seeds for drying;

V ($m.s^{-1}$) = The air velocity passing through the bin at the outlet;

S (m^2) = area of the outlet;

D_1, D_2 (kg.m^{-3}) = The air densities before and after passing through the bin;

q_1, q_2 (kJ.kg^{-1}) = The specific enthalpies of the air before and after passing through the bin;

t (h) = The drying time.

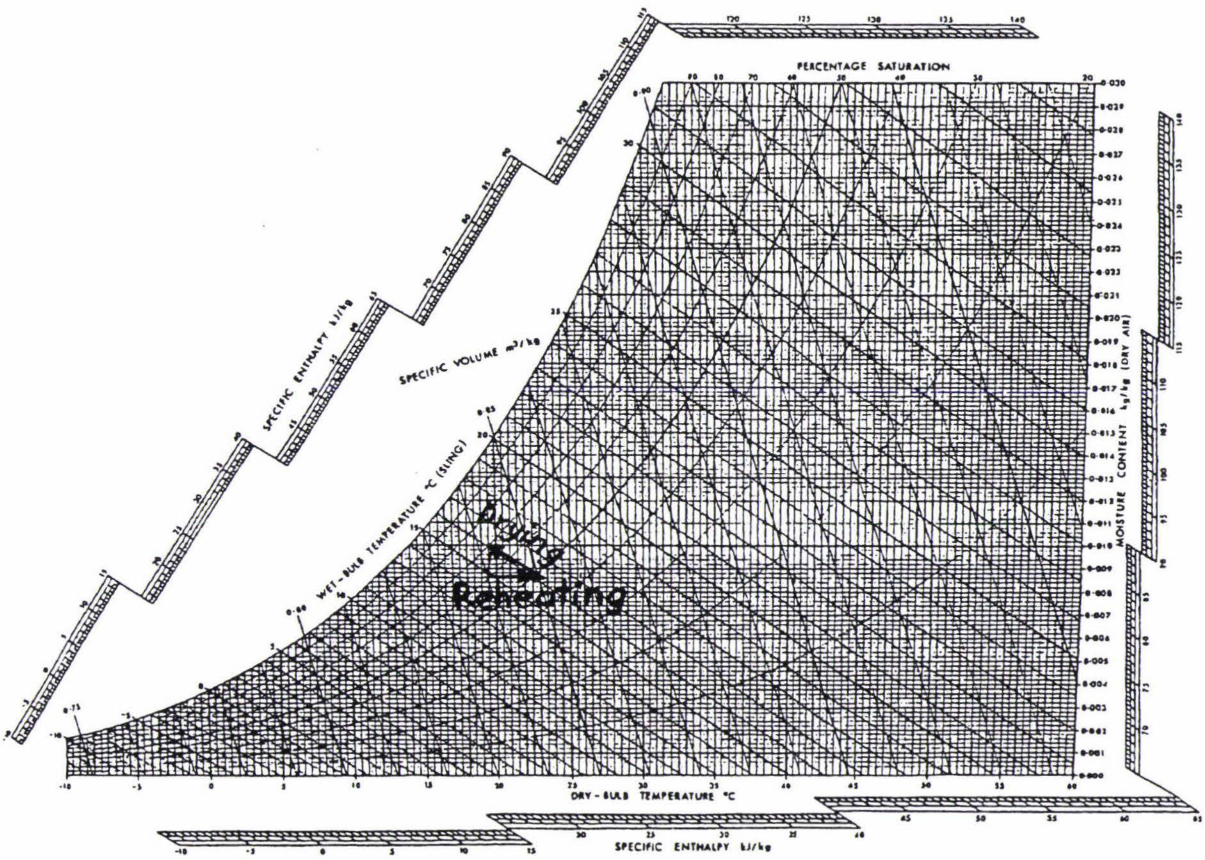


Fig. 3.9. Air reheating progress and energy calculation chart

The air densities (D_1, D_2) and the specific enthalpies (q_1, q_2) of the air before and after passing through the bin were measured from the psychrometric chart, based on the ambient temperature and temperature of the air after passing the bin. The ventilation bin had an outlet diameter of 0.08 m, therefore the area of the outlet is:

$$S_v = \frac{\pi . d^2}{4} = \frac{\pi \times 0.08^2}{4} = 0.005 \text{ m}^2 \qquad (3.14)$$

3.5. Storage conditions

After drying seeds to around 10% moisture content, seed germination and conductivity were immediately determined. Each seed lot after drying was split into two halves.

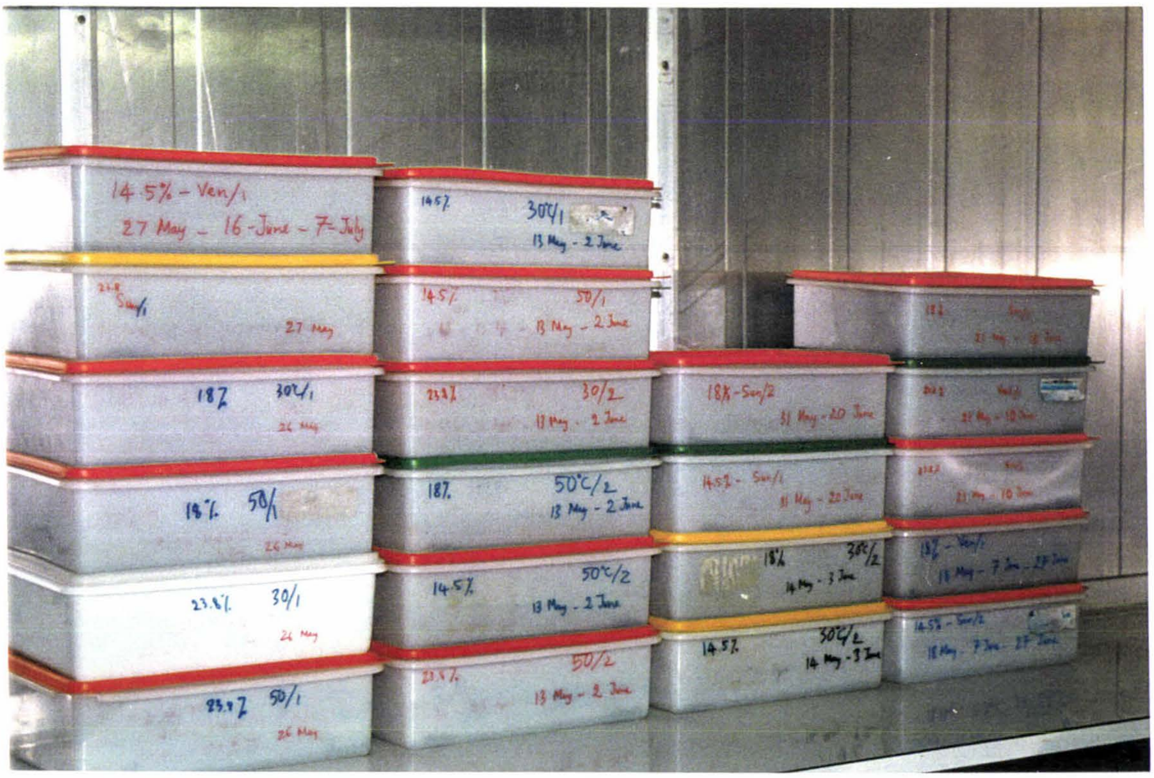


Fig. 3.10. Closed storage at 25°C temperature and 90% relative humidity

Fig. 3.11. Open storage at ambient conditions of 20.5°C temperature and 55% relative humidity

One half of each seed lot was placed onto the wiremesh above a solution of 30% glycerine and 70% distilled water. This system was closed in a plastic box and put into a 25°C room to establish 90% relative humidity conditions (Fig. 3.10). The other half of each seed lot was put into an open paper bag and placed in a laboratory room where average temperature and relative humidity were 20.5°C and 55% respectively (Fig. 3.11). After 20, 40 and 60 days of storage, seeds from both storage conditions were tesed for moisture content, germination, conductivity and hollow heart.

Experiment 2: EFFECT OF HIGH TEMPERATURE DRYING AND TEMPERING ON MAIZE SEED QUALITY

3.6. Introduction

Seeds are heat-sensitive. Drying air temperature and drying rate are particularly important to avoid internal seed breakage, cracking and splitting, fungal growth, and loss of germination and vigour. The use of high temperature for drying wet seeds is particularly injurious (Hill and Johnstone, 1985), because such drying conditions create internal tensions, producing tiny cracks that can lead to rupture of the seeds during subsequent treatments. The drying temperature for seed recommended by seed scientists ranges from 38 to 43°C (Copeland and McDonald, 1985).

However, some studies showed that seed can be dried at high temperature for a very short time, followed by tempering to re-distribute moisture and temperature inside the seed, thus reducing the percentage of cracking.

The temperature effect is associated with the time that the seeds are exposed to that temperature. Hence, it was possible to use high temperature seed drying for a short period of time. In addition, in order to eliminate the moisture gradient within individual kernels, the difference between grain temperature and temperature of the surrounding air after drying should not be too great. This might be done by gradual decreases in temperature to redistribute moisture within the kernel and this is referred to as "tempering". Escasinas (1986) suggested that tempering may alleviate cracking damage. Studies by Abe et al. (1992) on drying rough rice at high temperature with intermittent drying-tempering suggested that high temperature drying for short periods followed by tempering at lower temperature may retain seed viability.

3.7. Seed preparation

Maize (P-3902) was hand-harvested on 4th June from a Seed Technology Centre field, and shelled by hand to avoid seed cracking. Twelve kg of maize seeds of 28.2% m.c. at harvest was then mixed and divided by cone divider into 35 seed lots of 280 g each. One seed lot was used to immediately determine the initial quality of the seed. The other seed lots were separately put into a sealed plastic bucket and kept in a 5°C room for from 1 to 25 days.

3.8. Experimental treatments

The drying rate of granular materials in a deep bed is based upon the drying rate of each single kernel within the bed. Thus, deep-bed drying models may be derived from models that describe the drying behaviour of a single seed, or a thin layer of seeds (Brooker et al., 1982). All drying treatments in this experiment therefore were conducted in a single layer.

Three ovens were set at 60, 45 and 30°C for this experiment. Seeds (280 g) were spread in a single layer on a wiremesh tray.

Maize seeds were dried in the 60°C oven for 5, 10, 15, 20 or 25 minutes. Seeds were then taken out from the 60°C oven and put into another oven set at 30°C for 45 minutes to temper. This cycle was repeated as many times as required until seeds reached the desired m.c. of 13%. In order to know when the seed had reached 13% m.c. during drying, the formula (3.3) was used. Therefore, the seed lot was weighed after each cycle.

Another treatment was similarly conducted with tempering at room temperature of 21°C rather than at 30°C in an oven.

A drying treatment of seed at high temperature without tempering was also used. Seeds were continiously dried at 60°C until 13% seed m.c. was reached.

After drying, maize seeds were exposed to ambient temperature for 24 hours before seed quality tests were conducted. Three replicates were used for each treatment.

3.9. Parameters and measurement procedures

3.9.1. Seed moisture content

Seed m.c. was determined by using the air oven method as stated in section 3.4.1. However for maize, after grinding, the samples were put into 130°C for 4 hours according to ISTA (1993a) standards.

3.9.2. Stress cracking

Stress cracking in maize seeds was measured 24 hours after drying. A light "Maggy lamp" with a glass plate placed above (Fig. 3.12) was employed as a visual aid to detect stress cracks existing in the seed.

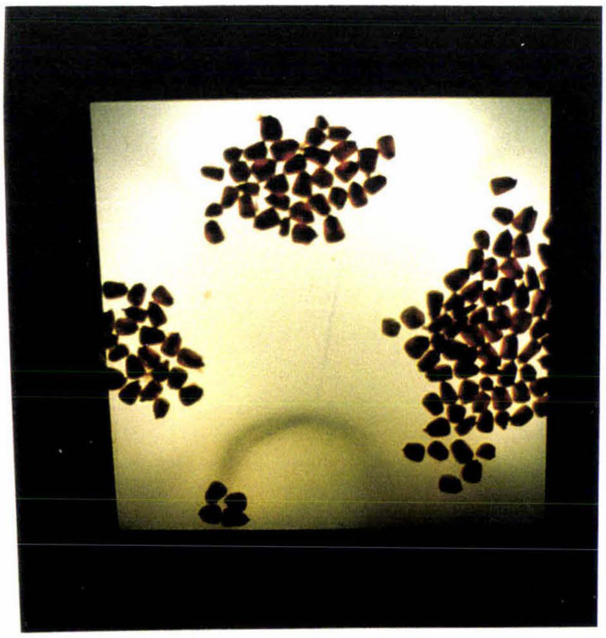


Fig. 3.12. A "Maggy lamp" model BG for checking seed stress cracks

3.9.3. Seed germination

Immediately after checking stress crack in seeds, a germination test was conducted. The procedure for seed germination test with maize is similar to that with pea as stated in section 3.4.2, the only difference being that the rolls of maize seeds, after being covered in plastic bags to prevent water evaporation, were placed in a 25°C room for 4- and 7-day counts as stated by ISTA (1993a).

Maize belongs to group A 1.2.3.2 (ISTA, 1993b). This means that maize is an agricultural and horticultural species, and its systematic class is monocotyledons. Its germination mode is hypogeal and shoot characteristics are not elongated. When germination is assessed, secondary roots are taken into account.

Therefore, a maize seedling was classed as normal if it satisfied all the parameters below:

- the primary root was intact or with slightly discoloured or necrotic spots. If the primary root was defective, but the secondary roots were sufficient and normally developed, the root system was defined as normal.
- the mesocotyl was intact or with slight defects, and the leaves were intact or with slight defects.
- the coleoptile was intact or with slightly discoloured or necrotic spots, loose twists, split for one third or less from the tip.

A maize seedling was defined as abnormal if it contained one or more of the parameters below:

- the primary root was either stunted or retarded, missing, broken, split from the tip, glassy, but insufficient normal secondary roots,
- the mesocotyl was either broken or spiral, tightly twisted,
- the coleoptile was either deformed or broken, spiral, tightly twisted, tip damaged or missing, strongly bent over, split more than one third of length from the tip,

- the leaves were either missing, damaged, deformed.

3.9.4. Accelerated ageing test

The major limitation of the germination test is that it is not sensitive enough to detect quality differences among high germination seed lots, because a small difference in the percentage of germination for the normal distibution on which the seed survival curve is based, represents a large difference in the progress of deterioration (Hampton, 1990). Hence, to determine the storability of the seed, a vigour test was conducted.

Fig. 3.13. Plastic chamber used for accelerated ageing test.

Accelerated ageing (AA) is one of the vigour tests that can be used for maize seed. This test reflects the ability of a seed lot to withstand the stresses of high temperature and humidity. Adjustment to seed moisture content is not required prior to carrying out an AA test. Seeds (40 g) were placed on wiremesh screens in a single layer. They were put in a plastic chamber above 40 ml of distilled water (Fig. 3.13). These chambers were closed and then put on to the middle shelf of a 45± 0.5°C oven for 72 hours (Hampton and TeKrony, 1995). After the ageing time, seeds were removed from the chambers and immediately rolled for a germination test.

3.9.5. Conductivity of the seed

The procedure for the conductivity test was similar to that of pea as stated in section 3.4.3.

3.10. Data analysis

A SAS (Statistical Analysis System) package (SAS, 1988) was used to analyse the experimental data. Analysis of variance was used in determining the differences between seed lot quality factors.

Regression analyses were used in determining the relationship between percentage of cracked maize seeds and germinative capacity immediately after drying, and after accelerated ageing.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment 1: COMPARISON OF PEA SEED DRYING METHODS

RESULTS

4.1. Effect of drying methods

4.1.1. Drying time

Four grain drying methods were evaluated for their performance. The average time consumption (in hours) for drying seeds at three initial moisture contents (23.8, 18.0 and 14.5%) to 10% taken by the different methods was significantly different ($P<0.05$) (Fig. 4.1). In these experiments, where the ambient temperature was 19°C, pea seed dried by the Sun took 37.1 hours. Drying by in-bin ventilation took the longest time of 54.3 hours. Sun drying was 1.5 times faster than the in-bin ventilation drying, but both were significantly slower than drying by Kiwi Mini dryers (Fig. 4.1).

The time consumed when drying by the Kiwi Mini dryers at either 30°C or 45°C was significantly different (Fig. 4.1). Drying at 30°C took 16.7 hours, 2.4 times longer than drying at 45°C.

4.1.2. Energy Consumption

The energy consumed for drying the seeds at three initial moisture contents (23.8, 18.0 and 14.5%) to 10% by the two natural drying methods was significantly less than that when drying by the Kiwi Mini dryers (Fig. 4.2). The natural in-bin ventilation method consumed the least energy (0.34 kWh), and Sun drying used 4.07 kWh to dry seeds. Drying by Kiwi Mini dryers at 45°C consumed 7 kWh, half of the energy when drying at 30°C.

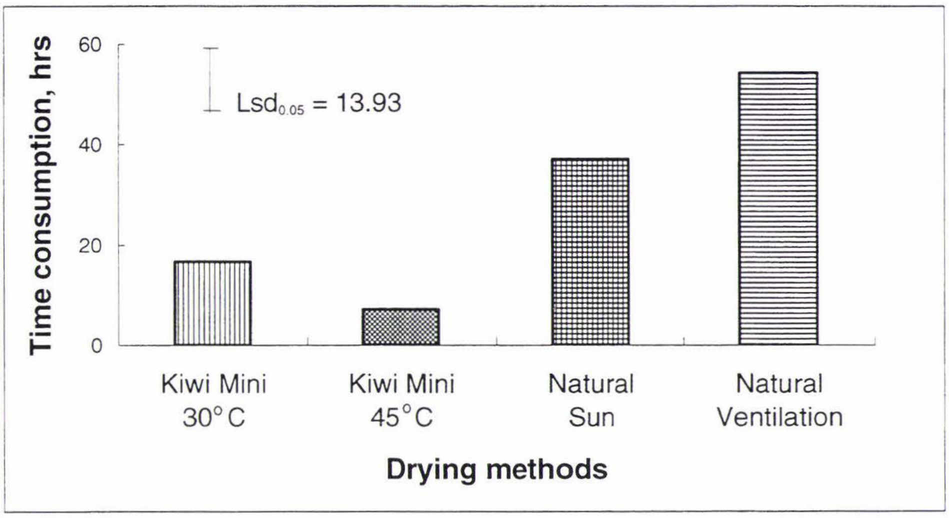


Fig. 4.1. Time consumption by selected drying methods.

