A STUDY OF THE CAUSES OF SEED DETERIORATION FOLLOWING PROCESSING IN MAIZE (*Zea mays* L.)

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ALFREDO B. ESCASINAS

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To my wife, Ruth

and daughter, Ruby Ann,

this piece of work is dedicated.

ABSTRACT

This experiment was designed to study the influence of commercial maize seed processing on seed quality. In particular, it aimed to determine:

1) the particular stage or stages of processing which could be responsible for a reduction in seed germination,
2) whether seed cracking contributes to the problem of seed deterioration after storage,
3) which of the various stages of processing seed cracking occurs,
4) possible ways of reducing seed damage caused by seed processing.

The results showed that seed processing adversely affected seed quality. The damage which occurred, however, did not cause any immediate reduction in seed viability but was strongly implicated in hastening seed deterioration in storage.

The stages of seed processing which most likely contributed to a reduction in seed germination following storage were cob drying, seed drying, shelling and the final stages of dressing, grading and treating. Hybrid XL72aa was less susceptible to processing damage than Hybrids D54 and XL81 although the former had less potential to germinate as indicated by its lower initial seed germination.

Remarkable levels of stress cracking occurred due to seed drying. In this particular experiment, stress cracking had no direct damaging effect on essential seed structures even though it hastened seed deterioration in storage depending on the type of cracks. Stress cracks which were not seen by X-ray in a longitudinal position but which could often be seen visually did not affect seed viability after storage for 12 months. This kind of crack appeared as tiny shallow cracks in a transverse line in seeds on an X-ray plate. Similarly, fissures located outside the germ area as revealed by X-ray radiography had no adverse effect on seed viability after storage. However, cracks which were detected by X-ray along the side or extending into the germ area seriously reduced seed viability in storage.

X-ray radiography is a useful technique for determining the specific location or magnitude of seed cracking in maize and can be used to critically assess the likely affects of seed cracking on seed storage longevity.

Machine shelling at a seed moisture content of 22% produced more broken seeds than shelling at either 18% or 14% moisture content.

After ear drying, tempering of the ears before shelling reduced the level of stress cracking after seed drying, particularly at temperatures of 30 C and 20 C. Generally, the germination after storage was higher in seeds from tempered ears before shelling than from ears which were not tempered at this stage.

Reducing seed drying temperature from 40 C to 20 C drastically reduced the levels of stress cracking and resulted in better seed viability after storage. Seed drying starting with a initial seed moisture content of 14% at 30 C or 18% at 40 C reduced the level of stress cracking.

After seed drying, seed tempering at the same drying temperature of 40 C did not reduce stress cracking but did reduce seed viability after storage. Seed tempering at a drying temperature of 30 C reduced stress cracking and resulted in higher seed viability after seed storage compared with non-tempered seeds. Tempering had no effect when seeds were dried at 20 C.

This study has clearly shown that mechanical seed processing is a major contributory cause of reduction in seed quality. Although seed damage may not be evident before seed storage it is clearly involved in hastening seed deterioration in storage. The study concludes that particular attention to ensure artificial seed drying at a relatively lower temperature and lower initial seed moisture content and tempering, play an important part in ensuring that seed damage and deterioration are both greatly reduced.

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GENERAL INTRODUCTION

The methods used to produce high quality hybrid maize seed in New Zealand are largely based upon practical experience which has been accumulated by seed companies over the past 40 years. As an integral part of this production system major attention has focussed on the maintenance and measurement of seed quality. Certainly the post harvest part of maize production process, particularly seed threshing, drying and storage, has been clearly implicated in the preservation of high quality seed.

The rapid expansion of the maize industry in New Zealand has occurred as a result of the activities of relatively few commercial companies. These companies have been responsible for the seed production, processing and local distribution of the bulk of the New Zealand maize seed crop. More recently, they have become active in the export of hybrid maize seed to other countries, particularly to Australia.

By other countries' standards the yields of maize in New Zealand are high. In 1984, for example, an estimated maize grain yield of 8.9 tonnes/ha was obtained from 22230 hectares of crop. The use of good quality seed is one of the contributory factors in obtaining such high grain yields. It is therefore, essential that supplies of high quality seed are maintained to ensure the expansion of a viable maize industry.

Over recent years, problems of seed deterioration have been noticed in New Zealand seed exported to Australia, a large decrease in germination being observed after only a few months even under good storage conditions. Such deterioration has occurred in seed which was thought to have the potential to retain high seed viability for at least a couple of years (Callender, 1984 personal communication). This problem was not noticed in New Zealand because seeds distributed to local farmers were planted shortly after production. But when seeds underwent storage in Australia, a drastic reduction in germination occurred in some lots which was indicative of the poor vigour. Visual examination on seeds showed some internal hairline fractures which were suspected to be the principal cause of the problem.