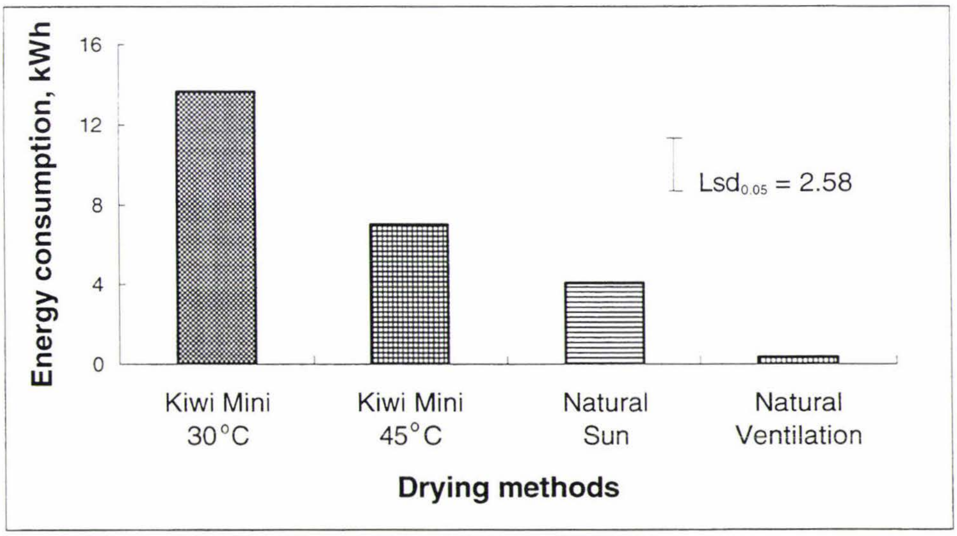


Fig. 4.2. Energy consumption by selected drying methods.

4.1.3. Seed germination

The effect of drying methods on germination of pea seed is presented in Fig. 4.3. Germination differences among the different drying methods were not significant, and averaged 74.6% seed germination.

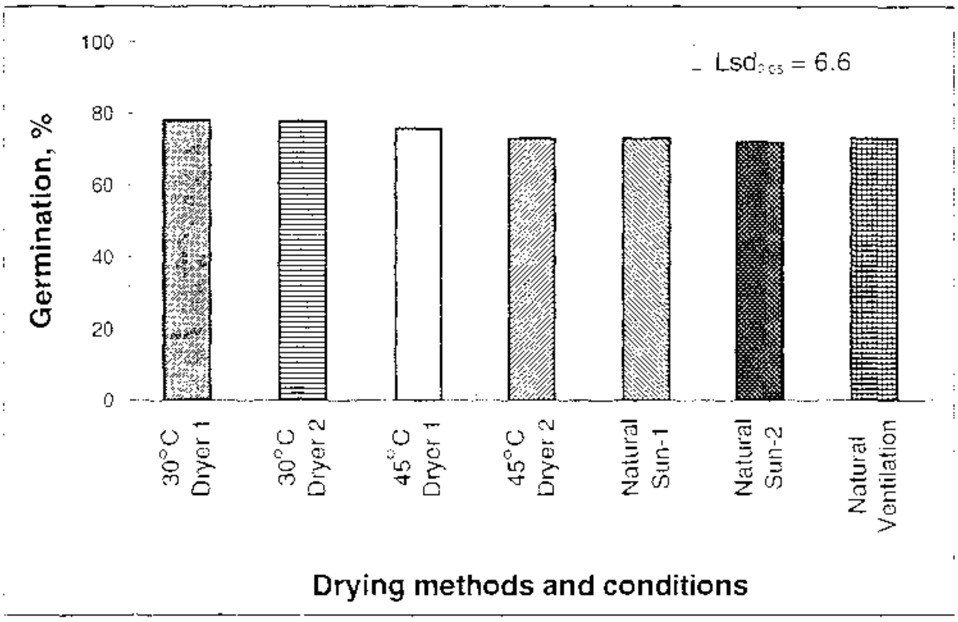


Fig. 4.3. Germination percentage as affected by selected drying methods and conditions.

4.1.4. Abnormal seedling and dead seed percentages

Table 4.1 showed that there were no discernable effects of drying methods on abnormal seedlings. The percentage of abnormal seedlings ranged from 18.7 - 24.3% among the various drying methods. Similar trends prevailed in the case of dead seeds, although the percentage of dead seeds was small and ranged between 2.7 and 6.3%.

Table 4.1. Abnormal seedling and dead seed percentages of pea seed after drying by different methods.

Seed characteristics	Drying methods							
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent*	LSD
Abnormal seedling, %	18.7_a	18.0_a	21.7_a	24.3_a	20.7_a	22.7_a	22.0_a	7.1
Dead seeds, %	3.3_a	4.3_a	2.7_a	2.7_a	6.3_a	5.3_a	5.0_a	3.9

** Vent = Natural Ventilation. This symbol is used in all following tables.*
Values with the same letter in rows are not significantly different at P < 0.05.

4.1.5. Seed conductivity and hollow heart

Seed dried at 30°C in Dryer 1 had significantly lower conductivity (17.7 $\mu S.cm^{-1}.g^{-1}$) than seed from the other drying conditions, which did not differ significantly (Table 4.2).

Table 4.2. Effects of drying methods on pea seed conductivity and hollow heart percentage.

Seed characteristics	Drying methods							
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent*	LSD
Conductivity $\mu S.cm^{-1}.g^{-1}$	17.7_a	19.4_{ab}	20.9_b	22.2_b	20.8_b	21.6_b	20.6_{ab}	3.0
Hollow heart, %	0.2_a	1.0_{ab}	0.8_{ab}	1.3_b	0.8_{ab}	0.8_{ab}	1.0_{ab}	0.9

Values with the same letter in rows are not significantly different at P < 0.05

Similar to the conductivity results, drying at 30°C in Dryer 1 gave the lowest (0.2%), while 45°C in Dryer 2 had the highest (1.3%) hollow heart percentage in seeds. The other drying conditions had a similar effect on hollow heart percentage (Table 4.2).

4.1.6. Seed quality following storage

a. 20 days

After 20 days of storage in open conditions, pea seeds dried at 30°C in Dryer 1 still had the highest germination, and this was significantly different from those of other seeds lots excluding the first Sun dried seed lot (Sun-1). However, drying methods and conditions had similar effects on germination after seeds were stored for 20 days in closed conditions (Table 4.3).

Table 4.3. Effect of drying methods on seed quality after 20 days of storage

Seed characteristics	Drying methods							
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.	LSD
Germination, %								
Open storage	77.7_{a}	70.3_{bc}	70.3_{bc}	71.7_{bc}	74.0_{ab}	68.0_{c}	71.3_{bc}	6.0
Closed storage	71.0_{a}	67.7_{a}	70.0_{a}	68.6_{a}	70.0_{a}	72.0_{a}	71.0_{a}	5.1
Abnormal, %								
Open storage	17.0_{a}	25.0_{bc}	26.7_{c}	24.0_{bc}	19.7_{ab}	26.0_{bc}	22.0_{abc}	6.6
Closed storage	24.3_{ab}	23.0_{ab}	22.7_{abc}	25.7_{a}	23.0_{ab}	18.7_{c}	21.3_{bc}	4.3
Dead seeds, %								
Open storage	5.3_{a}	4.7_{a}	3.0_{a}	4.3_{a}	6.3_{a}	6.0_{a}	6.7_{a}	3.8
Closed storage	4.7_{a}	9.3_{b}	7.3_{ab}	5.7_{ab}	7.0_{ab}	9.3_{b}	7.7_{ab}	4.4

Values with the same letter in rows are not significantly different at $P < 0.05$

b. 40 days

There were no discernable effects of drying conditions on germination, abnormal seedlings or on dead seed percentages when pea seeds were stored for 40 days in closed conditions (Table 4.4). However in open storage, significant differences in germination as well as in abnormal seedling percentage were found among drying conditions.

Table 4.4. Effect of drying methods on seed quality after 40 days of storage

Seed characteristics	Drying methods							
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.	LSD
Germination, %								
Open storage	77.0_a	67.0_{ab}	66.3_{ab}	70.3_{ab}	64.0_b	59.3_b	65.7_{ab}	12.0
Closed storage	64.3_a	63.0_a	59.7_a	63.0_a	59.7_a	59.7_a	64.0_a	11.2
Abnormal, %								
Open storage	17.0_a	28.0_{ab}	23.0_{ab}	21.7_{ab}	29.3_{ab}	34.3_b	26.3_{ab}	12.9
Closed storage	24.0_a	23.7_a	25.3_a	18.0_a	27.3_a	28.0_a	21.7_a	11.6
Dead seeds, %								
Open storage	6.0_a	5.0_a	10.7_a	8.0_a	6.7_a	6.4_a	8.0_a	5.8
Closed storage	11.7_a	13.3_a	15.0_a	19.0_b	13.3_a	12.3_a	14.3_a	4.0

Values with the same letter in rows are not significantly different at $P < 0.05$

c. 60 days

Germination of the seed lot dried at 30°C in Dryer 1 was highest and significantly different from that of the seed lots dried at 30°C in Dryer 2 and under natural drying conditions when they were open stored for 60 days. At this storage condition, the differences in abnormal seedling percentage were similar to the differences in germination.

Table 4.5. Effect of drying methods on seed quality after 60 days of storage

Seed characteristics	Drying methods							
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.	LSD
Germination, %								
Open storage	72.0_{a}	42.7_{c}	59.0_{ab}	64.0_{ab}	53.0_{bc}	41.0_{c}	49.3_{bc}	15.9
Closed storage	39.3_{a}	25.7_{ab}	32.0_{ab}	10.0_{b}	41.0_{a}	40.4_{a}	43.7_{a}	24.8
Abnormal, %								
Open storage	15.7_{a}	51.0_{d}	22.7_{ab}	25.0_{abc}	39.0_{bcd}	52.0_{d}	42.7_{cd}	19.6
Closed storage	30.7_{ab}	35.0_{ab}	35.7_{ab}	40.3_{a}	30.3_{ab}	31.3_{ab}	26.0_{b}	13.3
Dead seeds, %								
Open storage	12.3_{ab}	6.3_{b}	18.3_{a}	11.0_{ab}	8.0_{ab}	7.0_{b}	8.0_{ab}	11.1
Closed storage	30.0_{a}	39.3_{ab}	32.3_{a}	49.7_{b}	28.7_{a}	28.3_{a}	30.3_{a}	14.4

Values with the same letter in rows are not significantly different at $P < 0.05$

In closed storage, there were significant differences in germination as well as dead seed percentage when seeds were dried at 45°C in Dryer 2 compared to those of seeds dried at 30°C in Dryer 1 and natural drying conditions. The seed lot dried at 45°C in Dryer 2 produced only 10% germination and the highest dead seed percentage of 49.7%.

4.2. Effect of initial moisture content

4.2.1. Time and energy consumption

Time (in hours) and energy (in kWh) consumptions were affected by initial moisture content when drying. Pea seeds of initial m.c. of 14.5% took 21.1 hours to dry, while seeds of 23.8% initial m.c. took 37.4 hours (Table 4.6).

Energy consumed for drying pea seeds of 14.5% initial m.c. was 4.9 kWh, while it was 7.5 kWh to dry pea seeds of 23.8% initial m.c.

Table 4.6. Effects of initial seed moisture content on time and energy consumption required to dry seeds to 10% m.c.

Parameters	Initial seed moisture content, %			
	23.8	18.0	14.5	LSD
Time consumption, hrs	37.4_{a}	27.9_{ab}	21.1_{b}	12.1
Energy consumption, kWh	7.5_{a}	6.4_{ab}	4.9_{b}	2.2

Values with the same letter in rows are not significantly different at P < 0.05

4.2.2. Seed quality immediately after drying

Seed germination, abnormal seedlings and dead seed percentages (Table 4.7) showed no discernable effects of initial seed m.c. There were no significant effects of the initial seed m.c. on the conductivity and hollow heart of the seeds (Table 4.7).

Table 4.7. Effects of initial moisture content on seed quality characteristics after drying.

Seed quality characteristics	Initial seed moisture content, %			
	23.8	18.0	14.5	LSD
Germination, %	75.0_{a}	73.7_{a}	75.1_{a}	4.3
Abnormal seedlings, %	21.6_{a}	22.6_{a}	19.3_{a}	4.7
Dead seeds, %	3.4_{a}	3.7_{a}	5.6_{a}	2.6
Conductivity $\mu S.cm^{-1}.g^{-1}$	19.6_{a}	20.2_{a}	21.5_{a}	1.9
Hollow heart, %	0.8_{a}	0.9_{a}	0.9_{a}	0.6

Values with the same letter in rows are not significantly different at P < 0.05

4.2.3. Seed quality after storage

The average dead seed percentages after storage for 20, 40 and 60 days were not affected by initial seed m.c. (Table 4.8). However, germination was significantly different (63.7, 58.3 and 57.2%) for seeds of 23.8, 18.0 and 14.5% initial m.c. respectively, and abnormal seedlings increased significantly when initial seed m.c. decreased.

Table 4.8. Effects of initial moisture content on seed quality characteristics in storage.

Seed quality characteristics	Initial seed moisture content, %			
	23.8	18.0	14.5	LSD
Germination, %	63.7_a	58.3_b	57.2_b	4.4
Abnormal seedlings, %	23.5_a	28.2_b	30.1_b	3.6
Dead seeds, %	12.8_a	13.5_a	12.7_a	3.1

Values with the same letter in rows are not significantly different at $P < 0.05$

4.3. Effect of storage time

4.3.1 Seed germination

Twenty days of open storage had little effect on seed germination percentage. Germination reduced slightly from 74.6% immediately after drying to 71.9% after 20 days open storage, and then further decreased to 67.1 and 54.4% after storage for 40 and 60 days respectively (Fig. 4.4).

Germination of the seeds stored in closed conditions after 20 days was not significantly different from that immediately after drying. However, germination was significantly and adversely affected when seeds were stored for 40 and 60 days. The lowest germination of 33.1% was recorded after 60 days of storage.

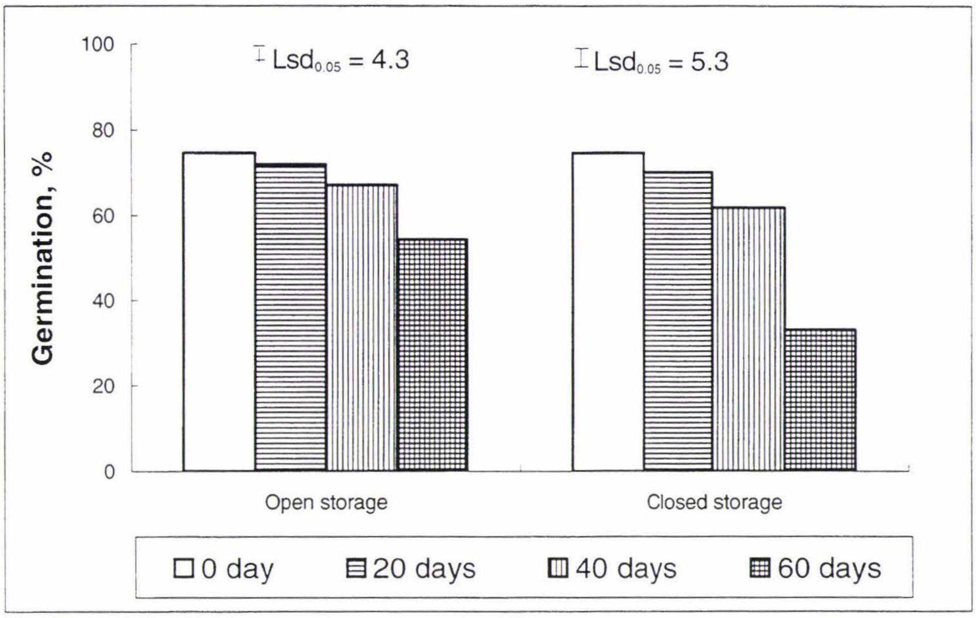


Fig. 4.4. Seed germination percentage as affected by periods of storage

4.3.2. Abnormal seedlings

The percentage of abnormal seedlings in both storage conditions was not significantly affected by storage length for up to 40 days, irrespective of whether seeds were stored in an open or closed environment. However, after 60 days of storage, mean abnormal seedling percentage increased to 35.4 and 32.8% in open and closed conditions respectively (Table 4.9).

Clearly, the seed lots with high initial seed m.c. took a longer time than the seed lots with low initial seed m.c. to dry to the same final seed m.c.

The amount of energy consumed by the different drying methods varied significantly. The energy consumed with sun drying was 12 times more than that for the in-bin natural ventilation (Fig. 4.2). This apparently higher level of sun energy consumption was partially because sun radiation was measured directly for determining energy consumed. However, all of this energy was not absorbed by the moisture in the seeds. On the other hand, energy determined when drying by in-bin natural ventilation was the actual energy absorbed.

Theoretically, the faster the drying operation, the more energy required to remove each kilogram of water from the grain bulk (Sims et al., 1983). In this case, the energy consumed when drying by Kiwi Mini dryers at 45°C was half of that when drying at 30°C, though the dryer set at 45°C had to supply more heat than at 30°C. This was because of the higher air velocity passing through the seed bulk in 30°C drying conditions (Appendix 1), which caused less heat absorption for drying, and thus more heat was lost through exhaustion. This led to more time needed for drying, and therefore more heat required to dry the seeds to the desired m.c.

Initial seed m.c. also affected energy consumption for drying. The seeds with the high initial seed m.c. of 23.8% consumed 1.5 times more energy than the seeds with the lowest initial seed m.c. of 14.5% (Table 4.6).

2. Seed quality

Difference in seed quality is manifested by the results of the germination and vigour tests. Pea seed vigour is expressed through conductivity and hollow heart (Perry, 1980). Seeds with high conductivity and high hollow heart percentage are considered to have a low vigour, even though their germination may be high. Furthermore, a high germinating seed lot with high conductivity and low hollow heart, or low conductivity and high hollow heart is also seen as being of low vigour (Hampton, 1984).

a. Microwave drying

A microwave was used as a pilot test for seed drying. The results from the preliminary tests (Table 3.1) agreed with earlier results from Dewan (1988) who had used a microwave oven to determine seed moisture content and eliminate storage fungi. He stated that elimination of storage fungi could not be obtained without a severe and unacceptable reduction in seed germination capacity. Wheat seeds of 14.2 and 16.1% m.c. respectively after having been exposed for 50 seconds on high power rating of 650 Watts in a microwave oven (Frequency of 2450 MHz) had their germination reduced by 80%. Other samples after an exposure of 120 seconds on a lower power rating of 195 Watts had germination reduced by 30%.

Such high rate of seed kill might be explained by the fact that the microwaves penetrate deeply into the seed, and the high rates of temperature increases (Adu and Otten, 1996) adversely affect the seed embryo. Therefore, microwave drying as a drying technique was not considered further for evaluation in these experiments.

b. Seed germination

Muckle and Stirling (1971) had earlier recommended that a maximum temperature of 38°C was safe for pea seed drying. However, Wanisekera (1981) found that drying temperatures of 20, 30, 40 and 50°C did not affect seed germination when he dried soybean to 8% m.c. In these experiments, the results from seed drying at 45°C were essentially similar to drying at 30°C, although the latter took a higher amount of energy and more time to dry. This confirmed the suggestion of Gane et al. (1984) that if pea seed m.c. is below 24%, the drying temperature should not exceed 49°C. On the other hand, in the present experiments, as pea seeds were spread on concrete floor for sun drying, heat was also expected to be conducted and might have affected seed embryos by direct contact with material bearing heat for a relatively long period. This had not affected seed germination immediately after drying, but might affect seed viability in storage. Drying methods also had no discernable effects on the number of abnormal seedlings and on dead seed percentage (Table 4.1). Similar results were found by Mian (1983) when he dried sweet corn seeds at 30 and 50°C, and he suggested that there were no significant differences in respect of germination, abnormal seedling and dead seed percentages. Harrington (1972) stated that high drying temperature, though not high enough to kill the seeds, might reduce seed vigour and storability.

Gane et al. (1984) stated that seeds harvested at 15% seed m.c. are brittle and prone to cracking, which increases leachate conductivity, thus reducing seed quality. However in this study, initial seed moisture content had no effect on seed germination, abnormal seedlings and dead seed percentages immediately after drying. This was probably because all the seeds were harvested at 28% m.c. and threshed at 24% m.c. because of the weather conditions (as stated in section 3.1). During storage, initial moisture content of the seeds seemed to have no effect on the average of dead seed percentages after storage for 20, 40 and 60 days, but germination reduced significantly with the reduction of initial seed m.c. from 23.8 and 18.0 to 14.5%. These decreases in germination were inversely correlated with increases in abnormal seedling percentage from 23.5 to 28.2 and 30.1% respectively (Table 4.8). This agreed with the results of conductivity (vigour) immediately after drying.

The slight reduction in germination during open storage (Fig. 4.4) agreed with Castillo (1992) who stored 5 pea seed lots from 2 cultivars (Pania and Princess) in different storage conditions for different length of times. His results showed that all seed lots decreased their germination relatively rapidly after 1 month and completely lost germination after 3 months when they were stored at 25°C, 95% r.h., while the same seeds were open stored at ambient condition for 18 months with only a slight reduction in their germination. The germination of soybean seeds after drying at 45°C (Sangakkara, 1988) decreased from 93 to 69% when stored in 40% r.h. at 20°C for 2 to 12 weeks, while it reduced from 31 to 4% with seeds stored in 90% r.h. at the same temperature for 2 to 8 weeks. Islam (1984) showed that the storage temperature of 28°C and 84% r.h. drastically reduced germination of pea seed within 8 weeks and seeds completely lost viability after 13 weeks of storage. Aguinaldo (1986) suggested that there were severe reductions in seed germination in both corn and soybean when the periods of storage increased to 8 weeks of storage in two storage conditions of 30°C, 80% r.h. and 20°C, 60% r.h. though germination dropped more rapidly in the first storage condition. From growth test, he found that the root and shoot dry weight of both species reduced significantly with the length of storage, especially in the high humidity condition.

The seeds stored in closed conditions after 20 days had no significant difference in germination from that immediately after drying (Fig. 4.4). This might be due to the fact that this storage time was not long enough for seed m.c. increases and mould development. However, the differences in germination were significant when seeds were stored for 40 and 60 days. The lowest value of 33.1% was received after 60 days of storage. This was because at this stage, seeds gained an equilibrium m.c. of over 20% at 25°C, 90% r.h., that was favourable for mould develop. Christensen (1972) stated that storage fungi have the unique ability to grow in seeds whose moisture contents are at an equilibrium with relative humidity between 65-90%. Mian (1983) and Aguinaldo (1986) found fast fungal infestation in maize seeds stored at 90 and 80% r.h. respectively, that led to a reduction in germination.

Harrington (1972), Tanner and Hume (1978), and Justice and Bass (1978) pointed out that storage temperature and seed moisture content which is a consequence of relative humidity are the most important factors affecting seed storability. Any combination of high temperature, high humidity and time of storage can cause detrimental effects on seed viability, from death through to the cause of chromosome damage and genetic mutations in some seeds such as broadbean and pea (Justice and Bass, 1978). In this experiment, storage conditions significantly affected germinability of the seed and dead seed percentage (Fig. 4.6). This was because the closed storage conditions increased seed m.c. and enhanced seed temperature. A combination of these factors is an ideal condition for mould development. Harrington (1973) also suggested that most seeds stored at higher humidities rapidly decay through fungal infection and metabolic processes.

c. Seed conductivity and hollow heart

Seyedin et al. (1984) suggested that high drying temperature might result in seed membrane damage, and therefore, increased electrical conductivity of the seed. Their results showed that maize seeds dried at 50°C had significantly lower germination than seeds dried at 35°C. In this experiment, drying methods excluding drying at 30°C in Dryer 1 had similar effects on conductivity (Table 4.2). Conductivity of pea seeds after drying by the Kiwi Mini dryer at 30°C in Dryer 1 was significantly lower than those dried by the Kiwi Mini dryer set at 45°C and by the sun. This finding confirmed the results of Harrington (1972) that high drying temperature, though not high enough to kill the seeds, might reduce seed vigour and storability. However, conductivity of all seed lots after drying by the different methods was less than 24 $\mu S.cm^{-1}.g^{-1}$. Based on the vigour grades provided by Gane et al. (1984), all pea seeds lots retained their vigour and would be suitable for early sowing.

Hollow heart is a physiological disorder of pea seeds. It is characterised by a sunken area in the centre on the surface of the cotyledons. Earlier research suggests that hollow heart does not directly affect seed germination and seedling growth but leads to rotting of the cotyledons (Heydecker and Kohistani, 1969). In this experiment, seeds dried at 30°C in Dryer 1 had a significantly lower hollow heart percentage than seeds dried at 45°C in Dryer 2 . The other drying conditions gave a similar effect on hollow heart percentage. It is possible that the lowest mean of drying air resistance (ratio of inlet and outlet air velocity, Appendix 1) accompanied with low temperature drying at 30°C in Dryer 1 did not raise seed temperature, while the highest mean of drying air resistance when drying at 45°C in Dryer 2 accompanied with this temperature might have increased seed temperature, which is considered one of the reasons for the development of hollow heart (Halligan, 1986). In addition, the drying at 45°C in Dryer 2 associated with closed storage condition of high humidity and high temperature caused the highest dead seed percentage (49.7%) and the lowest germination (10%) (Table 4.5).

The conductivity and hollow heart of the seeds showed that there were no significant differences in seed vigour between seeds of the three initial seed m.c. However, the conductivity results revealed that the lower the initial seed m.c., the higher the conductivity. This might be the result of slow deterioration (natural ageing) when the seeds were spread on the floor to lower m.c. before drying (section 3.2).

Most of the calculated expected field emergences (EFE) of the seed lots in this experiment were higher than their standard germinations (Appendix 12). This was because the formula (3.7) was derived from pea seed lots with standard germinations of over 85% (Hampton, pers. comm.). Therefore, the EFE was not considered further.

However during storage, conductivity of the seed was significantly affected by storage time in closed conditions (Table 4.11). Slight increases in seed conductivity were also recorded during storage in open conditions. This supported the result of Castillo (1992) who found that an increase in storage time caused increasing leachate conductivity: an indicator of the deterioration process. The difference in conductivity caused by different storage environments was also significant. Dried seeds stored in closed conditions showed higher conductivity (31.6 $\mu S.cm^{-1}.g^{-1}$) than seed stored in the open (21.6 $\mu S.cm^{-1}.g^{-1}$) (Table 4.13). Powell (1986) stated that in high relative humidity storage conditions, seed moisture contents are increased, and thus lead to changes in quantity of membrane phospholipids, and the formation of free radicals which can result in membrane damage. This result was similar to that of Castillo (1992) who had shown that after 12 months storage, conductivity of pea seeds increased from an average of 22.0 to 28.0 $\mu S.cm^{-1}.g^{-1}$ in ambient open storage. However, conductivity dramatically increased to 45 $\mu S.cm^{-1}.g^{-1}$ when seeds were stored at a high relative humidity of 95%, despite having a low temperature of 5°C.

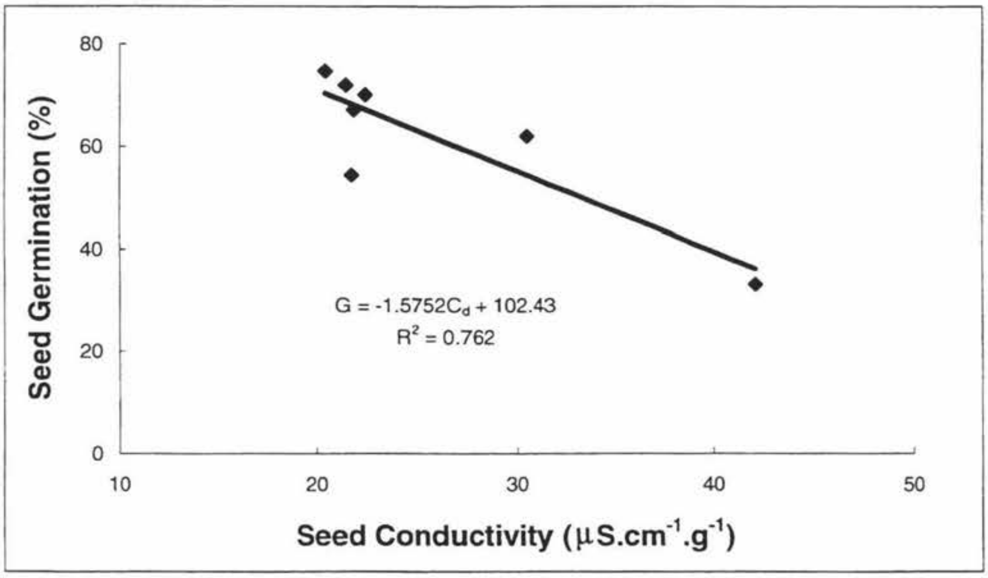


Fig. 4.7. Relationship between seed conductivity and germination during storage

An inverse relationship (r = - 0.87) (Fig. 4.7) between germination (Fig. 4.4) and conductivity (Table 4.11) during storage supported the earlier investigation of Castillo (1992), who suggested that pea seed conductivity was a good predictor of storage life. He found that conductivity seemed to have a better relationship with field emergence of pea seeds after storage (r = - 0.82 and - 0.76 with and without irrigation respectively) than any of other laboratory vigour methods. In addition, Singkanipa (1996) found that viability in soybean and wheat seed when stored at high temperature of 30°C and 95% r.h. decreased as conductivity increased.

During storage, the hollow heart percentage significantly increased after 40 and 60 days in both storage conditions (Table 4.12). This confirmed the statement of Hill (1996) that seed deterioration cannot be stopped by storage even under ideal storage conditions because of the natural ageing process (Justice and Bass, 1978). An increasing seed deterioration rate was recorded, especially in closed conditions. The closed storage gave a higher hollow heart than the open storage (Table 4.13). This might be caused by the difference of temperatures in storage. These results confirmed previous findings by Halligan (1986) and Castillo (1992), who indicated that seed hollow heart percentage increased with the increase in exposure time to high temperature.

3. Seed moisture content in storage

The length of storage had variable effects on seed m.c., depending on whether seeds were stored in open or closed conditions. In open storage conditions, seed m.c. essentially remained similar for up to 60 days, but in closed conditions it increased significantly (Fig. 4.5). However, between 40 and 60 days in closed storage, seed m.c. did not change significantly. This was possibly because seed m.c. reached an equilibrium m.c. in this environment after storage for 40 days.

The results were similar to that of Castillo (1992), who stored pea seeds at 25°C, 95% r.h., and found that seed m.c. increased from 11 to 26% within 1 month of storage and further increased to 28% after 3 months. In ambient open storage conditions, seed m.c. fluctuated from 9 to 12% during 24 months storage. The results were also similar to those of Wanisekera (1981) and Singkanipa (1996) who found that seeds stored at high humidity rapidly gained their equilibrium m.c.

Moisture content of the open stored seeds was significantly lower than that of the seeds stored in closed conditions. The relative humidity of 90% at 25°C in closed conditions, not unexpectedly, increased the seed m.c. to an average of 20.5% (Table 4.13). This resulted in reduced germination after storage in closed conditions, because temperature and seed m.c. are the key factors which influence seed deterioration in storage (Justice and Bass, 1978). Priestley (1986) also suggested that a small increase in seed m.c. would start activities of metabolic processes, and therefore cause seed deterioration and shorten storage life.

SUMMARY

Pea seeds of three initial moisture contents were dried using different methods (sun, natural in-bin ventilation, 30°C and 45°C artificial drying). All drying methods tested had similar effects on seed germination, even though time and energy consumptions for drying these seeds differed markedly. Natural drying (sun and in-bin ventilation) took longer to dry compared with artificial drying either at 30 or 45°C with a Kiwi Mini dryer. However, natural drying consumed less energy (freely available energy) than artificial drying. Initial seed m.c. did not significantly affect seed quality because all seeds were harvested and threshed at the same time and seed moisture.

Expected field emergence (EFE) of pea seeds under most treatment conditions was higher than the standard germination This was probably because all seed lots had germination less than 85%, and the EFE formula was derived from seed lots with high germinations.

Two storage conditions (open at 20.5°C, 55% r.h. and closed at 25°C, 90% r.h.) and length of storage periods (20, 40 and 60 days) had significant effects on seed quality. Seed quality (in terms of germination, conductivity and hollow heart) deteriorated irrespective of storage conditions. However, seeds in the severe storage environment (25°C, 90% r.h.) deteriorated more rapidly than those at 20.5°C, 55% r.h. Length of storage period was negatively correlated with seed quality. Seed m.c. during storage increased to equilibrium moisture content after 40 days in closed storage, while in open storage it remained constant.

Experiment 2: **EFFECT OF HIGH TEMPERATURE DRYING AND TEMPERING ON MAIZE SEED QUALITY**

RESULTS

4.5. Effect of exposure time to drying at 60°C followed by tempering at 21°C on seed quality

4.5.1. Percentage of cracked seeds

The percentage of seeds with transverse cracks was not affected by the time of exposure to 60°C for drying, irrespective of whether seeds were tempered or not (Table 4.14). The percentage of seeds with vertical cracks steadily increased from 40.7 to 69.9% with an increase in exposure time from 5 to 25 minutes, respectively. Drying for 240 minutes (4 hours) without tempering to reduce seed moisture content to a safe storage level resulted in 81% cracked seeds.

Table 4.14. Effect of exposure time to drying at 60°C followed by tempering at 21°C on percentage of maize seeds with cracks.

	Percentage of maize seeds with cracks						
Exposure time, (min.)	5	10	15	20	25	240**	LSD
Transverse cracks	4.3_a	9.7_a	7.0_a	9.3_a	10.2_a	4.0_a	8.9
Vertical cracks	40.7_a	54.3_b	61.7_{bc}	66.0_c	69.9_c	81.3_d	10.8
Total cracks	45.0_a	64.0_b	68.7_{bc}	75.3_{cd}	80.1_d	85.3_d	10.5

*** - without tempering. (This symbol is used for all following tables)*
Values with the same letter in rows are not significantly different at P < 0.05

However, when exposure time to drying was increased from 5 to 10 minutes, the percentages of seeds with vertical cracks increased significantly. A further increase in drying time from 10 to 15 minutes had no effect on seed cracking. Similarly when drying time was increased from 15 to 25 minutes, this had a similar effect on the percentage of seed with cracks.

4.5.2. Germination

After drying, the differences in germination between the 5- and 10-minute treatments were not significant with an average of 96.4%. However, the germination of seeds treated for 5 or 10 minutes each cycle was significantly different from the 75.7% germination of seeds treated with 25-minute exposures. Seeds exposed to continuous drying for 240 minutes without tempering had the lowest germination (19.7%), and it was highly significantly different from those of other treatments (Fig. 4.8).

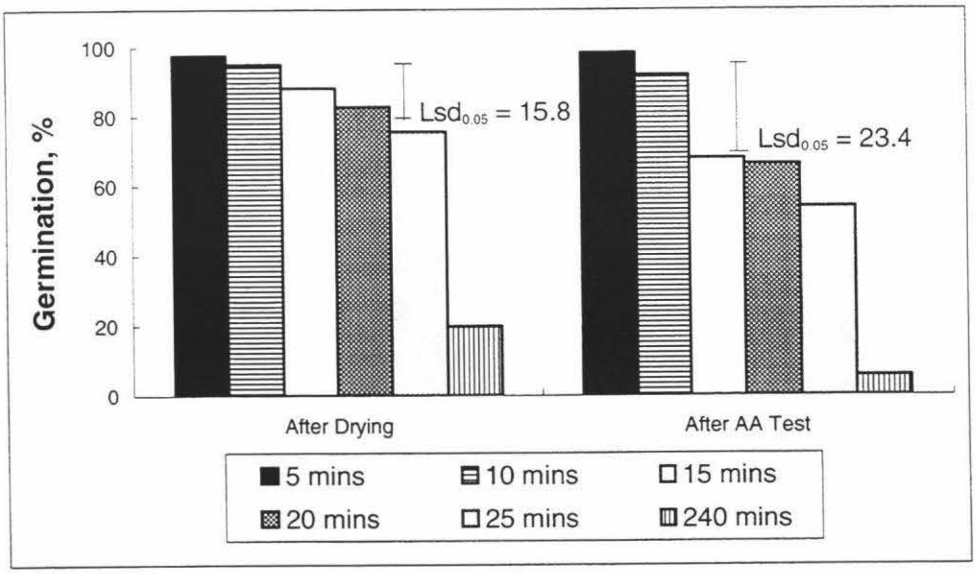


Fig. 4.8. Maize seed germination after drying and after the AA test in a 21°C tempering system with different exposure time cycles

The Accelerated Ageing (AA) test also showed that these were no apparent differences in germination between 5- and 10-minute treatments (Fig. 4.8). Similarly no effects on germination after an AA test were found among the 15-, 20- and 25-minute treatments with an average of 62.8%, although this was a reduction in germination as compared with those seeds having the 5- and 10-minute treatments.

4.5.3. Abnormal seedlings

The seeds exposed to 60°C for 15-, 20- and 25-minute cycles had no significant differences in the percentage of abnormal seedlings after drying as well as after AA (Table 4.15). Seeds treated at 60°C for 4 hours without tempering showed the same effect on abnormal seedlings as seeds treated for 15, 20 and 25 minutes for each cycle. The treatments of 5- and 10-minute exposure showed the lowest percentage of abnormal seedlings both after drying and after the AA test.