Even under good storage conditions, it may be valid to suspect seed cracking as a cause of the rapid and early deterioration of seeds. Some workers have emphasised the deleterious effects of seed injury on seed storage life. Seed injury does not only reduce the production of normal seedlings but also decreases the storage potential of damaged seeds (Justice and Bass, 1978). Waelti et al. (1969) stated that kernel injury affects both short-term and long-term storage of maize seeds, and Moore (1972) has shown that damaged seeds clearly do not store as well as intact seeds. Small and hidden injuries in seeds, including bruises, may not cause immediate loss in viability but they can become critical in regulating the rate of ageing of seeds. Injured areas die early upon ageing and promote rapid weakening and early death of surrounding normal tissues. This results in a drastic reduction of seed germination.

In view of these facts, it was thought valuable to initiate a detailed study of the seed processing system used by one large maize producing company (HBF Dalgety N.Z. Ltd, Gisborne) to trace the possible cause or causes of the problem which contributed to the seed deterioration after storage. This study was therefore conducted to determine any particular stage or stages of processing which could be responsible for a reduction in seed germination; to determine if seed cracking contributes to the problem of seed deterioration after storage; to determine which of the various stages of processing seed cracking occurs and to determine possible ways to reduce or alleviate the problem.

The study was carried out from May, 1984 to November 1985 and involved the drawing of representative samples from successive points in the processing sequence and their assessment for initial and post-storage seed quality.

CHAPTER 1
REVIEW OF LITERATURE

A. Seed Processing

When seed is freshly harvested, it is usually unsuitable for either planting or storage. The seed may have a high moisture content and contain various contaminants such as leaves, stems, weed seeds and live and dead insects, as well as damaged and immature seeds (Salleh, 1982). The seed therefore, needs to be processed before it is suitable for storage or planting. Such processing involves upgrading the quality of seed by removing foreign material and undesirable seed, improving the planting condition of the seed and applying protectants (Gregg et al., 1970; Copeland, 1976). The ultimate goal of seed processing is therefore to obtain the maximum percentage of pure crop seed with a maximum germination potential.

The flow pattern of seed in a processing plant varies according to the kind of seed. Generally, however, the sequence follows the following pattern of operations (Salleh, 1982).

A.1 Conditioning and Precleaning

Seeds received at the processing plant may be directly processed or go into temporary storage while waiting processing. Predrying may also be necessary for some seeds as they are susceptible to mechanical damage when processed at high moisture content. Maize is sometimes shelled in the processing plant after predrying. Conditioning and precleaning consists of scalping, debearding, hulling, shelling or any other operations to remove awns or other appendages to make seed flow more readily through cleaners and elevators.

A.2 Drying

Precleaned seeds should be dried gently, while also avoiding excessive temperature to maintain germination quality. Drying may be in single or multiple stages with or without tempering depending on the crop. After drying to a safe moisture level, the seed is cooled and stored in bulk, preferably in ventilated bins.

A.3 Cleaning

This operation is basically similar to that of precleaning but is more refined. It includes the removal of inert material, weed seeds, other crop seeds, and broken seeds that are larger or smaller than the crop seed. This is generally done on an air screen cleaner.

A.4 Grading

This phase separates seeds according to physical differences. Seeds may be graded according to length, thickness, size, surface texture and shape such as flat or round seeds. All these separations can be done by screen- or disc-separation or a draper separation with velvet cloth in the case of separation according to differences in seed coat texture. This results in the retention of seeds in a seed lot with similar physical characteristics.

A.5 Seed Treatment

After cleaning and grading, high purity seeds can be bagged for storage or shipment. Often the seeds are treated with pesticide or fungicide chemicals just prior to bagging to control pests and diseases. These chemicals may be applied in dust or slurry form. A dye is sometimes introduced to ensure that the user will know that the seeds have been treated and are unsuitable for human or animal consumption.

A.6 Packaging

The treated seeds are weighed and packed in uniform weight bags, closed and ready for shipment or storage. The bags should be labelled to indicate the species, cultivar, grade, chemical treatment and other relevant information.

B. Seed Damage Due to Processing

Damage to seeds increased as harvesting and processing machines came into general usage (Justice and Bass, 1978). Mechanical damage of maize kernels begins with the mechanical process of harvesting and may continue at every subsequent operation during drying, handling or shelling. These operations can therefore, further decrease the quality of the seed.

B.1 Shelling Damage

During seed processing, the number of undamaged kernels decreases as processing progresses. The shelling operations have been identified as the most serious source of injury (Wortman et al., 1951). Injuries ranged from cracked crowns, chipped crowns, cracked sides of kernel, to tip cap removal. These kinds of seed damage result in decreased crop stands. Open cracks or chips in the germ face or in the crown cause the greatest reduction while closed cracks have a smaller but significant effect. Injury to the seed coat over the horny endosperm causes relatively little reduction in germination.

In a conventional combine, Chowdhury et al., (1978) mentioned that maize kernels are subjected to mechanical damage while passing through the shelling crescent. The subsequent operations inside the combine such as sieving and cleaning action, separation over the straw walkers and transportation by the augers, may also all contribute to mechanical damage of the kernels.