Table 4.15. Effect of exposure time to drying at 60°C followed by tempering at 21°C on abnormal seedling percentage

	Abnormal seedlings, %						
Exposure time, (min.)	5	10	15	20	25	240**	LSD
After drying	2.0_a	4.3_{ab}	10.3_{abc}	15.3_{bc}	19.3_c	20.0_c	12.2
After AA Test	1.3_a	5.7_{ab}	21.0_{bc}	21.0_{bc}	28.3_c	14.0_{abc}	15.5

Values with the same letter in rows are not significantly different at $P < 0.05$

4.5.4. Percentage of dead seeds

The results showed that all treatments, except the treatment without tempering, produced no significant differences for dead seed percentages after drying, with an average of 1.9% (Table 4.16). However, after the AA test they did differ significantly, with a range from 0.3 to 17.7%.

The seeds treated for 240 minute without tempering produced the highest percentage of dead seeds after drying (60.3%) and after the AA test (80.3%).

Table 4.16. Effect of exposure time to drying at 60°C followed by tempering at 21°C on dead seed percentage

	Dead seed, %						
Exposure time, (min.)	5	10	15	20	25	240**	LSD
After drying	0.3_a	0.7_a	1.3_a	2.0_a	5.0_a	60.3_b	5.7
After AA Test	0.3_a	2.3_{ab}	11.0_{abc}	12.7_{bc}	17.7_c	80.3_d	10.8

Values with the same letter in rows are not significantly different at $P < 0.05$

4.5.5. Conductivity

The differences in conductivity of the seeds after different times of exposure to 60°C drying were not significant with an average of 0.89 $\mu S.cm^{-1}.g^{-1}$ (Table 4.17). However, they were significantly lower when compared with that of the treatment without tempering (1.04 $\mu S.cm^{-1}.g^{-1}$).

Table 4.17. Effect of exposure time to drying at 60°C followed by tempering at 21°C on conductivity of the seed

Seed characteristics	Exposure time to drying for each cycle (min.)						
	5	10	15	20	25	240**	LSD
Conductivity, $\mu S.cm^{-1}.g^{-1}$	0.86_a	0.88_a	0.90_a	0.89_a	0.91_a	1.04_b	0.13

Values with the same letter in rows are not significantly different at $P < 0.05$

4.6. Effect of exposure time to drying at 60°C followed by tempering at 30°C on seed quality

4.6.1. Percentage of cracked seeds

The percentage of maize seeds with transverse cracks did not differ significantly with an average of 6.9% among exposure time treatments (Table 4.18). The percentages of seeds with vertical cracks, and therefore the percentages of seeds with both crack types were significantly affected by exposure time. However, the treatments with the 15 minutes or higher of exposure in each cycle had similar effects on vertical cracks and on total cracks.

Table 4.18. Effect of exposure time to drying at 60°C followed by tempering at 30°C on percentage maize seeds with cracks

	Percentage of maize seeds with cracks						
Exposure time, (min.)	5	10	15	20	25	240**	LSD
Transverse cracks	7.4_a	8.7_a	8.6_a	6.2_a	6.7_a	4.0_a	6.7
Vertical cracks	44.9_a	57.0_b	65.8_c	69.1_c	73.3_{cd}	81.3_d	8.4
Total cracks	52.3_a	65.7_b	74.4_{bc}	75.3_{bc}	80.0_{cd}	85.3_d	9.7

Values with the same letter in rows are not significantly different at $P < 0.05$

4.6.2. Germination

After drying, the differences in germination of 97 and 96.3% between the 5- and 10-minute treatments respectively were not significant (Fig. 4.9). However, germination of seeds treated for 5 or 10 minutes each cycle was significantly different from seeds treated with the 20 minute (89.7%) and 25 minute (85.3%) exposures.

After the AA test, as for immediately after drying, the 5- and 10-minute treatments did not significantly affect germination which averaged 95.4%. Similar effects on germination after AA were also found between the 15- and 20-minute treatments with an average of 70.9%.

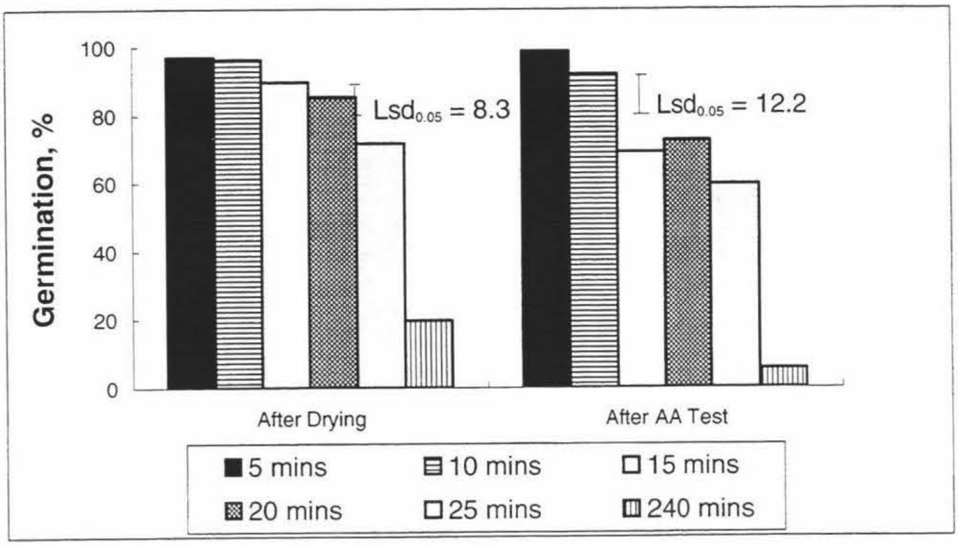


Fig. 4.9. Maize seed germination after drying and after the AA test in a 30°C tempering system with different exposure time cycles

4.6.3. Abnormal seedlings

The treatments of 5- and 10-minute cycles produced no significant differences in abnormal seedlings after drying as well as after AA. However as exposure time increased, so did the production of abnormal seedlings (Table 4.19).

4.6.4. Percentage of dead seeds

The results showed that seeds treated for 5-, 10-, 15- and 20-minutes exposures produced no significant differences in dead seed percentages after drying (Table

4.20). However after the AA test, the dead seed percentages of treatments for 5 and 10 minutes cycles were significantly lower than those of the treatment for 15 and 20 minutes cycles.

Table 4.19. Effect of exposure time to drying at 60°C followed by tempering at 30°C on abnormal seedling percentage

Abnormal seedling, %							
Exposure time, (min.)	5	10	15	20	25	240**	LSD
After drying	2.3_{a}	2.7_{a}	9.3_{b}	6.7_{ab}	22.7_{c}	20.0_{c}	5.5
After AA Test	1.0_{a}	5.0_{ab}	20.7_{cd}	15.7_{bcd}	25.3_{d}	14.0_{bc}	10.7

Values with the same letter in rows are not significantly different at P < 0.05

Table 4.20. Effect of exposure time to drying at 60°C followed by tempering at 30°C on dead seed percentage

Dead seed,	Exposure time to drying for each cycle (min.)						
%	5	10	15	20	25	240**	LSD
After drying	0.7_{a}	1.0_{a}	1.0_{a}	1.7_{a}	5.7_{b}	60.3_{c}	3.8
After AA Test	0.3_{a}	3.0_{a}	10.3_{b}	11.7_{b}	15.0_{b}	80.3_{c}	5.4

Values with the same letter in rows are not significantly different at P < 0.05

4.6.5. Conductivity

The differences in conductivity between seeds after different times of exposure in this tempering system were not significant (average of 0.88 $\mu S.cm^{-1}.g^{-1}$). They were also found to be significantly lower compared with that of the treatment without tempering (Table 4.21).

Table 4.21. Effect of exposure time to drying at 60°C followed by tempering at 30°C on conductivity of the seed

Seed characteristics	Exposure time to drying for each cycle (min.)						
	5	10	15	20	25	240**	LSD
Conductivity, μS. cm^{-1}.g^{-1}	0.87$_a$	0.87$_a$	0.92$_a$	0.88$_a$	0.84$_a$	1.04$_b$	0.12

Values with the same letter in rows are not significantly different at P < 0.05

4.7. Effect of tempering temperature on seed quality

4.7.1. Percentage of cracked seeds

Table 4.22 showed that there were no significant effects of tempering temperature on the percentage of transverse cracks as well as total cracks. However, the percentage of seeds with vertical cracks when seeds were tempered at 30°C (62%) was significantly higher than that for the 21°C tempering (58.5%).

Table 4.22. Effect of two tempering temperatures on percentage of maize seeds with cracks

	Maize seeds with cracks (%)		
Tempering temperature, °C	21°C	30°C	LSD
Transverse cracks	8.1$_a$	7.5$_a$	3.6
Vertical cracks	58.5$_a$	62.0$_b$	0.8
Total cracks	66.6$_a$	69.5$_a$	4.2

Values with the same letter in rows are not significantly different at P < 0.05

4.7.2. Germination

Tempering temperature did not significantly affect seed germination after drying or after the AA test, with averages of 88.0 and 77.1%, respectively (Fig. 4.10).

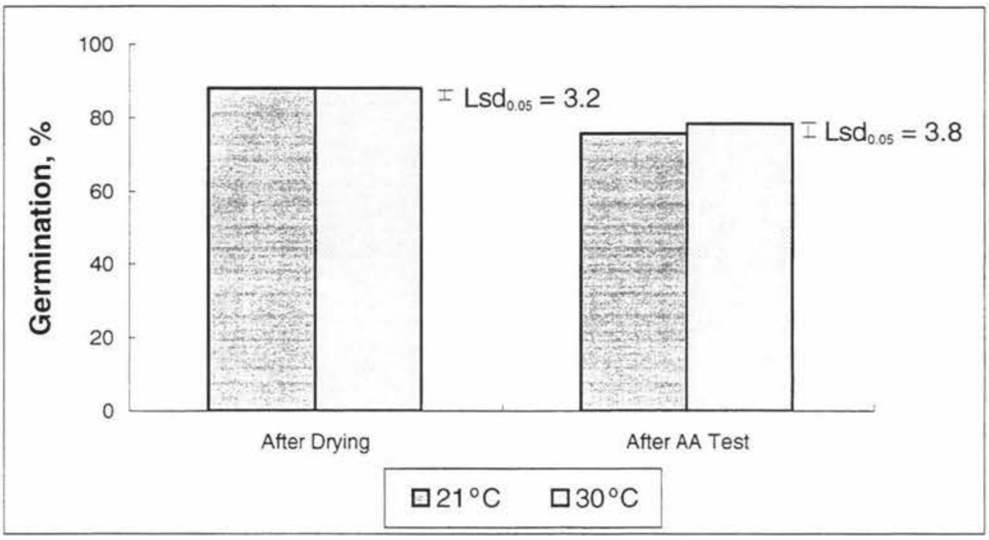


Fig. 4.10. Maize seed germination after drying and after the AA test at different tempering temperatures

4.7.3. Conductivity

Conductivity of the seeds did not differ when using different tempering temperatures of 21°C and 30°C at $P<0.05$, and averaged 0.88 $\mu S.\ cm^{-1}.g^{-1}$.

DISCUSSION

1. Effect of exposure time to drying at 60°C followed by tempering on seed quality

a. Percentage of cracked seeds

The percentage of maize seeds with transverse cracks did not differ significantly among a range of exposure times varying from 5 to 25 minutes, irrespective of whether seeds were tempered at 21°C, 30°C, or not tempered. On the other hand, the percentage of seeds with vertical cracks steadily increased with an increase in exposure time from 5 to 25 minutes (Tables 4.14 and 4.18). These data agreed with Hill (1996), who had suggested that transverse stress cracks occur as a result of mechanical damage during threshing, and that high temperature drying was the cause of creating vertical cracks. In this experiment, all the seeds were threshed by hand, and therefore all seed lots had a small and relative constant percentage of seeds having transverse cracks, even though exposure time increased.

The percentages of seeds with vertical cracks increased significantly when exposure time to drying was increased from 5 to 25 minutes. This confirmed the conclusion of Mendoza and Rigor (1983) that temperature and time of exposure were more important than other factors such as species and initial moisture content. They recommended a short drying time followed by tempering for commercial paddy drying. Teter (1987) also stated that multi-pass drying with intermittent process of high temperature drying followed by tempering when paddy was exposed for a short time resulted in fewer fissured grains than single pass (without tempering) drying. He also stated that cascade dryers, that is a unique type of columnar drying, combine drying and tempering sections throughout the height of the column. Abe et al. (1992) suggested that recycling procedures of drying at 45 to 55°C for 5 to 10 minutes and tempering at 25°C for 45 minutes were appropriate for reducing the percentage of cracked rough rice during drying.

There were no significant effects of tempering temperature on the percentage of seeds with transverse cracks as well as total cracks. However, the percentage of seeds with vertical cracks when seeds were tempered at 30°C was significantly higher than that for the 21°C tempering (Table 4.22). Earlier studies of Escasinas (1986) showed that maize seeds dried at 40°C and tempered at 30°C had less stress cracking, and therefore had higher seed viability after storage for 12 months, than seeds tempered at the same drying temperature of 40°C, which while they had similar cracking, had remarkably reduced seed viability. This result supported the suggestion of Abe et al. (1992) that temperature of the tempering tank of most present commercial grain driers that ranges between 35 and 40°C should be lowered to 25°C to obtain a low percentage of cracked rice grains.

Drying for 240 minutes (4 hours) without tempering resulted in the highest percentage of cracked seeds (Tables 4.14 and 4.18). This result supported the studies of Kunze (1979) and Sharma and Kunze (1982) who concluded that rough rice of either 14 or 20% moisture content exposed to 60°C for 2 hours or more resulted in many grains with stress cracks after the drying stopped, and only a few whole rice grains remained. They also indicated that with rapid drying at 60°C in a single pass from harvest to storage moisture content, too many grains will have cracks within 48 hours after drying, and additional cracks with a slower rate will develop in another 72 hours.

b. Germination

After drying, the differences in germination between the 5- and 10-minute treatments were not significant, but these germinations were significantly greater from that of seeds treated with 25-minute exposures, irrespective of whether seeds were tempered at 21 or 30°C (Figs. 4.8 and 4.9). The time of 25 minutes each cycle for exposure to 60°C might be too long for seed maize. Abe et al. (1992) achieved the highest germination of 98% when they conducted experiments with either drying at 40°C for 5 to 10 minutes with tempering at 25 and 35°C for 45 minutes, or a 50°C drying temperature for 3 minutes of exposure plus a 35°C tempering temperature for 45 minutes. The results showed that seeds treated for 5-, 10-, 15- and 20-minutes exposures produced no significant differences in dead seed percentages after drying (Tables 4.16 and 4.20). Exposure for 20 minutes or less for a 60°C drying cycle affected the production of abnormal seedlings rather than dead seeds (Tables 4.15 and 4.19).

The seeds exposed to continuous drying for 240 minutes without tempering had the lowest germination. This treatment showed the same effect on abnormal seedlings as the 15-, 20 or 25-minute cycle treatments (Tables 4.15 and 4.19). Therefore, the big reduction in germination was because high temperature killed seeds during drying (Tables 4.16 and 4.20) rather than resulting in abnormal seedlings. Such effect of severe drying condition was earlier reported by Herter and Burris (1989), who showed that maize seeds of 43-47% moisture content dried at 50°C did not germinate.

The AA test showed that the differences in germination between the 5- and 10-minute treatments were not significant. Similar germination after an AA test were found among the 15-, and 20-minute treatments, but these were reduced in germination as compared with those seeds having 5- and 10-minute treatments in both tempering temperatures. The results also showed that exposure times of 10 and 15 minutes resulted in significantly different dead seed percentage after the AA test (Tables 4.16 and 4.20). The exposure of seeds to 60°C for 15 minutes for each cycle in this experiment might not pose danger immediately for seed germination, but did reduce seed vigour. This confirmed the suggestions of Justice and Bass (1978) and Priestley (1986) that the loss of vigour precedes the loss of viability. To retain high vigour, seeds should not be exposed to 60°C for more than 10 minutes each cycle.

Tempering temperatures of 21 and 30°C did not significantly affect germination and vigour of the seeds (Fig. 4.10). This agreed with the result of Abe et al. (1992) who showed that when rice seeds were multi-pass dried at 50°C for 5 or 10 minutes, seeds retained high germination, irrespective of whether tempering temperature was 25 or 35°C, even though the percentage of cracked seeds differed.

c. Conductivity

Perry (1973) showed that seeds with coat cracks produced higher conductivity than seeds without this structural defect. However, in this experiment, the differences in conductivity of the seeds after different times of exposure to drying were not significant, irrespective of which tempering tempeature was used (Tables 4.17 and 4.21), even though the percentage of seeds with cracks was very different (Tables 4.14 and 4.18). The lack of effect of exposure time and tempering temperature on seed conductivity in this study might be because the drying stress cracks in the seeds were internal cracks as suggested by Mashauri (1991), not external ones, which results in a rapid solute leakage during soaking.

The conductivity of the seeds dried without tempering was significantly higher than that of the other intermittent treatments. This was because high temperature of 60°C for a long time (4 hours) killed most seeds. This could have been due to loss of membrane integrity which resulted in more leakage (Wang and Hampton, 1991). However, in the present study this phenomenon was not studied.

2. Relationship between high temperature drying induced cracks and seed germination and vigour

Escasinas (1986) suggested that stress cracking had no immediate effect on quality, but caused seed deterioration in storage depending upon the type or location of cracks. He stated that the cracks that extended into the germ area seriously reduced seed viability in storage. Escasinas (1986) also found a negative correlation between stress cracking and germination after 12 months of storage. He showed that when stress cracking increased from 0 to 70%, seed germination was decreased from 74.5 to 47.5%.

Aziz (1985) observed that seed cracking did not affect the germination immediately after drying but was the point of infestation of storage fungi and insects, that led to reduced storability.

In this experiment, germination (G) of maize seeds after drying was found to have a polynomial relationship with the percentage of seeds having either vertical stress cracks or total stress cracks (C) with negative correlations r = - 0.74 and r = - 0.82, respectively (Figs. 4.11 and 4.12). The relationships were as follows:

$G = -0.021C^2 + 1.7611C + 60.633$ with vertical stress cracks only, and

$G = -0.0211C^2 + 2.051C + 48.577$ when both transverse and vertical cracks were taken into account.

These models also showed that highest germination obtained after drying was for seeds with 50% or less cracks. Biologically, germination of the seed lot cannot increase when percentage of cracked seeds increases. Therefore, the left parts (from 50%-crack position) of these graphs, which indicates a slight positive relationship between germination and percentage of stress cracks, become biologically unsuitable. These parts might be straight-horizontal lines showing the unchanged germination when percentage of seeds with stress cracks is less than 50%. Therefore, the relationships found are of more significance when more than 50% of seeds have stress cracks.