The speed and clearance of the cylinder sheller has also been shown to affect seed damage during shelling. Hall and Johnson (1970) showed that as the speed of the combine cylinder sheller is increased from 400 rpm to 600 rpm, seed germination decreases from 80% to 60%. When the cylinder clearance is decreased from 0.625 inch to 0.25 inch, germination may be reduced by 15% at a cylinder speed of 400 rpm. Chowdhury et al., (1978) also showed that total kernel damage increased from 26.3% to 42.0% when the sheller cylinder speed was increased from 450 rpm to 650 rpm. Byg and Hall (1968) also explained that the

higher the cylinder speed of the sheller the greater the damage to the maize kernels. Such damage occurs because the energy transferred from the cylinder to the kernels is in excess of the energy needed for shelling and therefore, contributes to greater kernel injury.

Various workers have found that problems of mechanical seed damage are associated with seed moisture content. Some reports have revealed that the percentage of kernels damaged during shelling is proportional to the moisture content of the kernels (Burrough et al., 1953; Johnson et al., 1963).

A range of different critical values of seed moisture content have been quoted by different workers in terms of cracking damage. For example, Brooker et al., (1974) stated that the optimum seed moisture content for limiting breakage caused by shelling of maize is about 22%. Increased damage and loss of germination occurs below or above this value. However, Jindal et al., (1979) observed that the breakage rate of maize kernels attained its lowest level at about 25% moisture content, increasing rapidly as the moisture content increased or decreased from this value. On the other hand, Waelti et al. (1979) found that kernel damage during shelling increased rapidly as kernel moisture rose above 20%. Hall and Johnson (1970) found that the minimum damage during shelling occurred at a moisture level between 17% and 24%.

It is quite obvious that the literature is conflicting in terms of the precise minimum seed moisture content for a minimum mechanical damage to seeds during shelling. This apparent confusion may be due to the different characteristics of various hybrids studied. Some hybrids have larger and heavier kernels while others have a thicker covering over the germ and therefore are more resistant to damage than the other less protected hybrids (Wortman et al., 1951).

B.2 Handling Damage

Aside from the shelling operation, seed damage also occurs due to handling techniques. Fiscus et al. (1971) investigated the seed damage resulting from commercial handling practices using a bucket elevator, a grain throwing device, or a drop spout compared with free fall. Breakage of shelled maize from a free fall of 100 feet was 12.8% and 7.8% for samples with 12.6% and 15.2% moisture contents, respectively. At 40 feet, breakage levels fell to 4.6% and 0.5% for seed with moisture contents of 12.6% and 15.2%, respectively. The data indicate greater damage at lower moisture contents. The same trend of results occurred in the grain throwers, spout drop and bucket elevator tests. Least damage occurred with the bucket elevator with 0.91% and 0.66% breakage at 12.7% and 15.1% moisture levels, respectively. It was also observed that the elevator buckets which were only half filled showed significantly more damage than when seed was elevated in full buckets. Presumably, the higher breakage was due to a larger percentage of kernels impacting on steel either when the buckets fill or during the elevation process. If the bucket is full, much of the impact is caused by grain against grain. The drop test confirmed that impact of grain on grain caused less breakage than grain on concrete.

Sands and Hall (1971) determined the damage to shelled maize during transport in a screw conveyor. They found that the screw conveyor caused only a very small amount of damage to dry shelled maize of 13% moisture content when operated at full capacity. But the level of damage increased greatly when the conveyor was operated at one-fourth capacity. At full capacity the conveyor caused a level of damage equivalent to 1 bu per 10,000 bu of shelled maize at one-fourth capacity. Hall (1974) explained that if the screw-type conveyor is operated at less than full capacity, the maize kernels can be bounced around within the conveyor and can strike against the metal surfaces; at full capacity the maize cushions itself against the impact. At high speeds and at less than full capacity a considerable amount of high velocity contact can occur between the maize kernels and

adjacent metal surfaces. Hall recommended that the most effective method of reducing maize kernel damage during handling is to operate the equipment at full capacity and at the recommended speed or less; and that minimum damage will occur if maize is handled at about 20% to 24% moisture content.

B.3 Reduction of Seed Storage Life Due to Mechanical Damage

Seed damage not only affects immediate seed viability but can also apparently impairs seed storage performance. However, mechanical damage may not immediately destroy the viability of the seed but can subsequently increase seed deterioration rate in storage (Brooker et al., 1974; Justice and Bass, 1978; Moore, 1972). Waelti et al. (1969) reported that kernel injury affects both short term and long term maize seeds storage and that seeds with 29% damage deteriorated 2 or 3 times faster than undamaged seeds.

Injured seeds are attacked more readily by fungi than uninjured seeds (Alberts, 1927; Koehler, 1954). Hence, injured seeds deteriorate faster in storage due to higher risk of fungal invasion.

Moore (1972) confirmed that damaged seeds do not store as well as intact seeds and that fungi enter the seeds through cracks in the seed coat. Small and hidden injuries in the seeds, including bruises, may not cause immediate loss of viability. However, they can become critical with ageing of the seeds. During storage, the injured areas serve as centres of infection and result in accelerated ageing that shortens the duration of viability. Injured areas, in addition to dying early, also promote rapid weakening and early death of surrounding normal tissues. Large and deep-seated injured tissues, by being in contact with extreme amounts of non-injured tissues, are much more destructive during the early stages than are small injuries with only minor peripheral contact with sound tissues. If an initial injury is non-critical that it has no immediate effect on viability, but is located on or near an essential part of an embryo structure a seed can readily become non-viable with only a

minor amount of additional deterioration. Injuries near or on the embryonic axis usually bring about a more rapid loss of viability during storage than injuries of similar size located in less important areas of the seed.

The reduction in seed storage life is a direct indication of the reduction in seed vigour caused by mechanical damage. Nikilov and Kirilov (1983) demonstrated the reduction in seed vigour due to mechanical damage. In their study, the percentage germination of maize with 18 - 59% mechanical damage was not decreased when sown under favourable temperature (20 C) conditions. However, germination was greatly decreased when favourable conditions after some days were changed to unfavourable temperature conditions (4 - 6 C). The decrease was proportional to the degree of damage and duration of unfavourable conditions. The germination of seeds with 55% mechanical damage was decreased when sown directly under unfavourable conditions which after some days were changed to favourable conditions. These results reflected the low vigour of seeds with mechanical damage which most probably reduces seed storage potential.

B.4 Stress Cracking Due to Seed Drying

The occurrence of internal cracking in seeds plays a vital role in affecting seed life. Stress cracks are fissures in the maize endosperm which are readily visible under bright light (Thompson et al., 1969). These hairline cracks develop in the kernel endosperm but the seed coat is not ruptured (Thompson and Foster, 1963).

Drying speed, expressed in terms of moisture loss in percentage points per hour, is considered to be the most significant factor in stress crack development (Thompson and Foster, 1963). Harrington (1972) stated that rapid drying can cause seed injury by cracking the endosperm as a result of rapid shrinking ofouter parts of the seed while the inner parts are still undried. When drying rates are too fast, a very steep moisture gradient is created between the suface and the centre of the seed. The evaporation of seed moisture from the seed surface

is much faster than the diffusion of moisture from the centre to the surface of the seed. This unequal drying throughout the seed tissues due to excessive drying rates causes the development of stress cracks (Copeland, 1976). Ekstrom et al. (1966), on the othe hand, concluded that moisture gradient stress or a combination of moisture stress and thermal stress are most likely to cause stress cracks in maize kernels. The authors estimated that a temperature difference of at least 97 C must exist between the centre and the outer surface of the kernel for cracking to occur due to temperatures effects alone.

High drying temperatures have also been implicated as one of the major contributors to drying speed and hence as a contributor to high degrees of stress cracking in maize kernels. Various workers had shown that up to a certain limit, increasing the seed drying temperature increases the levels of stress cracking in maize seeds (Ross and White, 1972; Westerman et al., 1973; Thompson and Foster, 1963). The work of Thompson and Foster (1963) showed that the percentage of 'checked' kernels (defined as having two or more stress cracks intersecting) increased with increased drying temperatures. Temperatures of 60 C, 87.8 C and 115.6 C resulted in 20.2%, 29.6% and 33.9% checked kernels, respectively.

The effect of initial seed moisture contents on stress crack development during seed drying has also been studied. Reports show that stress crack development is significantly increased when seeds are dried at a higher initial moisture than at lower initial moisture contents (Ross and White, 1972; White and Ross, 1972; Thompson and Foster, 1963). The field test data of Thompson and Foster (1963) revealed that seeds with initial moisture contents of about 20% and 30% resulted in maize seeds with total stress cracks of 18.4% and 55.7%, respectively, when dried to a moisture content of 14% at a temperature of 26.7 C. In laboratory tests, the authors observed that drying seeds from 22%, 17% and 14% initial moisture contents to a final 12% moisture content produced levels of stress cracking of 98.2%, 89.1% and 26.4% respectively, at a drying temperature of 71.1 C.

The development of stress cracks in seeds was observed to occur more after cooling than immediately after drying. In fact, it is possible to hear the stress cracks forming in dried samples as they are cooled (Thompson and Foster, 1963). Tests both in the field and in the laboratory indicate that rapid cooling of hot maize seeds after drying contributes to its brittleness by producing numerous hairline cracks in the kernel endosperm. Examination of hot maize kernels before cooling showed few stress cracks. Many of the cracks occurred when the stresses due to rapid cooling were added to the stresses built up during heat drying (Thompson and Foster, 1969).

The direct effect of stress cracking has been found to impair seed viability. Pana (1977) reported a significant and positive correlation between the total degree of cracking and the average decrease in seed germination. Impairment of seed viability was closely associated with the amount of cracking. When cracking increased, severe reduction in viability occurred. It was noted that the reduction in germination depended on the size and location of the cracks in the seed. The bigger and closer the cracks were to the embryonic axis, the more severe the reduction in seed germination which occurred.

B.4.1 Research Work on Reduction of Stress Cracking During Drying

Despite the alarming effect of stress cracks on maize seeds, few workers have developed procedures to overcome or alleviate the problem. In laboratory tests, Thompson and Foster (1963) observed that applying steam to the kernels immediately after drying apparently relieved the stress by wetting the outside of the kernel and making it less friable with a resultant reduction in stress cracking. They also found that tempering the seeds by putting them inside a vacuum bottle for 24 hours while they were still hot immediately after drying at 87.8 C to 115.5 C allowed the seeds to cool slowly resulting in only 3% stress cracks. Seeds which were cooled rapidly immediately after drying without tempering had 43% cracks. They concluded that delaying cooling until after a suitable tempering period was beneficial.