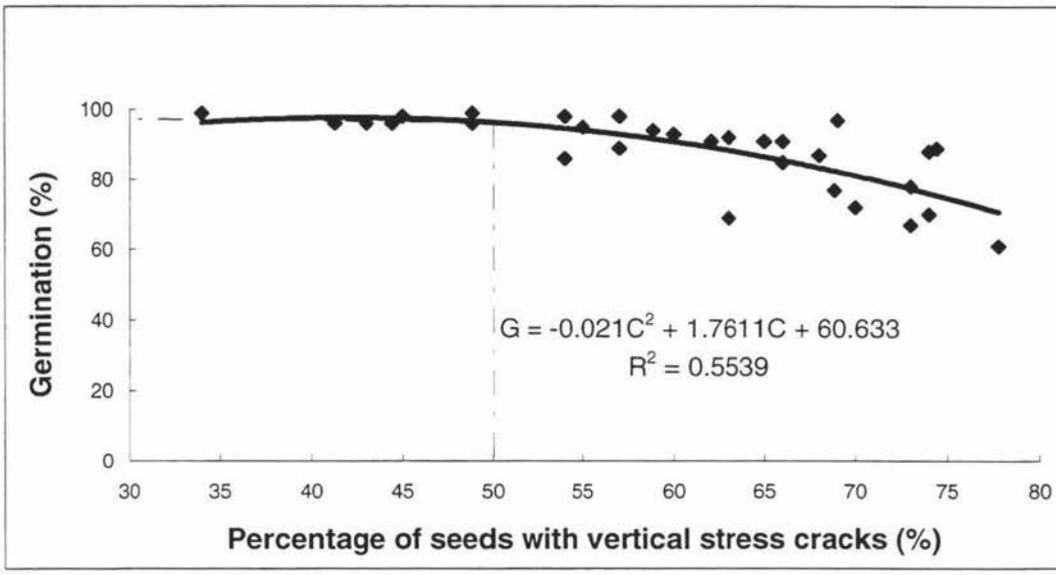


Fig. 4.11. Relationship between percentage of seeds with vertical stress cracks and seed germination immediately after drying

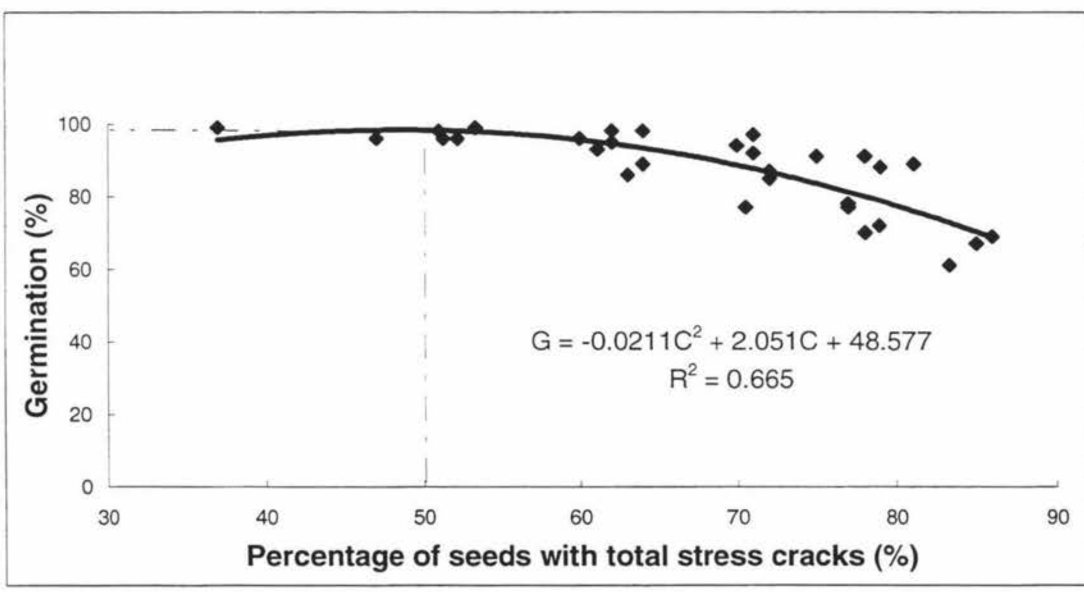


Fig. 4.12. Relationship between percentage of seeds with total stress cracks and seed germination immediately after drying

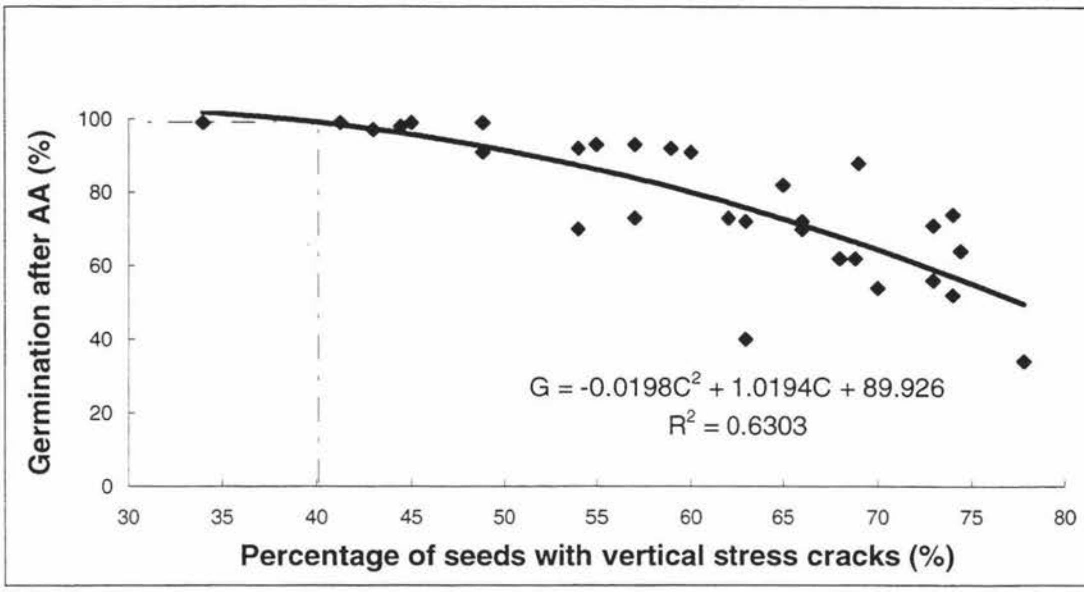


Fig. 4.13. Relationship between percentage of seeds with vertical stress cracks and seed germination after the AA test

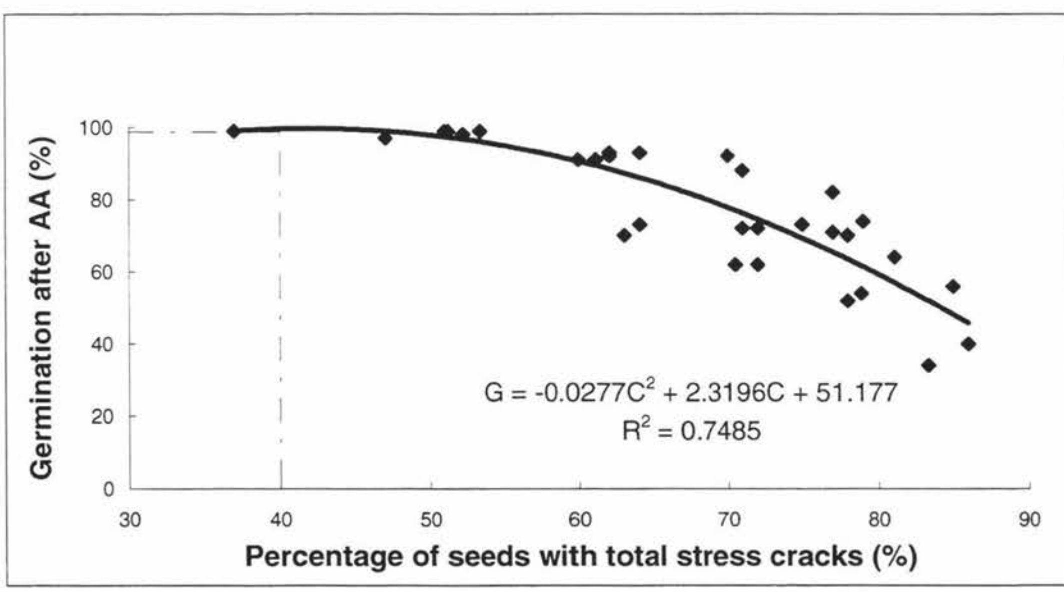


Fig. 4.14. Relationship between percentage of seeds with total stress cracks and seed germination after the AA test

A similar relation was also found between germination after the AA test and percentage of seeds with either vertical stress cracks or total stress cracks with r = - 0.79 and r = - 0.87 respectively (Figs. 4.13 and 4.14). The relationships were as follows:

$G = -0.0198C^2 + 1.0194C + 89.926$ with vertical stress cracks only, and

$G = -0.0277C^2 + 2.3196C + 51.177$ when both transverse and vertical cracks were taken into account.

Germination after AA reduced faster than germination immediately after drying as the percentage of seeds with stress cracks increased. This agreed with Wang and Hampton (1991) who suggested that seed vigour often decreases before any loss of germination. However, with less than 50% of seeds with stress cracks, although seeds still showed high germination after drying (Figs. 4.11 and 4.12), they did not maintain constant germination after AA test (Figs. 4.13 and 4.14). The maximum germination gained from these relationships are at about 40%-crack position. Therefore, similar to the above recommendation, the relationships found are of more significance when more than 40% of seeds have stress cracks.

SUMMARY

Maize seeds (*Zea mays* **L.**) at initial moisture content of 28% were dried at 60°C for different times (5, 10, 15, 20 and 25 minutes), and then tempered for 45 minutes at either 21 or 30°C. These drying cycles were repeated until seeds reached the desired moisture content of 13%. Dried seeds were then exposed to ambient temperature of 21°C for 24 hours before seed quality (in terms of stress cracking, germination and vigour) was determined.

The results showed that the increased time per cycle of exposure to 60°C drying resulted in an increased percentage of seeds with vertical cracks and therefore seeds with total stress cracks, because the transverse-cracked seed percentage remained constant irrespective of different exposure times.

Seed germination tests showed that when exposure time was less than 15 minutes per drying cycle, seeds retained high germination. However, germination after the AA test showed that only seeds dried for 10 minutes per cycle or less maintained high vigour. However, seed conductivity did not differ with different exposure times and tempering temperatures. Seeds dried continuously at 60°C for 4 hours to 13% seed moisture content without tempering had their germination reduced to 20%, and vigour to 6%.

For maize seed, high temperature drying at 60°C without tempering was unsuitable. However, if seeds were dried at 60°C for 5 or 10 minutes per cycle followed by low temperature tempering, seed germinability and vigour were maintained. This procedure could be feasible, provided it was cost effective.

Relationships between the percentage of stress cracked seeds and germination of maize seeds after drying and after the AA test were polynomial. These relationships were recommended to apply to determined germination before and after the AA test when seed lot has more than 50 and 40% stress cracked seed percentage respectively.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The minimisation of postharvest losses has been a key issue in producing grain. Drying and storage are the major operations in postharvest biotechnology. If not carried out correctly, these operations markedly influence seed quality. Based on the experimental results the following conclusions can be drawn:

1. A standard microwave oven even with a low power rating of 195 W was not suitable for drying legume seed.

2. Drying by natural ventilation consumed less energy than artificial drying. In fact, since such energy is freely available, the only costs are capital costs for setting up the dryer. Drying by artificial dryers set at 30°C consumed twice as much energy as that at 45°C. However, because of bad weather condition at harvest, it would be erroneous to conclude that 30°C drying always consumes double the energy of 45°C drying.

3. Natural sun drying may be satisfactorily adopted for small scale drying in terms of seed quality. However, it requires a large open space to expose seed for drying, and separate storage space overnight. Sun drying also consumes more time and labour to spread, aerate and collect seeds each day. This may be appropriate for farmers with small farms in the North of Vietnam, where there is abundant manpower available. However, lack of control in the drying process may result in seed overdying or underdrying. In addition, because of the need to handle large quantities of seeds, seeds could be easily contaminated due to mixing of dirt and fungi. Thus, big farms in the south of Vietnam and the state warehouses should use artificial dryers to reduce harvested seed moisture content.

4. No significant differences in seed quality characteristics (germination, conductivity) were found between the selected drying methods. Artificial drying has great advantages for seed production in terms of time and labour savings, though it can cause severe loss of seed quality and vigour if it is not carried out properly. Results from this study suggest that pea seeds can be dried at up to 45°C without reducting seed quality.

5. Initial moisture content of pea seeds significantly affected the time for drying and energy consumption. However, it did not affect seed quality immediately after drying because of the poor initial condition of seeds found at harvest in this experiment.

6. Poor storage conditions significantly increased the number of dead seeds rather than abnormal seedlings. Pea seeds stored at 25°C and 90% r.h. lost quality more quickly than those stored at 20.5°C and 55% r.h. Therefore, high temperature and high humidity in storage, which commonly occurs in Vietnam, as well as in other tropical countries, must be controlled to reduce seed viability loss. Seed should be close-stored in moisture proof packages, such as aluminium foil or plastic film for small seed lots. In large scale operations, temperature and relative humidity in silos must be kept low to maintain a safe seed moisture content throughout storage.

7. Conductivity of pea seeds had an inverse relationship with seed germination.

8. Intermittent drying-tempering of maize seeds during high temperature drying (60°C) resulted in a significantly lower percentage of cracked seeds (depending upon the time of exposure to drying in each cycle) than seeds which were not tempered. Tempering temperatures of 21°C and 30°C had similar effects on stress cracking in maize seeds, seed germination and vigour when seeds were dried at 60°C. Therefore, tempering at ambient laboratory temperature (around 21°C) is recommended.

9. Periods of drying at 60°C for up to 10 minutes per cycle allowed seeds to retain high quality for sowing purposes, even though the percentage of cracked seeds was over 50% in both tempering conditions.

10. Drying at 60°C without tempering dramatically reduced germination and vigour of maize seed and is not recommended.

11. Conductivity of maize seeds remained constant, although seed vigour was reduced with increase of exposure time to drying. Therefore, the accelerated ageing (AA) test was a better method of assessing maize seed vigour than conductivity in this study.

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APPENDICES

APPENDIX 1. Drying characteristics of selected drying methods

Table A1.1. Drying conditions for seed at 23.8% initial moisture content

Parameters	Treatments						
	MiniKiwi Dryer				Natural Drying		
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Drying air Temperature, °C	30.0	30.0	44.6	45.0			20.21
Exhaust Temperature, °C	27.8	28.8	35.7	33.3			19.26
Ambient Temperature, °C	21.8	22.4	22.0	21.5	19.9	19.8	20.11
Concrete Temperature, °C					22.4	20.1	
Inlet Air Velocity. m/s	5.75	6.82	2.60	2.90			-
Outlet Air Velocity, m/s	1.31	1.37	0.54	0.42			1.40
Drying time, hrs	24.0	21.0	10.0	10.0	33.0	54.0	73.5
Radiation, W/m^2					485.3	340.3	

Vent.: In-Bin Natural Ventilation Drying

**-1 and *-2 are two different conditions*

Table A1.2. Drying conditions for seed at 18.0% initial moisture content

Parameters	Treatments						
	MiniKiwi Dryer				Natural Drying		
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Drying air Temperature, °C	30.0	30.0	45.8	45.0			16.8
Exhaust Temperature, °C	25.6	29.5	36.4	34.4			16.2
Ambient Temperature, °C	21.3	20.4	22.0	22.5	19.3	17.0	16.8
Concrete Temperature, °C					19.3	18.5	
Inlet Air Velocity. m/s	7.62	6.50	3.27	2.98			-
Outlet Air Velocity, m/s	1.25	1.36	0.44	0.43			1.10
Drying time, hrs	16.0	14.0	6.5	6.0	39.5	37.5	52.0
Radiation, W/m^2					314.1	431.5	

Table A1.3. Drying conditions for seed at 14.5% initial moisture content

Parameters	Treatments						
	MiniKiwi Dryer				Natural Drying		
	30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Drying air Temperature, °C	30.0	30.0	44.0	44.8			18.8
Exhaust Temperature, °C	27.8	28.2	33.9	35.8			17.2
Ambient Temperature, °C	21.4	21.3	20.8	19.8	17.5	15.8	18.8
Concrete Temperature, °C					18.9	17.4	
Inlet Air Velocity. m/s	6.57	6.18	3.07	2.99			-
Outlet Air Velocity, m/s	1.26	1.11	0.39	0.40			0.61
Drying time, hrs	12.0	13.0	5.0	5.0	28.0	30.5	37.5
Radiation, W/m^2					464.9	405.1	

APPENDIX 2. Statistical data analysis of time and energy consumption using a SAS package.

2.1. Analysis of time consumption data for drying pea

```
options ls=78 ps=63 nocenter;
title 'Analysis of time consumption data for drying pea';
data time;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30', '45', 'SN', 'VT';
 input time @@; output;
 end; end;
cards;
22.5 10.0  43.5  73.5
15.0  6.25 38.5  52.0
12.5  5.0  29.25 37.5
;
run;
proc glm data=time;
 class IMC dry;
 model time=IMC dry / ss1;
 means IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

IMC            3    14.5 18.0 23.8
DRY            4    30 45 SN VT
Number of observations in data set = 12
```

Dependent Variable: TIME

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4554.760417	910.952083	18.73	0.0013
Error	6	291.843750	48.640625		
Corrected Total	11	4846.604167			

R-Square	C.V.	Root MSE	TIME Mean
0.939784	24.22327	6.974283	28.79167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
IMC	2	536.572917	268.286458	5.52	0.0437
DRY	3	4018.187500	1339.395833	27.54	0.0007

2.2. Analysis of energy consumption data for drying pea

```
options ls=78 ps=63 nocenter;
title 'Analysis of energy consumption data for drying pea';
data energy;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30', '45', 'SN', 'VT';
 input energy @@; output;
 end; end;
cards;
15.71 9.03 4.75 0.58
14.83 6.54 3.95 0.24
10.37 5.41 3.50 0.19
;
run;
proc glm data=energy;
 class IMC dry;
 model energy=IMC dry / ss1;
 means IMC dry /t;
run;
```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
IMC	3	14.5 18.0 23.8
DRY	4	30 45 SN VT

Number of observations in data set = 12

Dependent Variable: ENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	298.6977167	59.7395433	35.85	0.0002
Error	6	9.9970500	1.6661750		
Corrected Total	11	308.6947667			

R-Square	C.V.	Root MSE	ENERGY Mean
0.967615	20.62536	1.290804	6.258333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
IMC	2	14.1490167	7.0745083	4.25	0.0710
DRY	3	284.5487000	94.8495667	56.93	0.0001

APPENDIX 3. Seed germination raw data

Table A3.1. Germination (%) of pea seeds at 23.8% initial moisture content

		Seed germination, % (Initial germination 82%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		80	80	76	73	75	71	70
Open Storage	After 20 days	78	74	75	73	76	72	70
	After 40 days	79	71	72	74	76	65	62
	After 60 days	74	62	64	67	73	53	52
Closed Storage	After 20 days	73	72	70	72	74	70	70
	After 40 days	68	70	54	65	61	65	66
	After 60 days	57	10	48	8	49	44	49

Table A3.2. Germination (%) of pea seeds at 18.0% initial moisture content

		Seed germination, % (Initial germination 83%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		81	75	72	70	68	72	78
Open Storage	After 20 days	82	69	72	70	70	69	72
	After 40 days	78	67	68	65	67	49	67
	After 60 days	72	34	66	61	50	35	40
Closed Storage	After 20 days	74	65	72	67	67	72	72
	After 40 days	61	63	56	63	61	46	58
	After 60 days	42	30	39	5	47	31	34

Table A3.3. Germination (%) of pea seeds at 14.5% initial moisture content

		Seed germination, % (Initial germination 79%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		73	78	79	76	76	73	71
Open Storage	After 20 days	73	68	64	72	76	63	72
	After 40 days	74	63	59	72	49	64	68
	After 60 days	70	32	47	64	36	35	56
Closed Storage	After 20 days	66	66	68	67	69	74	71
	After 40 days	64	56	69	61	57	68	68
	After 60 days	19	37	9	17	27	46	48

APPENDIX 4. Statistical data analysis of seed germination using a SAS package.