Seed tempering has proved beneficial and feasible in reducing the amount of seed cracking after drying. Tempering provides time for moisture within the kernel to move from the interior to the external surface where it is readily available for evaporation (Hall, 1980). The process reduces the moisture gradient between the internal and external surfaces of the seed. Allowing the hot kernels to temper before cooling relieves some of the drying stress and reduces the brittleness of dried corn, hence, reducing the occurrence of stress cracks (Thompson and Foster, 1969.

Seed tempering is readily done by putting the seeds in a closed container after drying to prevent further evaporation of moisture. The process allows the moisture within the seed to diffuse to the seed surface without evaporating to the surrounding atmosphere due to the sealed environment of the seed. Ideally, tempering takes place in an airtight and well-insulated container so that no moisture escapes and no heat is conducted out of the grain. Under these conditions the change in the average temperature and moisture content of the grain due to tempering is negligible. The only change which occurs is in the moisture distribution in the kernels (Sabbah et al., 1972).

Based on the principle of tempering, a grain drying method known as dryeration was developed (Hall, 1980; Thompson and Foster, 1969; Winfield, 1969). Dryeration combines high speed drying with aeration cooling to improve grain quality and to increase drying capacity. With dryeration, hot maize kernels are removed from the dryer, allowed to temper for a few hours in a spearate bin, and then cooled slowly with aeration.

In commercial grain drying practice, Hall (1980) reported that by dryeration, wet grains of about 20 - 30% moisture are placed in the dryer bin at about 93 C. When grain moisture content has decreased to about 16 - 18%, the grains are transferred hot to a separate closed bin. The grains are held hot at their own temperature of between 54 C and 66 C (when transferred) for about 4 - 8 hours. No other source of heat is added. After a tempering period of about 8 hours, unheated air

is blown through the grain at low airflow rate (1 - 1.5 cfm/bu) removing 1 to 3% moisture while cooling the grain over about 12 hours. When the grain reaches about 14 - 15% moisture it is moved to another separate bin for storage or marketing.

It is obvious, however, that the drying temperature used in the dryeration process reported is beyond the temperature limit for drying seed maize. Such temperature effectively kills or reduces the viability of seeds. Nevertheless, research work has clearly shown the remarkable effect of the tempering process in reducing stress cracks and suggests that such a technique could be readily applied to seeds dried within the temperature limits for maize seeds.

B.5 Impairment of Seed Viability and Vigour Due to Seed Drying

Maize seed drying after harvest is essential. The enormous influence of seed moisture content on seed longevity makes artificial drying almost mandatory in the production of high quality seeds (Boyd et al., 1975). However, Thompson (1979) reported that artificial drying can depress the germinability of seeds, giving rise to abnormal seedlings, affecting the permeability of the seed coat and destroying enzymes particularly at high drying temperatures.

Several workers have shown that the initial moisture content of maize seeds during drying largely influences the degree of damage to seeds due to high drying temperature. Wileman and Ullstrup (1945) observed that damage occurred on seeds with high initial moisture content when they were dried at a relatively high drying temperature. Maize seeds with an initial moisture content of 35% or more dropped rapidly in germination when dried to 12% moisture at an air temperature as high as 48.9 C, while the germination of maize with an initial moisture content of 20 - 25% suffered no appreciable reduction. When the moisture content was less than 20% a drying temperature of up to 54 C had no deleterious effect. However, Brown et al. (1979) observed that the seed viability of maize with an initial moisture content of 20 - 30% was not significantly reduced by drying temperature of up to 60 C. Remarkable reductions only occurred at any drying temperatures above this value.

The work by Peplinski et al. (1975) has shown that maize with an initial moisture content of 24% retained 92% germination after drying to 12% moisture at a temperature of 32 C. However, when 25% moisture content seeds were dried at 49 C the germination was reduced to 84%. Seeds dried at 82 C and 149 C were all dead. On the other hand, Kiesselbach (1939) observed that seed viability and vigour were not reduced by artificial drying at 42 C to 44 C when the initial moisture content of the grain did not exceed 38%.

These different findings show variable results on the safe drying temperatures for maize seeds. Nevertheless, a number of workers have reported that high air temperatures above about 43 C are detrimental to the viability of maize seeds (Hukill, 1974; Justice and Bass, 1978; Roberts et al., 1972).

Although initial seed viability may be adversely affected by high drying temperatures seed vigour can also be seriously reduced. Navratil and Burris (1984) have demonstrated deleterious effects on both germination and vigour of maize seeds by high drying temperature. At a harvest moisture of 25%, no reduction in viability was observed from maize inbred B73 when seed was dried at 35 C to 50 C. However, seed vigour was reduced as indicated by cold test performance. Cold test results showed 98% germination from seeds dried at 35 C, but only 69% from seeds dried at 50 C. Similarly, inbred maize MO17 did not show a reduction in germination when dried at 45 C but cold test results showed only an 85% germination compared to 95% germination of seeds dried at 35 C. Again, although seed viability was not reduced by a drying temperature of 45 C, seed vigour was adversely affected.

In an electrical conductivity study, Seyeden et al. (1984) observed that maize seeds dried at 50 C had higher conductivity values than seeds dried at 35 C. The increased leaching of sugars and electrolytes from seeds dried at 50 C may be indicative of increased membrane permeability, which may be due to deteriorative changes. Reduction in the number and size of starch grains in the embryonic axis from seeds dried at 50 C was

also noted. Thus, it was concluded that the embryo may be the primary source of leachate sugars. High drying temperatures resulted in hydrolysis of starch in the embryonic axis. Moreover, it was found that both shoot and root dry weight were significantly reduced at a 50 C drying temperature. This clearly shows the drastic reduction in seed vigour which can occur due to drying at relatively higher temperatures. The reduction in seed vigour is due to heat damage which primarily results in inactivation of the cells accompanied by an alteration in permeability (Hutchinson et al., 1946).

B.6 Production of Seedling Abnormalities

Different types of damage to seed can cause a reduction in seed germinability not only due to direct killing of the embryo but also due to the production of seedling abnormalities which are not included in normal germination counts. ISTA (1976) attributed damaged seedlings to be generally caused by external factors such as mechanical handling, heat, drought and insect damage. Deformed or unbalanced seedlings are attributed to earlier external influences such as unfavourable growing conditions of the parent plant, poor ripening conditions for the seed, premature harvesting, effect of pesticides, poor cleaning procedures or inappropriate storage conditions, or as a result of genetic factors or natural ageing of the seed.

Mechanical processing operations may cause injury that affects the subsequent development of seedlings depending on the location and intensity of injury (MacKay and Flood, 1968). Generally, it has been found that injured seeds produce more abnormal seedlings (Toole, 1950). Root damage is often found in cereals and grass seeds. MacKay and Flood (1968) have associated root injury with the embryo structure and degree of exposure of the radicle. Split coleoptiles and broken shoots in mechanically damaged cereal seeds are also common (MacKay, 1972). Moore (1972) found that this type of damage is more common in round seeds of maize where the embryo is slightly bulging. Mechanically damaged cereal seeds produce more abnormal seedlings with root damage, split coleoptiles and broken shoots.

Apart from harvesting and cleaning, seed drying, especially at high temperatures, has also been implicated as a cause of abnormal seedlings (Heydecker, 1972). Wellington and Bradnock (1964) observed that barley seedlings which had developed from seed following high temperature drying have poorly developed primary roots or seminal roots, short coleoptiles, or plumules which do not elongate and fail to emerge. Heydecker (1972) noted that in some cases, seedling abnormalities caused by seed drying are indistinguishable from those caused by other factors.

C. The Use of X-ray Radiography for Studying Seed Quality

The use of X-ray radiography for determining seed quality was pioneered by Lundstrom (1903) who used the technique to detect completely and incompletely filled seeds. At present it is considered to be a very useful method for assessing seed quality.

It has been successfully employed to detect various types of seed damage. Kamra (1964) reviewed the work of various researchers regarding the general use of X-rays in seed analysis and concluded it was valuable for assessing the quality of different kinds of seeds.

C.1 The Principles of X-ray Radiography

Kamra (1964) pointed out that various kinds of X-ray machines have been tried by different workers. In principle, any machine producing soft X-rays (Grenz rays) could be used for seed radiography. The variables involved, such as the KV, MA, focus, and exposure time need to be varied according to the object. Soft X-rays are differentially absorbed by different parts of the seeds such as testa, endosperm, and embryo, depending upon their thickness and can be recorded on film (Banerjee et al., 1973). It is therefore, possible to recognise the structure of endosperm and embryo and to detect mechanical injuries and damage caused by insects or drying.

The small dose of X-rays given to the seed using this radiography system does not appear to be injurious to the seed as far as damage to seed germination is concerned (Gustafsson and Simak, 1958; Swaminathan and Kamra, 1961). Kamra and Simak

(1965) observed that germination of Scots pine, Norway spruce and celery were not affected by long exposure of seeds to X-rays. Therefore, the seeds used in X-ray analysis can still be used for subsequent germination studies.

C.2 Important Uses of X-ray Radiography in Seeds

Kamra (1964) reported that following uses of the X-ray radiography technique for a wide variety of seeds.

C.2.1 Detection of Insect Infection in Grain - The detection of insect larvae, pupae, adults or excrements in seed or gain is not only important for seed testing work but also for the milling industry. Some insects infest the seed without visible external signs. The females of granary weevil (Sitophilus granarius L.) and rice weevil (Sitophilus oryzae L.) for example, lay eggs in a grain kernel and then immediately seal the minute cavity with a gelatinous material similar in appearance of the grain. This makes visual detection practically impossible. The whole development of the weevil then takes place within the kernel without externally visible signs until adults emerge. The different stages of development can be identified in an X-ray picture (Kamra, 1964; Milner et al., 1950).

C.2.2 Detection of Weathering Damage - Seed in the field before harvest is subject to alternate wetting and drying and thus may suffer weathering damage. Milner et al. (1952) observed by X-ray radiography that weathered seeds of wheat had internal cracks or fissures oriented at right angles to the longitudinal axis of the kernel. In non-weathered grains no such cracks were visible.