4.1. Analysis of Pea Germination data immediately after drying

```
options ls=78 ps=63 nocenter;
title 'Analysis of Pea Germination data immediately after drying';
data germitn;
 do moisture = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input germitn @@; output;
 end; end;
cards;
80  80  76  73  75  71  70
81  75  72  70  68  72  78
73  78  79  76  76  73  71
;
run;
proc glm data=germitn;
 class moisture dry;
 model germitn=moisture dry / ss1;
 means moisture dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

MOISTURE       3    14.5 18.0 23.8
DRY            7    30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 21
```

Dependent Variable: GERMITN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	118.2857143	14.7857143	1.09	0.4305
Error	12	162.6666667	13.5555556		
Corrected Total	20	280.9523810			

R-Square	C.V.	Root MSE	GERMITN Mean
0.421017	4.934111	3.681787	74.61905

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MOISTURE	2	8.6666667	4.3333333	0.32	0.7324
DRY	6	109.6190476	18.2698413	1.35	0.3100

4.2. Analysis of Germination data for pea in OPEN storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Germination data for pea in OPEN storage';
data germitn;
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input germitn @@; output;
 end; end; end;
cards;
80  80  76  73  75  71  70
81  75  72  70  68  72  78
73  78  79  76  76  73  71

78  74  75  73  76  72  70
82  69  72  70  70  69  72
73  68  64  72  76  63  72

79  71  72  74  76  65  62
78  67  68  65  67  49  67
74  63  59  72  49  64  68

74  62  64  67  73  53  52
72  34  66  61  50  35  40
70  32  47  64  36  35  56
;
run;
proc glm data=germitn;
 class day IMC dry;
 model germitn=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
DAY	4	0 20 40 60
IMC	3	14.5 18.0 23.8
DRY	7	30-1 30-2 45-1 45-2 SN-1 SN-2 VT

Number of observations in data set = 84

Dependent Variable: GERMITN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	7552.416667	686.583333	13.77	0.0001
Error	72	3590.571429	49.869048		
Corrected Total	83	11142.988095			

R-Square	C.V.	Root MSE	GERMITN Mean
0.677773	10.53813	7.061802	67.01190

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DAY	3	5043.273810	1681.091270	33.71	0.0001
IMC	2	679.238095	339.619048	6.81	0.0020
DRY	6	1829.904762	304.984127	6.12	0.0001

4.3. Analysis of Germination data for pea in CLOSE storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Germination data for pea in CLOSE storage';
data germitn;
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input germitn @@; output;
 end; end; end;
cards;
80  80  76  73  75  71  70
81  75  72  70  68  72  78
73  78  79  76  76  73  71

73  72  70  72  74  70  70
74  65  72  67  67  72  72
66  66  68  67  69  74  71

68  70  54  65  61  65  66
61  63  56  63  61  46  58
64  56  69  61  57  68  68

57  10  48   8  49  44  49
42  30  39   5  47  31  34
19  37   9  17  27  46  48
;
run;
proc glm data=germitn;
 class day IMC dry;
 model germitn=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

DAY            4    0 20 40 60
IMC            3    14.5 18.0 23.8
DRY            7    30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 84

Dependent Variable: GERMITN
                                     Sum of            Mean
Source                    DF        Squares          Square    F Value      Pr > F

Model                     11    22797.52381      2072.50216      27.88      0.0001
Error                     72     5352.04762        74.33399
Corrected Total           83    28149.57143

                    R-Square           C.V.        Root MSE          GERMITN Mean
                    0.809871       14.38665        8.621716              59.92857

Source                    DF      Type I SS     Mean Square    F Value      Pr > F

DAY                        3    21831.28571      7277.09524      97.90      0.0001
IMC                        2      208.50000       104.25000       1.40      0.2526
DRY                        6      757.73810       126.28968       1.70      0.1336
```

4.4. Analysis of Germination data for pea between Storage conditions

```
options ls=78 ps=63 nocenter;
title 'Analysis of Germination data for pea between Storage conditions';
data germitn;
 do storage = 'OPEN', 'CLOSE';
 do day = 20 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input germitn @@; output;
 end; end; end; end;
```

```
cards;
78  74  75  73  76  72  70
82  69  72  70  70  69  72
73  68  64  72  76  63  72
79  71  72  74  76  65  62
78  67  68  65  67  49  67
74  63  59  72  49  64  68
74  62  64  67  73  53  52
72  34  66  61  50  35  40
70  32  47  64  36  35  56

73  72  70  72  74  70  69
74  65  72  67  67  72  72
66  66  68  67  69  74  71
68  70  54  65  61  65  66
61  63  56  63  61  46  58
64  56  69  61  57  68  68
57  10  48   8  49  44  49
42  30  39   5  47  31  34
19  37   9  17  27  46  48
;
run;
proc glm data=germitn;
 class storage day IMC dry;
 model germitn= storage day IMC dry / ss1;
 means storage day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels    Values

STORAGE         2    CLOS OPEN
DAY             3    20 40 60
IMC             3    14.5 18.0 23.8
DRY             7    30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 126

Dependent Variable: GERMITN
                                       Sum of            Mean
Source                     DF         Squares          Square    F Value      Pr > F

Model                      11     22168.11111      2015.28283      19.65      0.0001
Error                     114     11689.76190       102.54177
Corrected Total           125     33857.87302

                     R-Square            C.V.        Root MSE             GERMITN Mean
                     0.654740        16.94889        10.12629                 59.74603

Source                     DF       Type I SS     Mean Square    F Value      Pr > F

STORAGE                     1      2819.17460      2819.17460      27.49      0.0001
DAY                         2     16922.39683      8461.19841      82.51      0.0001
IMC                         2      1015.11111       507.55556       4.95      0.0087
DRY                         6      1411.42857       235.23810       2.29      0.0397
```

APPENDIX 5. Abnormal seedlings raw data

Table A5.1. Abnormal seedlings (%) of pea seeds at 23.8% initial moisture content

		Abnormal seedlings, % (Initial abnormal seedlings 12%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		18	15	21	22	20	26	29
Open Storage	After 20 days	20	21	23	22	19	22	22
	After 40 days	15	25	16	22	19	28	30
	After 60 days	11	33	12	28	22	41	39
Closed Storage	After 20 days	22	21	19	24	19	18	21
	After 40 days	21	17	30	17	24	22	19
	After 60 days	19	42	24	39	30	24	23

Table A5.2. Abnormal seedlings (%) of pea seeds at 18.0% initial moisture content

		Abnormal seedlings, % (Initial abnormal seedlings 16%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		17	20	26	29	26	22	18
Open Storage	After 20 days	14	25	25	26	24	25	25
	After 40 days	18	28	18	20	26	46	27
	After 60 days	19	61	9	16	43	56	54
Closed Storage	After 20 days	23	23	22	28	27	19	24
	After 40 days	27	20	27	20	26	41	29
	After 60 days	28	31	34	37	25	38	30

Table A5.3. Abnormal seedlings (%) of pea seeds at 14.5% initial moisture content

		Abnormal seedlings, % (Initial abnormal seedlings 18%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		21	19	18	22	16	20	19
Open Storage	After 20 days	17	29	32	24	16	31	19
	After 40 days	18	31	35	23	43	29	22
	After 60 days	17	59	47	31	52	59	35
Closed Storage	After 20 days	28	25	27	25	23	19	19
	After 40 days	24	34	19	17	32	21	17
	After 60 days	45	32	49	45	36	32	25

APPENDIX 6. Dead seed raw data

Table A6.1. Dead seed (%) of pea seeds at 23.8% initial moisture content

		Dead seed, % (Initial dead seed 6%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		2	5	3	5	5	3	1
Open Storage	After 20 days	2	5	2	5	5	6	8
	After 40 days	6	4	12	4	5	7	8
	After 60 days	15	5	24	5	5	6	9
Closed Storage	After 20 days	5	7	11	4	7	12	9
	After 40 days	11	13	16	18	15	13	15
	After 60 days	24	48	28	53	21	32	28

Table A6.2. Dead seed (%) of pea seeds at 18.0% initial moisture content

		Dead seed, % (Initial dead seed 1%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		2	5	2	1	6	6	4
Open Storage	After 20 days	4	6	3	4	6	6	3
	After 40 days	4	5	14	15	7	5	6
	After 60 days	9	5	25	23	7	9	6
Closed Storage	After 20 days	3	12	6	5	6	9	4
	After 40 days	12	17	17	17	13	13	13
	After 60 days	30	39	27	58	28	31	36

Table A6.3. Dead seed (%) of pea seeds at 14.5% initial moisture content

		Dead seed, % (Initial dead seed 3%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		6	3	3	2	8	7	10
Open Storage	After 20 days	10	3	4	4	8	6	9
	After 40 days	8	6	6	5	8	7	10
	After 60 days	13	9	6	5	12	6	9
Closed Storage	After 20 days	6	9	5	8	8	7	10
	After 40 days	12	10	12	22	11	11	15
	After 60 days	36	31	42	38	37	22	27

APPENDIX 7. Seed conductivity raw data

Table A7.1. Conductivity ($\mu S.cm^{-1}.g^{-1}$) of pea seeds at 23.8% initial moisture content

		Conductivity, $\mu S.cm^{-1}.g^{-1}$ (Initial conductivity 13.27 $\mu S.cm^{-1}.g^{-1}$)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		15.30	19.71	17.50	22.80	20.93	22.00	19.11
Open Storage	After 20 days	16.60	19.33	21.49	25.65	18.25	19.14	20.21
	After 40 days	18.60	19.47	21.47	26.62	19.10	20.74	20.17
	After 60 days	16.88	23.79	21.60	23.46	17.93	21.58	17.43
Closed Storage	After 20 days	21.64	24.70	23.79	26.83	23.66	22.58	18.81
	After 40 days	29.05	25.87	35.71	26.90	32.60	27.52	25.07
	After 60 days	39.99	43.59	41.18	42.68	45.06	39.20	41.12

Table A7.2. Conductivity ($\mu S.cm^{-1}.g^{-1}$) of pea seeds at 18.0% initial moisture content

		Conductivity, $\mu S.cm^{-1}.g^{-1}$ (Initial conductivity 13.40 $\mu S.cm^{-1}.g^{-1}$)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		17.38	18.65	20.84	21.75	20.61	22.19	19.92
Open Storage	After 20 days	18.10	21.66	24.30	21.74	23.31	26.19	23.87
	After 40 days	20.96	22.81	22.74	21.34	23.34	23.60	23.75
	After 60 days	19.90	21.53	22.92	21.99	19.49	25.64	23.44
Closed Storage	After 20 days	20.65	22.06	22.90	22.97	21.94	22.75	23.27
	After 40 days	30.54	35.75	33.86	22.91	27.93	36.31	35.78
	After 60 days	39.27	37.98	44.46	44.80	39.02	47.00	51.45

Table A7.3. Conductivity ($\mu S.cm^{-1}.g^{-1}$) of pea seeds at 14.5% initial moisture content

		Conductivity, $\mu S.cm^{-1}.g^{-1}$ (Initial conductivity 18.63 $\mu S.cm^{-1}.g^{-1}$)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		20.37	19.86	24.31	22.10	20.79	20.45	22.77
Open Storage	After 20 days	21.77	20.61	20.10	20.33	22.20	23.40	22.14
	After 40 days	22.14	22.29	22.63	19.23	21.66	22.34	22.59
	After 60 days	22.64	21.88	24.77	22.54	24.48	18.82	23.05
Closed Storage	After 20 days	18.71	20.00	21.71	20.57	22.23	23.25	22.88
	After 40 days	28.30	31.75	30.08	27.87	33.69	33.69	29.98
	After 60 days	42.99	40.99	43.02	41.41	38.49	41.25	39.84

APPENDIX 8. Statistical data analysis of seed conductivity using a SAS package.

8.1. Analysis of Pea Conductivity data immediately after drying

```
options ls=78 ps=63 nocenter;
title 'Analysis of Pea Conductivity data immediately after drying';
data cond;
 do moisture = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input cond @@; output;
 end; end;
cards;
15.30  19.71  17.50  22.80  20.93  22.00  19.11
17.38  18.65  20.84  21.75  20.61  22.19  19.92
20.37  19.86  24.31  22.10  20.79  20.45  22.77
;
run;
proc glm data=cond;
 class moisture dry;
 model cond=moisture dry / ss1;
 means moisture dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class       Levels    Values

MOISTURE       3      14.5 18.0 23.8
DRY            7      30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 21
```

```
Dependent Variable: COND
                                       Sum of             Mean
Source                  DF            Squares           Square   F Value      Pr > F

Model                    8        53.45959048       6.68244881      2.39      0.0844
Error                   12        33.57913333       2.79826111
Corrected Total         20        87.03872381

                  R-Square               C.V.         Root MSE                COND Mean
                  0.614205           8.182049         1.672800                 20.44476

Source                  DF          Type I SS      Mean Square   F Value      Pr > F

MOISTURE                 2        13.30886667       6.65443333      2.38      0.1349
DRY                      6        40.15072381       6.69178730      2.39      0.0937
```

8.2. Analysis of Conductivity data for pea in OPEN storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Conductivity data for pea in OPEN storage';
data cond;
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input cond @@; output;
 end; end; end;
cards;
15.30  19.71  17.50  22.80  20.93  22.00  19.11
17.38  18.65  20.84  21.75  20.61  22.19  19.92
20.37  19.86  24.31  22.10  20.79  20.45  22.77

16.60  19.33  21.49  25.65  18.25  19.14  20.21
18.10  21.66  24.30  21.74  23.31  26.19  23.87
21.77  20.61  20.10  20.33  22.20  23.40  22.14

18.60  19.47  21.47  26.62  19.10  20.74  20.17
20.96  22.81  22.74  21.34  23.34  23.60  23.75
22.14  22.29  22.63  19.23  21.66  22.34  22.59

16.88  23.79  21.60  23.46  17.93  21.58  17.43
19.90  21.53  22.92  21.99  19.49  25.64  23.44
22.64  21.88  24.77  22.54  24.48  18.82  23.05
;
run;
proc glm data=cond;
 class day IMC dry;
 model cond=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels     Values

DAY            4     0 20 40 60
IMC            3     14.5 18.0 23.8
DRY            7     30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 84

General Linear Models Procedure

Dependent Variable: COND
                                       Sum of             Mean
Source                  DF            Squares           Square   F Value      Pr > F

Model                   11        162.0908976       14.7355361      4.03      0.0001
Error                   72        263.0234833        3.6531039
Corrected Total         83        425.1143810

                  R-Square               C.V.         Root MSE                COND Mean
                  0.381288           8.953867         1.911309                 21.34619
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DAY	3	24.08580000	8.02860000	2.20	0.0957
IMC	2	50.98166667	25.49083333	6.98	0.0017
DRY	6	87.02343095	14.50390516	3.97	0.0017

8.3. Analysis of Conductivity data for pea in CLOSE storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Conductivity data for pea in CLOSE storage';
data cond;
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input cond @@; output;
 end; end; end;
cards;
15.30  19.71  17.50  22.80  20.93  22.00  19.11
17.38  18.65  20.84  21.75  20.61  22.19  19.92
20.37  19.86  24.31  22.10  20.79  20.45  22.77

21.64  24.70  23.79  26.83  23.66  22.58  18.81
20.65  22.06  22.90  22.97  21.94  22.75  23.27
18.71  20.00  21.71  20.57  22.23  23.25  22.88

29.05  25.87  35.71  26.90  32.60  27.52  25.07
30.54  35.75  33.86  22.91  27.93  36.31  35.78
28.30  31.75  30.08  27.87  33.69  33.69  29.98

39.99  43.59  41.18  42.68  45.06  39.20  41.12
39.27  37.98  44.46  44.80  39.02  47.00  51.45
42.99  40.99  43.02  41.41  38.49  41.25  39.84
;
run;
proc glm data=cond;
 class day IMC dry;
 model cond=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
DAY	4	0 20 40 60
IMC	3	14.5 18.0 23.8
DRY	7	30-1 30-2 45-1 45-2 SN-1 SN-2 VT

Number of observations in data set = 84

Dependent Variable: COND

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	6242.373151	567.488468	70.23	0.0001
Error	72	581.779824	8.080275		
Corrected Total	83	6824.152975			

R-Square	C.V.	Root MSE	COND Mean
0.914747	9.853826	2.842583	28.84750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
DAY	3	6154.299585	2051.433195	253.88	0.0001
IMC	2	17.142050	8.571025	1.06	0.3515
DRY	6	70.931517	11.821919	1.46	0.2031

8.4. Analysis of Conductivity data for pea in between storage conditions

```
options ls=78 ps=63 nocenter;
title 'Analysis of Conductivity data for pea in between storage conditions';
data cond;
 do storage = 'OPEN', 'CLOSE';
 do day = 20 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input cond @@; output;
 end; end; end; end;
cards;
16.60  19.33  21.49  25.65  18.25  19.14  20.21
18.10  21.66  24.30  21.74  23.31  26.19  23.87
21.77  20.61  20.10  20.33  22.20  23.40  22.14
18.60  19.47  21.47  26.62  19.10  20.74  20.17
20.96  22.81  22.74  21.34  23.34  23.60  23.75
22.14  22.29  22.63  19.23  21.66  22.34  22.59
16.88  23.79  21.60  23.46  17.93  21.58  17.43
19.90  21.53  22.92  21.99  19.49  25.64  23.44
22.64  21.88  24.77  22.54  24.48  18.82  23.05