C.2.3 Determination of Mechanical Damage - The determination of the amount of mechanical damage to seed during processing is important as it influences the loss of germination capacity during storage. In spite of the importance of mechanical damage to seed, there are so far no rapid methods available for determining its extent. Kamra (1963) has shown that it is

possible to determine the amount of mechanical damage in Scots Pine seed with the X-ray contrast method using organic contrast agents like urografin and umbradil. Only mechanically damaged seeds are impregnated, allowing them to be easily distinguished by X-ray radiography from undamaged (unimpregnated) seeds.

C.2.4 Determination of Drying Damage - Stress cracking in seeds can occur due to artificial drying. The extent of cracking can be seen by the use of X-ray radiography. Milner et al. (1952) observed internal fissuring of maize seeds and cracked and broken kernels of rice resulting from uneven stresses due to severe drying conditions, using this technique.

C.2.5 Determining of Viability - Physiological damage influences the germination capacity of seed. It is a collective term which refers to the damage seed may suffer not from mechanical treatment but from such factors as unfavourable storage conditions, ageing, high drying temperature, et., which impair seed germination. This kind of damage is not directly visible on the seed (Kamra, 1963). Simak (1957) found barium chloride to be a most suitable agent for impregnating dead tissues in Scots Pine seeds and therefore, a good contrasting agent compared to non impregnated viable seeds as seen on an X-ray plate or photograph. The X-ray contrast method was also used by Verma (1978) in maize using seeds which were impregnated with barium chloride. He found the method to be valuable in determining the viability of seeds. Kamra (1963) overcome the problem of the impregnation of fresh and dead seeds by using differential organic contrasting agents such as urografin or umbradil which impregnate dead seeds only.

C.2.6 Detection of Polyembryony - The detection of seeds containing two or more embryos is often desirable for genetic studies. The procedure of growing the whole seeds and then looking for those which are polyembryonic is laborious and time-consuming. By X-ray analysis it is possible to separate the poly- from mono-

embryonic seeds easily and quickly (Ehrenberg et al., 1955). This method has also been used successfully in citrus seeds by Swaminathan and Kamra (1961).

C.2.7 Embryo and Endosperm Development - In order to be able to germinate, a seed must possess an embryo which has developed to a certain definite stage. It has been found by Simak and Gustafsson (1954) and Simak (1957) that there is a direct relationship between embryo and endosperm development and germinability of the seeds of Scots Pine. Seeds which fail to develop an embryo and/or endosperm are empty and can readily be seen by X-ray analysis.

C.2.8 Stereoradiography - The use of a stereoradiography technique in which two pictures of an object are taken from different angles can be used to develop a three-dimensional view of seed and to examine the depth of impregnation in the case of impregnated seeds (Kamra, 1964).

Very limited reports had been published about the use of X-ray radiography in maize. Most of the available literature is on small-seeded crops such as pine and spruce seeds, etc.

Nevertheless, the methods outlined are useful for studies on maize. It seems likely that seed quality of maize with regard to internal cracking and germinability due to physiological causes could be usefully determined by the use of X-ray radiography.

D. Seed Moisture Content and Seed Storage

Seed storage life depends on seed moisture content and the temperature and relative humidity of the storage environment. Of these, Barton (1961) considered the seed moisture content to be the most important factor influencing seed deterioration.

Generally, the problems of maintaining seed quality increase with seed moisture contents as follows (Harrington, 1972):

Seed moisture above	8 - 9%	- insects become active and reproduce
Seed moisture above	12 - 14%	- fungi grow on and in seed
Seed moisture above	18 - 20%	- heating may occur
Seed moisture above	40 - 60%	- germination may occur.

The 'Rule of Thumb' for moisture indicates a doubling effect on seed life for every 1% decrease in seed moisture within the range of 5 - 14% moisture content (Harrington, 1972). In a moist environment brought about by high seed moisture, fungi, bacteria and insect populations may build up rapidly causing heating due to respiration of seeds and organisms. Milner et al. (1947) studied the effect of moisture content on wheat respiration and found that seeds with a moisture content below 14.5% had low and constant respiratory rates. At higher moisture values, respiration values were shown to increase, accompanied by mould growth and chemical deterioration of seeds as indicated by the increase in fat acidity values, higher levels of reducing sugars and loss of germination. In maize, Olafson et al (1954) reported that respiration rates increased only slightly with time at moisture levels below 14.7%, but a marked acceleration occurred at higher moistures. This indicated the influence of seed moisture on respiration rate and consequent seed deterioration.

Douglas (1975) and Harrington (1972) have both suggested that maize seed should not be stored at 14% moisture content or higher. Christensen and Kaufmann (1969) reported that seed moisture contents below those in equilibrium with a relative humidity of 65% will keep seeds free of fungi. For maize these moistures range from 12.5 to 13.5%. Hence, any moisture content above those levels can result in the destruction of seed quality due to fungal infestation. Kennedy (1979) stated that the safe storage moisture content for starchy seeds should be not more than 12%.