21.64  24.70  23.79  26.83  23.66  22.58  18.81
20.65  22.06  22.90  22.97  21.94  22.75  23.27
18.71  20.00  21.71  20.57  22.23  23.25  22.88
29.05  25.87  35.71  26.90  32.60  27.52  25.07
30.54  35.75  33.86  22.91  27.93  36.31  35.78
28.30  31.75  30.08  27.87  33.69  33.69  29.98
39.99  43.59  41.18  42.68  45.06  39.20  41.12
39.27  37.98  44.46  44.80  39.02  47.00  51.45
42.99  40.99  43.02  41.41  38.49  41.25  39.84
;
run;
proc glm data=cond;
 class storage day IMC dry;
 model cond=storage day IMC dry / ss1;
 means storage day IMC dry /t;
run;
```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
STORAGE	2	CLOS OPEN
DAY	3	20 40 60
IMC	3	14.5 18.0 23.8
DRY	7	30-1 30-2 45-1 45-2 SN-1 SN-2 VT

Number of observations in data set = 126

Dependent Variable: COND

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	5436.678196	494.243472	20.20	0.0001
Error	114	2789.891541	24.472733		
Corrected Total	125	8226.569737			

R-Square	C.V.	Root MSE	COND Mean
0.660868	18.56454	4.946992	26.64754

Source	DF	Type I SS	Mean Square	F Value	Pr > F
STORAGE	1	3151.100096	3151.100096	128.76	0.0001
DAY	2	2137.591740	1068.795870	43.67	0.0001
IMC	2	57.794573	28.897287	1.18	0.3108
DRY	6	90.191787	15.031965	0.61	0.7185

APPENDIX 9. Hollow heart raw data

Table A9.1. Hollow heart (%) of pea seeds at 23.8% initial moisture content

		Hollow heart, % (Initial hollow heart 0%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		0.5	0.5	1.0	1.0	0.5	1.0	1.0
Open Storage	After 20 days	0.5	1.5	2.5	1.0	0.5	2.0	1.0
	After 40 days	0.5	3.0	2.5	1.0	1.5	1.5	0.5
	After 60 days	1.5	3.0	3.0	2.5	1.5	1.5	1.0
Closed Storage	After 20 days	0.5	0.5	3.0	1.0	1.5	2.0	2.0
	After 40 days	3.0	1.5	3.0	4.5	2.0	4.0	4.0
	After 60 days	5.0	8.0	6.0	5.0	4.5	3.5	7.0

Table A9.2. Hollow heart (%) of pea seeds at 18.0% initial moisture content

		Hollow heart, % (Initial hollow heart 0.5%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		0.0	0.5	1.0	2.0	1.5	0.5	1.0
Open Storage	After 20 days	0.5	2.0	1.0	2.0	1.0	0.5	1.5
	After 40 days	1.0	2.0	1.0	2.0	0.5	0.5	1.0
	After 60 days	1.0	2.0	1.5	2.5	1.0	1.0	1.0
Closed Storage	After 20 days	2.5	1.5	2.0	2.0	1.0	1.5	1.0
	After 40 days	2.0	4.0	4.0	4.5	4.0	2.0	2.0
	After 60 days	4.0	4.5	3.0	6.0	3.5	1.5	2.5

Table A9.3. Hollow heart (%) of pea seeds at 14.5% initial moisture content

		Hollow heart, % (Initial hollow heart 0.5%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		0.0	2.0	0.5	1.0	0.5	1.0	1.0
Open Storage	After 20 days	0.5	1.0	0.5	1.5	0.5	1.0	1.5
	After 40 days	0.5	1.5	1.0	1.0	0.5	0.5	1.5
	After 60 days	0.5	1.0	2.0	1.5	1.0	1.0	2.0
Closed Storage	After 20 days	1.5	1.0	0.5	1.0	2.0	2.0	3.0
	After 40 days	2.0	2.5	2.0	1.5	3.5	4.5	4.0
	After 60 days	2.5	4.0	3.0	5.5	5.0	5.5	4.5

APPENDIX 10. Seed moisture content raw data

Table A10.1. Seed moisture content (%) of pea seeds at 23.8% initial moisture content

		Seed moisture content, % (Initial seed moisture content 23.8%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		10.3	9.9	10.5	10.6	10.4	11.3	13.1
Open Storage	After 20 days	11.2	11.2	11.0	10.5	10.8	10.9	11.2
	After 40 days	10.7	10.7	10.4	10.5	10.7	10.7	10.9
	After 60 days	10.7	10.9	10.4	10.7	11.1	10.7	10.9
Closed Storage	After 20 days	19.9	19.2	18.9	18.4	19.5	18.9	19.5
	After 40 days	21.5	20.7	21.5	20.5	24.1	20.8	21.4
	After 60 days	21.5	21.1	21.0	20.6	21.1	20.6	21.2

Table A10.2. Seed moisture content (%) of pea seeds at 18.0% initial moisture content

		Seed moisture content, % (Initial seed moisture content 18.0%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		10.5	10.3	9.8	10.5	11.2	11.0	12.1
Open Storage	After 20 days	11.0	11.4	11.3	10.9	10.9	10.8	11.0
	After 40 days	10.5	10.9	10.3	10.9	10.7	11.0	11.1
	After 60 days	10.7	11.3	10.5	10.9	10.8	10.7	10.6
Closed Storage	After 20 days	20.0	19.5	18.5	18.6	18.6	20.2	20.4
	After 40 days	22.0	21.7	21.5	21.0	21.2	20.5	21.3
	After 60 days	21.8	21.9	21.4	21.3	20.6	20.5	20.9

Table A10.3. Seed moisture content (%) of pea seeds at 14.5% initial moisture content

		Seed moisture content, % (Initial seed moisture content 14.5%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		9.9	10.4	10.1	9.8	11.3	11.2	12.1
Open Storage	After 20 days	10.6	10.7	10.6	10.4	10.8	11.0	11.7
	After 40 days	10.5	10.5	10.4	10.3	11.1	11.1	11.5
	After 60 days	10.9	11.1	10.7	10.7	10.8	10.5	10.4
Closed Storage	After 20 days	18.7	18.3	18.9	18.4	20.5	19.6	20.6
	After 40 days	20.5	20.2	20.1	20.5	20.8	20.9	21.0
	After 60 days	20.8	20.7	20.5	20.7	20.5	20.7	20.7

APPENDIX 11. Statistical data analysis of seed moisture content using a SAS package.

11.1. Analysis of Pea Final Moisture data pea in OPEN storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Pea Final Moisture data pea in OPEN storage';
data moist;
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input moist @@; output;
 end; end; end;
cards;
10.3   9.9  10.5  10.6  10.4  11.3  13.1
10.5  10.3   9.8  10.5  11.2  11.0  12.1
 9.9  10.4  10.1   9.8  11.3  11.2  12.1

11.2  11.2  11.0  10.5  10.8  10.9  11.2
11.0  11.4  11.3  10.9  10.9  10.8  11.0
10.6  10.7  10.6  10.4  10.8  11.0  11.7

10.7  10.7  10.4  10.5  10.7  10.7  10.9
10.5  10.9  10.3  10.9  10.7  11.0  11.1
10.5  10.5  10.4  10.3  11.1  11.1  11.5

10.7  10.9  10.4  10.7  11.1  10.7  10.9
10.7  11.3  10.5  10.9  10.8  10.7  10.6
10.9  11.1  10.7  10.7  10.8  10.5  10.4
;
run;
proc glm data=moist;
 class day IMC dry;
 model moist=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels     Values

DAY             4     0 20 40 60
IMC             3     14.5 18.0 23.8
DRY             7     30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 84

Dependent Variable: MOIST
                                         Sum of            Mean
Source                      DF          Squares          Square    F Value       Pr > F

Model                       11       7.17166667      0.65196970       3.57       0.0005
Error                       72      13.16642857      0.18286706
Corrected Total             83      20.33809524

                      R-Square             C.V.        Root MSE              MOIST Mean
                      0.352622         3.957788        0.427630                10.80476

Source                      DF      Type I SS     Mean Square    F Value       Pr > F

DAY                          3     0.59142857      0.19714286       1.08       0.3639
IMC                          2     0.11880952      0.05940476       0.32       0.7237
DRY                          6     6.46142857      1.07690476       5.89       0.0001
```

11.2. Analysis of Pea Final Moisture data pea in CLOSE storage

```
options ls=78 ps=63 nocenter;
title 'Analysis of Pea Final Moisture data pea in CLOSE storage';
data moist;
```

```
 do day = 0 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input moist @@; output;
 end; end; end;
cards;
10.3   9.9  10.5  10.6  10.4  11.3  13.1
10.5  10.3   9.8  10.5  11.2  11.0  12.1
 9.9  10.4  10.1   9.8  11.3  11.2  12.1

19.9  19.2  18.9  18.4  19.5  18.9  19.5
20.0  19.5  18.5  18.6  18.6  20.2  20.4
18.7  18.3  18.9  18.4  20.5  19.6  20.6

21.5  20.7  21.5  20.5  24.1  20.8  21.4
22.0  21.7  21.5  21.0  21.2  20.5  21.3
20.5  20.2  20.1  20.5  20.8  20.9  21.0

21.5  21.1  21.0  20.6  21.1  20.6  21.2
21.8  21.9  21.4  21.3  20.6  20.5  20.9
20.8  20.7  20.5  20.7  20.5  20.7  20.7
;
run;
proc glm data=moist;
 class day IMC dry;
 model moist=day IMC dry / ss1;
 means day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

DAY            4    0 20 40 60
IMC            3    14.5 18.0 23.8
DRY            7    30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 84

Dependent Variable: MOIST
                                      Sum of           Mean
Source                     DF        Squares         Square    F Value      Pr > F

Model                      11    1532.711429     139.337403     320.86      0.0001
Error                      72      31.266667       0.434259
Corrected Total            83    1563.978095

                     R-Square           C.V.       Root MSE              MOIST Mean
                     0.980008       3.653288       0.658984                18.03810

Source                     DF      Type I SS    Mean Square    F Value      Pr > F

DAY                         3    1519.887619     506.629206    1166.65      0.0001
IMC                         2       2.392381       1.196190       2.75      0.0704
DRY                         6      10.431429       1.738571       4.00      0.0016
```

11.3. Analysis of Pea Final Moisture data pea in between Storage conditions

```
options ls=78 ps=63 nocenter;
title 'Analysis of Pea Final Moisture data pea in between Storage conditions';
data moist;
 do storage = 'OPEN', 'CLOSE';
 do day = 20 to 60 by 20;
 do IMC = '23.8', '18.0', '14.5';
 do dry = '30-1', '30-2', '45-1', '45-2', 'SN-1', 'SN-2', 'VT';
 input moist @@; output;
 end; end; end; end;
cards;
11.2  11.2  11.0  10.5  10.8  10.9  11.2
11.0  11.4  11.3  10.9  10.9  10.8  11.0
10.6  10.7  10.6  10.4  10.8  11.0  11.7
10.7  10.7  10.4  10.5  10.7  10.7  10.9
10.5  10.9  10.3  10.9  10.7  11.0  11.1
10.5  10.5  10.4  10.3  11.1  11.1  11.5
```

```
10.7  10.9  10.4  10.7  11.1  10.7  10.9
10.7  11.3  10.5  10.9  10.8  10.7  10.6
10.9  11.1  10.7  10.7  10.8  10.5  10.4

19.9  19.2  18.9  18.4  19.5  18.9  19.5
20.0  19.5  18.5  18.6  18.6  20.2  20.4
18.7  18.3  18.9  18.4  20.5  19.6  20.6
21.5  20.7  21.5  20.5  24.1  20.8  21.4
22.0  21.7  21.5  21.0  21.2  20.5  21.3
20.5  20.2  20.1  20.5  20.8  20.9  21.0
21.5  21.1  21.0  20.6  21.1  20.6  21.2
21.8  21.9  21.4  21.3  20.6  20.5  20.9
20.8  20.7  20.5  20.7  20.5  20.7  20.7
;
run;
proc glm data=moist;
 class storage day IMC dry;
 model moist=storage day IMC dry / ss1;
 means storage day IMC dry /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

STORAGE        2    CLOS OPEN
DAY            3    20 40 60
IMC            3    14.5 18.0 23.8
DRY            7    30-1 30-2 45-1 45-2 SN-1 SN-2 VT
Number of observations in data set = 126

Dependent Variable: MOIST
                                     Sum of             Mean
Source                   DF         Squares           Square    F Value       Pr > F

Model                    11     2953.409524       268.491775     558.92       0.0001
Error                   114       54.762540         0.480373
Corrected Total         125     3008.172063

                   R-Square            C.V.         Root MSE              MOIST Mean
                   0.981795        4.432509         0.693090                15.63651

Source                   DF       Type I SS      Mean Square    F Value       Pr > F

STORAGE                   1     2929.982222      2929.982222    6099.39       0.0001
DAY                       2       16.976349         8.488175      17.67       0.0001
IMC                       2        1.767778         0.883889       1.84       0.1635
DRY                       6        4.683175         0.780529       1.62       0.1465
```

APPENDIX 12. Expected field emergence (EFE)

Table A12.1. EFE (%) of pea seeds at 23.8% initial moisture content

		EFE, % (Initial EFE 81%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		79	78	76	72	74	71	**71**
Open Storage	After 20 days	77	74	73	72	76	72	**71**
	After 40 days	78	71	71	72	75	**67**	**65**
	After 60 days	74	**64**	**66**	**68**	73	**58**	**59**
Closed Storage	After 20 days	73	71	69	71	73	70	**71**
	After 40 days	67	69	55	65	61	65	66
	After 60 days	56	**21**	**49**	**21**	49	**47**	49

Bold values are greater than standard germination

Table A12.2. EFE (%) of pea seeds at 18.0% initial moisture content

		EFE, % (Initial EFE 82%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		80	75	72	70	**69**	72	77
Open Storage	After 20 days	80	69	71	70	70	69	71
	After 40 days	76	**68**	**69**	**67**	**68**	**56**	**68**
	After 60 days	72	**45**	**67**	**64**	**57**	**45**	**49**
Closed Storage	After 20 days	73	**67**	71	**68**	**68**	72	72
	After 40 days	**62**	61	**57**	**64**	**62**	**50**	**59**
	After 60 days	**46**	**38**	**43**	**18**	**50**	**37**	**38**

Bold values are greater than standard germination

Table A12.3. EFE (%) of pea seeds at 14.5% initial moisture content

		EFE, % (Initial EFE 78%)						
Drying Methods		30°C-1	30°C-2	45°C-1	45°C-2	Sun-1	Sun-2	Vent.
Immediately after Drying		73	76	76	75	75	73	71
Open Storage	After 20 days	73	**69**	**67**	72	75	**65**	72
	After 40 days	74	**65**	**63**	72	**56**	**66**	**69**
	After 60 days	70	**44**	**53**	**66**	**46**	**47**	**60**
Closed Storage	After 20 days	**68**	**68**	**69**	**69**	69	73	70
	After 40 days	64	**58**	68	**63**	**58**	65	66
	After 60 days	**29**	**42**	**22**	**27**	**35**	**48**	**50**

Bold values are greater than standard germination

APPENDIX 13. Raw data of maize seed with stress cracks.

Table A13.1. Percentage of maize seed having stress cracks.

Cycle exposure Time (min.)	Tempering condition	Repls	% seed with Tran. Crack	% seed with Vert. Crack	% total seed with Crack
60°C	No Temp.	1	4	81	85
		2	4	82	86
		3	4	81	85
5	30°C	1	10	41.25	51.25
		2	7.78	44.44	52.22
		3	4.44	48.89	53.33
10		1	8	54	62
		2	7	57	64
		3	11.11	60	71.11
15		1	7	57	64
		2	6.67	74.44	81.11
		3	12	66	78
20		1	5	74	79
		2	12	65	77
		3	1.67	68.33	70
25		1	12	73	85
		2	4	74	78
		3	4	73	77
5	Ambient (21°C)	1	4	43	47
		2	3	34	37
		3	6	45	51
10		1	7	55	62
		2	11.11	58.89	70
		3	11.11	48.89	60
15		1	8	63	71
		2	4	68	72
		3	9	54	63
20		1	13	62	75
		2	6	66	72
		3	8.89	70	78.89
25		1	23	63	86
		2	2	69	71
		3	5.56	77.78	83.34

APPENDIX 14. Statistical data analysis of maize seed stress cracks using a SAS package.

14.1. Analysis of Maize transverse crack - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize transverse crack - Tempering at 30oC';
data trcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input trcrack @@; output;
 end; end;
cards;
10      8       7       5      12    4
 7.78   7       6.68   12       4    4
 4.44  11.11   12       1.67    4    4
;
run;
proc glm data=trcrack;
 class repl treat;
 model trcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: TRCRACK
                                        Sum of            Mean
Source                    DF           Squares          Square   F Value     Pr > F

Model                      7       51.97366667      7.42480952      0.55     0.7784
Error                     10      134.49493333     13.44949333
Corrected Total           17      186.46860000

                    R-Square              C.V.        Root MSE          TRCRACK Mean
                    0.278726          52.94545        3.667355              6.926667

Source                    DF         Type I SS     Mean Square   F Value     Pr > F

REPL                       2        6.42653333      3.21326667      0.24     0.7919
TREAT                      5       45.54713333      9.10942667      0.68     0.6506
```

14.2. Analysis of Maize vertical crack - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize vertical crack - Tempering at 30oC';
data vcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input vcrack @@; output;
 end; end;
cards;
41.25  54  57     74     73  81
44.44  57  74.44  65     74  82
48.89  60  66     68.33  73  81
;
run;
proc glm data=vcrack;
 class repl treat;
 model vcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels     Values

REPL            3     1 2 3
TREAT           6     05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: VCRACK
                                      Sum of              Mean
Source                      DF       Squares            Square   F Value       Pr > F

Model                        7   2500.504683        357.214955     16.93       0.0001
Error                       10    210.954767         21.095477
Corrected Total             17   2711.459450

                      R-Square          C.V.          Root MSE            VCRACK Mean
                      0.922199      7.039951          4.592981               65.24167

Source                      DF     Type I SS       Mean Square   F Value       Pr > F

REPL                         2     31.369633         15.684817      0.74       0.5000
TREAT                        5   2469.135050        493.827010     23.41       0.0001
```

14.3. Analysis of Maize total crack - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize total crack - Tempering at 30oC';
data ttcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input ttcrack @@; output;
 end; end;
cards;
51.25  62     64     79  85  85
52.22  64     81.11  77  78  86
53.33  71.11  78     70  77  85
;
run;
proc glm data=ttcrack;
 class repl treat;
 model ttcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels     Values

REPL            3     1 2 3
TREAT           6     05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: TTCRACK
                                      Sum of              Mean
Source                      DF       Squares            Square   F Value       Pr > F

Model                        7   2074.842189        296.406027     10.41       0.0007
Error                       10    284.815122         28.481512
Corrected Total             17   2359.657311

                      R-Square          C.V.          Root MSE           TTCRACK Mean
                      0.879298      7.395000          5.336807               72.16778

Source                      DF     Type I SS       Mean Square   F Value       Pr > F

REPL                         2     12.674144          6.337072      0.22       0.8044
TREAT                        5   2062.168044        412.433609     14.48       0.0003
```

14.4. Analysis of Maize transverse crack - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize transverse crack - Tempering at 21oC';
data trcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input trcrack @@; output;
 end; end;
cards;
4  7      8  13     23     4
3  11.11  4   6      2     4
6  11.11  9   8.89   5.56  4
;
run;
proc glm data=trcrack;
 class repl treat;
 model trcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: TRCRACK
                                        Sum of             Mean
Source                       DF        Squares           Square   F Value     Pr > F

Model                         7    183.4291056       26.2041579      1.10     0.4295
Error                        10    237.7325222       23.7732522
Corrected Total              17    421.1616278

                       R-Square           C.V.         Root MSE          TRCRACK Mean
                       0.435531       65.65728         4.875782              7.426111

Source                       DF      Type I SS      Mean Square   F Value     Pr > F

REPL                          2     69.5526778       34.7763389      1.46     0.2772
TREAT                         5    113.8764278       22.7752856      0.96     0.4864
```

14.5. Analysis of Maize vertical crack - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize vertical crack - Tempering at 21oC';
data vcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input vcrack @@; output;
 end; end;
cards;
43  55     63  62  63     81
34  58.89  68  66  69     82
45  48.89  54  70  77.78  81
;
run;
proc glm data=vcrack;
 class repl treat;
 model vcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values
```

```
REPL          3    1 2 3
TREAT         6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: VCRACK
                                 Sum of          Mean
Source              DF          Squares        Square   F Value      Pr > F

Model                7      2913.367589    416.195370     11.84      0.0004
Error               10       351.467589     35.146759
Corrected Total     17      3264.835178

              R-Square            C.V.      Root MSE         VCRACK Mean
              0.892348        9.514646      5.928470            62.30889

Source              DF        Type I SS   Mean Square   F Value      Pr > F

REPL                 2        11.866078      5.933039      0.17      0.8470
TREAT                5      2901.501511    580.300302     16.51      0.0001
```

14.6. Analysis of Maize total crack - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize total crack - Tempering at 21oC';
data ttcrack;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input ttcrack @@; output;
 end; end;
cards;
47  62  71  75     86     85
37  70  72  72     71     86
51  60  63  78.89  83.34  85
;
run;
proc glm data=ttcrack;
 class repl treat;
 model ttcrack= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels     Values

REPL          3    1 2 3
TREAT         6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18
Dependent Variable: TTCRACK
                                 Sum of          Mean
Source              DF          Squares        Square   F Value      Pr > F

Model                7      3112.393283    444.627612     13.38      0.0002
Error               10       332.330367     33.233037
Corrected Total     17      3444.723650

              R-Square            C.V.      Root MSE        TTCRACK Mean
              0.903525        8.266739      5.764810            69.73500

Source              DF        Type I SS   Mean Square   F Value      Pr > F

REPL                 2        28.988100     14.494050      0.44      0.6583
TREAT                5      3083.405183    616.681037     18.56      0.0001
```

14.7. Analysis of Maize transvese crack - between 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize transvese crack - between 30oC and 21oC';
data trcrack;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input trcrack @@; output;
```

```
 end; end;
cards;
7.4 8.7 8.6 6.2  6.7
4.3 9.7 7.0 9.3 10.2
;
run;
proc glm data=trcrack;
 class temper treat;
 model trcrack= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels    Values

TEMPER          2    21oC 30oC
TREAT           5    05-M 10-M 15-M 20-M 25-M
Number of observations in data set = 10

Dependent Variable: TRCRACK
                                        Sum of            Mean
Source                    DF           Squares          Square    F Value      Pr > F

Model                      5       13.21500000      2.64300000       0.63      0.6887
Error                      4       16.67400000      4.16850000
Corrected Total            9       29.88900000

                    R-Square              C.V.        Root MSE          TRCRACK Mean
                    0.442136          26.14200        2.041690              7.810000

Source                    DF         Type I SS     Mean Square    F Value      Pr > F

TEMPER                     1        0.84100000      0.84100000       0.20      0.6766
TREAT                      4       12.37400000      3.09350000       0.74      0.6102
```

14.8. Analysis of Maize vertical crack - between 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize vertical crack - between 30oC and 21oC';
data vcrack;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input vcrack @@; output;
 end; end;
cards;
44.9  57    65.8  69.1  73
40.7  54.3  61.7  66    69.9
;
run;
proc glm data=vcrack;
 class temper treat;
 model vcrack= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels    Values

TEMPER          2    21oC 30oC
TREAT           5    05-M 10-M 15-M 20-M 25-M
Number of observations in data set = 10

Dependent Variable: VCRACK
                                        Sum of            Mean
Source                    DF           Squares          Square    F Value      Pr > F

Model                      5       1062.868000      212.573600     948.99      0.0001
Error                      4          0.896000        0.224000
Corrected Total            9       1063.764000
```

	R-Square	C.V.	Root MSE		VCRACK Mean
	0.999158	0.785668	0.473286		60.24000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TEMPER	1	29.584000	29.584000	132.07	0.0003
TREAT	4	1033.284000	258.321000	1153.22	0.0001

14.9. Analysis of Maize total crack - between 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize total crack - between 30oC and 21oC';
data ttcrack;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input ttcrack @@; output;
 end; end;
cards;
52.3 65.7 74.4 75.3 80
45   64   68.7 75.3 80.1
;
run;
proc glm data=ttcrack;
 class temper treat;
 model ttcrack= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
TEMPER	2	21oC 30oC
TREAT	5	05-M 10-M 15-M 20-M 25-M

Number of observations in data set = 10

Dependent Variable: TTCRACK

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1212.132000	242.426400	42.12	0.0015
Error	4	23.024000	5.756000		
Corrected Total	9	1235.156000			

	R-Square	C.V.	Root MSE		TTCRACK Mean
	0.981359	3.524040	2.399167		68.08000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TEMPER	1	21.316000	21.316000	3.70	0.1266
TREAT	4	1190.816000	297.704000	51.72	0.0011

APPENDIX 15. Maize seed germination raw data

Table A15.1. Maize seed quality after it was dried from 28.2% to 13% with tempering at 30°C for 45 minutes.

Drying at 60°C for	Reps.	Germination / Abnormal / Dead seed after drying		Conductivity		Germination / Abnormal / Dead seed after AA test	
			Mean		**Mean**		**Mean**
Initial			**99/1/0**		**0.677**		
42°C			**92/7/1**		**1.013**		**92/3/5**
No T.	1	22/23/55	**20/20/60**	1.073	**1.038**	6/16/78	**6/14/80**
	2	17/19/64		1.013		7/9/84	
	3	20/18/62		1.029		4/17/79	
5 mins	1	96/3/1	**97/2/1**	0.959	**0.872**	99/1/0	**99/1/0**
	2	96/4/0		0.852		98/2/0	
	3	99/0/1		0.805		99/0/1	
10 mins	1	98/1/1	**96/3/1**	0.840	**0.869**	92/5/3	**92/5/3**
	2	98/2/0		0.905		93/5/2	
	3	93/5/2		0.863		91/5/4	
15 mins	1	89/10/1	**90/9/1**	0.903	**0.915**	73/18/9	**69/21/10**
	2	89/10/1		0.898		64/25/11	
	3	91/8/1		0.944		70/19/11	
20 mins	1	88/10/2	**85/13/2**	0.847	**0.877**	74/15/11	**72/16/12**
	2	91/8/1		0.778		82/12/6	
	3	77/21/2		1.005		62/20/18	
25 mins	1	67/29/4	**71/23/6**	0.827	**0.836**	56/32/12	**60/25/15**
	2	70/23/7		0.863		52/32/16	
	3	78/16/6		0.818		71/12/17	

Table A15.2. Maize seed quality after it was dried from 28.2% to 13% with tempering at ambient temperature of 21°C for 45 minutes.

Drying at 60°C for	Reps.	Germination / Abnormal / Dead seed after drying		Conductivity		Germination / Abnormal / Dead seed after AA test	
			Mean		**Mean**		**Mean**
Initial			**99/1/0**		**0.677**		
42°C			**92/7/1**		**1.013**		**92/3/5**
No T.	1	22/23/55	**20/20/60**	1.073	**1.038**	6/16/78	**6/14/80**
	2	17/19/64		1.013		7/9/84	
	3	20/18/62		1.029		4/17/79	
5 mins	1	96/3/1	**97/2/1**	0.910	**0.859**	97/2/1	**98/1/1**
	2	99/1/0		0.868		99/1/0	
	3	98/2/0		0.798		99/1/0	
10 mins	1	95/5/0	**95/4/1**	0.912	**0.882**	93/5/2	**92/6/2**
	2	94/5/1		0.862		92/6/2	
	3	96/3/1		0.872		91/6/3	
15 mins	1	92/7/1	**88/10/2**	0.905	**0.896**	72/15/13	**68/21/11**
	2	87/12/1		0.872		62/28/10	
	3	86/12/2		0.912		70/20/10	
20 mins	1	91/9/0	**83/15/2**	0.789	**0.887**	73/13/14	**66/21/13**
	2	85/14/1		0.849		72/20/8	
	3	72/23/5		1.023		54/30/16	
25 mins	1	69/28/3	**76/19/5**	0.932	**0.907**	40/40/20	**54/28/18**
	2	97/3/0		0.787		88/9/3	
	3	61/27/12		1.002		34/36/30	

APPENDIX 16. Statistical data analysis of maize seed germination using a SAS package.

16.1. Analysis of Maize Germination after drying - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after drying - Tempering at 30oC';
data germitn;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input germitn @@; output;
 end; end;
cards;
96 98 89 88 67 22
96 98 89 91 70 17
99 93 91 77 78 20
;
run;
proc glm data=germitn;
 class repl treat;
 model germitn= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels    Values

REPL            3    1 2 3
TREAT           6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: GERMITN
                                         Sum of              Mean
Source                     DF           Squares            Square    F Value      Pr > F

Model                       7       12955.72222        1850.81746      87.90      0.0001
Error                      10         210.55556          21.05556
Corrected Total            17       13166.27778

                     R-Square              C.V.          Root MSE         GERMITN Mean
                     0.984008          5.989514          4.588633             76.61111

Source                     DF         Type I SS       Mean Square    F Value      Pr > F

REPL                        2           0.77778           0.38889       0.02      0.9817
TREAT                       5       12954.94444        2590.98889     123.05      0.0001
```

16.2. Analysis of Maize Germination after drying - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after drying - Tempering at 21oC';
data germitn;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input germitn @@; output;
 end; end;
cards;
96 95 92 91 69 22
99 94 87 85 97 17
98 96 86 72 61 20
;
run;
proc glm data=germitn;
 class repl treat;
 model germitn= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: GERMITN
                                       Sum of            Mean
Source                    DF          Squares          Square   F Value      Pr > F

Model                      7      12782.50000      1826.07143     24.09      0.0001
Error                     10        758.00000        75.80000
Corrected Total           17      13540.50000

                    R-Square             C.V.        Root MSE          GERMITN Mean
                    0.944020         11.38081        8.706320              76.50000

Source                    DF        Type I SS     Mean Square   F Value      Pr > F

REPL                       2        185.33333        92.66667      1.22      0.3350
TREAT                      5      12597.16667      2519.43333     33.24      0.0001
```

16.3. Analysis of Maize Germination after AA test - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after AA test - Tempering at 30oC';
data germitn;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input germitn @@; output;
 end; end;
cards;
99 92 73 74 56 6
98 93 64 82 52 7
99 91 70 62 71 4
;
run;
proc glm data=germitn;
 class repl treat;
 model germitn= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: GERMITN
                                       Sum of            Mean
Source                    DF          Squares          Square   F Value      Pr > F

Model                      7      16430.38889      2347.19841     52.02      0.0001
Error                     10        451.22222        45.12222
Corrected Total           17      16881.61111

                    R-Square             C.V.        Root MSE          GERMITN Mean
                    0.973271         10.13508        6.717308              66.27778

Source                    DF        Type I SS     Mean Square   F Value      Pr > F

REPL                       2          1.44444         0.72222      0.02      0.9841
TREAT                      5      16428.94444      3285.78889     72.82      0.0001
```

16.4. Analysis of Maize Germination after AAtest - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after AAtest - Tempering at 21oC';
data germitn;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input germitn @@; output;
 end; end;
cards;
97 93 72 73 40 6
99 92 62 72 88 7
99 91 70 54 34 4
;
run;
proc glm data=germitn;
 class repl treat;
 model germitn= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: GERMITN
                                       Sum of            Mean
Source                    DF          Squares          Square   F Value      Pr > F

Model                      7      16849.05556      2407.00794     14.52      0.0002
Error                     10       1657.88889       165.78889
Corrected Total           17      18506.94444

                    R-Square             C.V.        Root MSE           GERMITN Mean
                    0.910418         20.10115        12.87590               64.05556

Source                    DF       Type I SS     Mean Square   F Value      Pr > F

REPL                       2       388.11111       194.05556      1.17      0.3493
TREAT                      5     16460.94444      3292.18889     19.86      0.0001
```

16.5. Analysis of Maize Germination after drying - between 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after drying - between 30oC and 21oC';
data germitn;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input germitn @@; output;
 end; end;
cards;
97    96.3  89.7  85.3  71.7
97.9  95    88.3  82.7  75.7
;
run;
proc glm data=germitn;
 class temper treat;
 model germitn= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

TEMPER         2    21oC 30oC
TREAT          5    05-M 10-M 15-M 20-M 25-M
```

```
Number of observations in data set = 10

Dependent Variable: GERMITN
                                     Sum of            Mean
Source                  DF          Squares          Square   F Value      Pr > F

Model                    5      738.6300000     147.7260000     43.47      0.0014
Error                    4       13.5940000       3.3985000
Corrected Total          9      752.2240000

                  R-Square             C.V.        Root MSE          GERMITN Mean
                  0.981928         2.095841        1.843502              87.96000

Source                  DF        Type I SS     Mean Square   F Value      Pr > F

TEMPER                   1        0.0160000       0.0160000      0.00      0.9486
TREAT                    4      738.6140000     184.6535000     54.33      0.0010
```

16.6. Analysis of Maize Germination after AA Test - between 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Germination after AA Test - between 30oC and 21oC';
data germitn;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input germitn @@; output;
 end; end;
cards;
98.7  92  69  72.7  59.7
98.3  92  68  66.3  54
;
run;
proc glm data=germitn;
 class temper treat;
 model germitn= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels     Values

TEMPER          2     21oC 30oC
TREAT           5     05-M 10-M 15-M 20-M 25-M
Number of observations in data set = 10

Dependent Variable: GERMITN
                                     Sum of            Mean
Source                  DF          Squares          Square   F Value      Pr > F

Model                    5      2461.721000      492.344200    103.22      0.0003
Error                    4        19.080000        4.770000
Corrected Total          9      2480.801000

                  R-Square             C.V.        Root MSE          GERMITN Mean
                  0.992309         2.833830        2.184033              77.07000

Source                  DF        Type I SS     Mean Square   F Value      Pr > F

TEMPER                   1        18.225000       18.225000      3.82      0.1223
TREAT                    4      2443.496000      610.874000    128.07      0.0002
```

APPENDIX 17. Statistical data analysis of maize seed conductivity using a SAS package.

17.1. Analysis of Maize Conductivity - Tempering at 30°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Conductivity - Tempering at 30oC';
data cond;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input cond @@; output;
 end; end;
cards;
0.959  0.840  0.903  0.847  0.827  1.073
0.852  0.905  0.898  0.778  0.863  1.013
0.805  0.863  0.944  1.005  0.818  1.029
;
run;
proc glm data=cond;
 class repl treat;
 model cond= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class      Levels    Values

REPL            3    1 2 3
TREAT           6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: COND
                                    Sum of           Mean
Source                    DF       Squares         Square    F Value      Pr > F

Model                      7    0.07958722     0.01136960       2.61      0.0824
Error                     10    0.04361789     0.00436179
Corrected Total           17    0.12320511

                    R-Square          C.V.       Root MSE              COND Mean
                    0.645973      7.328253       0.066044               0.901222

Source                    DF     Type I SS    Mean Square    F Value      Pr > F

REPL                       2    0.00243611     0.00121806       0.28      0.7621
TREAT                      5    0.07715111     0.01543022       3.54      0.0422
```

17.2. Analysis of Maize Conductivity - Tempering at 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Conductivity - Tempering at 21oC';
data cond;
 do repl = 1 to 3 by 1;
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M', 'NO-T';
  input cond @@; output;
 end; end;
cards;
0.910  0.912  0.905  0.789  0.932  1.073
0.868  0.862  0.872  0.849  0.787  1.013
0.798  0.872  0.912  1.023  1.002  1.029
;
run;
proc glm data=cond;
 class repl treat;
 model cond= repl treat / ss1;
 means repl treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

REPL           3    1 2 3
TREAT          6    05-M 10-M 15-M 20-M 25-M NO-T
Number of observations in data set = 18

Dependent Variable: COND
                                     Sum of            Mean
Source                    DF        Squares          Square    F Value      Pr > F

Model                      7     0.07481589      0.01068798       2.09      0.1407
Error                     10     0.05122056      0.00512206
Corrected Total           17     0.12603644

                    R-Square           C.V.        Root MSE              COND Mean
                    0.593605       7.851254        0.071569               0.911556

Source                    DF      Type I SS     Mean Square    F Value      Pr > F

REPL                       2     0.01301944      0.00650972       1.27      0.3223
TREAT                      5     0.06179644      0.01235929       2.41      0.1105
```

17.3. Analysis of Maize Conductivity - betweent 30°C and 21°C

```
options ls=78 ps=63 nocenter;
title 'Analysis of Maize Conductivity - betweent 30oC and 21oC';
data cond;
 do temper = '30oC', '21oC';
 do treat = '05-M', '10-M', '15-M', '20-M', '25-M';
  input cond @@; output;
 end; end;
cards;
0.872  0.869  0.915  0.877  0.836
0.859  0.882  0.896  0.887  0.907
;
run;
proc glm data=cond;
 class temper treat;
 model cond= temper treat / ss1;
 means temper treat /t;
run;
```

General Linear Models Procedure

```
Class Level Information

Class     Levels    Values

TEMPER         2    21oC 30oC
TREAT          5    05-M 10-M 15-M 20-M 25-M
Number of observations in data set = 10

Dependent Variable: COND
                                     Sum of            Mean
Source                    DF        Squares          Square    F Value      Pr > F

Model                      5     0.00229840      0.00045968       0.73      0.6397
Error                      4     0.00253560      0.00063390
Corrected Total            9     0.00483400

                    R-Square           C.V.        Root MSE              COND Mean
                    0.475465       2.861065        0.025177               0.880000

Source                    DF      Type I SS     Mean Square    F Value      Pr > F

TEMPER                     1     0.00038440      0.00038440       0.61      0.4796
TREAT                      4     0.00191400      0.00047850       0.75      0.6041
```