The general rule that the lower the seed moisture content the longer the seed storage life is true to a certain extent for orthodox seeds. However, recalcitrant seed species behave in a different manner. Drying of recalcitrant seeds results in a decline of viability (King and Roberts, 1980) and in some recalcitrant species seed viability can only be maintained at moisture contents above 20%.

Although storage of orthodox seeds with as low as 5 - 6% moisture content prolongs seed storage life, further drying to lower the moisture content can cause damage (Harrington, 1973). Overdrying results in desiccation injury. Nutile (1964) observed in several crop species that viability declined when seed moisture was below 2% and as period in storage increased. Seeds of celery, eggplant, pepper, and kentucky bluegrass sealed at 1.0% and 0.4% moisture and carrot, tomato, and red fescue at 0.4% showed little injury after six months but viability was seriously impaired after 5 years storage. Soybean dried to 3.0 - 3.5% moisture and planted at those moisture levels showed aborted development of the radicle. Increasing the moisture of those seeds to 11% before planting resulted in normal radicle development.

Harrington (1973) reported that if seeds are dried below 4 - 5% moisture, deterioration is somewhat faster than with seeds of 5 - 6% moisture. This is probably due to damage from lipid autoxidation. It is believed that at low moisture contents of about 5%, the monomolecular layer of water that surrounds macromolecules in seeds is removed from the macromolecules - a layer that is protective against oxidative proceses. This oxidation can be the result of oxygen penetration, ultraviolet light or metallic ions present in the seeds (Lea, 1962). This facilitates the destruction of macromolecules such as enzymes and membrane protein by the free radical. The most serious autoxidation occurs in lipids. Unsaturated lipids in seed cells may break, producing two free radicals at the double bonds (Koostra et al., 1969). These free radicals can react with other lipids destroying the structure of cell membranes causing chromosomal abnormalities and even mutations. In imbibed cells, enzymes produce tocopherols (Vitamin E) as natural antioxidants. Tocopherols combine with free radicals rendering them harmless. But in very dry seeds,

enzymes are inactive and no more tocopherols are produced while those previously present are used up in storage. The free radicals produced by autoxidation of lipids are very reactive in seeds of low moisture content. Hence, cells are destroyed, and if enough cells in the meristematic regions are dead the seed can no longer germinate.

Therefore, even though extremely dry seeds can be stored for a long time without loss in germination capacity, an intermediate moisture content gives maximum seed longevity. It appears, therefore, that about 5 - 6% seed moisture content is the ideal moisture content for maximum storage life (Harrington, 1973).

E. Seed Moisture Content and Relative Humidity

Seed moisture content is a function of the relative humidity of the surrounding environment. The hygroscopic nature of seeds allows them to adjust their moisture content to equilibrium with any given relative humidity (Copeland, 1976; Harrington, 1972). When seeds are stored in an environment with relative humidity higher than the seed equilibrium moisture content, the seeds will absorb moisture. However, when seeds are stored in an environment with relative humidity lower than the seed equilibrium moisture content, they will release moisture to the environment. This occurs continuously until seed equilibrium moisture content is reached. At this point, net movement of moisture from seed to air or from air to seed is zero (Justice and Bass, 1978).

Different kinds of seeds have different moisture values at a given level of relative humidity. This is because the molecules in the seeds vary in the amount of water they adsorb. Proteins adsorb most water, starch and cellulose less but still a considerable quantity, while lipids adsorb no water (Harrington, 1973). Thus, at a given relative humidity, oily seeds contain less water than starchy seeds. When measured at 25 C, yellow dent maize seeds have equilibrium moisture contents of 8.4, 10.5, 12.9 and 14.8% at relative humidities of 30, 45, 60 and 75% respectively, while the corresponding moisture contents for soybeans are 6.2, 7.4, 9.7 and 13.2%, respectively (ASAE, 1971). Sweet corn has equilibrium moisture contents of 7.0, 9.0, 10.6 and 12.8% at these same respective levels

of temperature and humidity (Harrington, 1960). These differences are due to higher amounts of starch content in dent maize and to high lipid contents in soybean.

Even within one species the equilibrium moisture content of individual seeds at a given relative humidity varies as a result of differences in seed size and seed coat thickness (Copeland, 1976). Moreover, within a seed lot, seeds do not end up at the same moisture content at the same relative humidity level due to the hysteresis phenomenon. At a given relative humidity, the equilibrium moisture content of a seed lot will be higher for seed with an initially higher moisture content than for seeds with an initially lower moisture content. According to Justice and Bass (1978) when seeds lose water and reach equilibrium at any given relative humidity, the equilibrium moisture content of the seeds may be higher than if dry seeds are allowed to gain moisture to reach equilibrium at the same level of relative humidity. Harrington (1973) suggested that hysteresis occurs because on rehydration, dried macromolecules do not completely unfold at intermediate moisture levels and thus do not have as many sites available for adsorption of water molecules.

F. Temperature and Seed Storage

Temperature is the second most important factor that affects seed storage life. The 'Rule of Thumb' for temperature indicates a doubling of the life of the seed for every 5 C reduction in temperature down to at least 0 C (Harrington, 1973). Decreasing seed temperature has been shown to decrease seed respiration rate. The work of Ragai and Loomis (1953) has shown that respiration of maize seeds free from fungi was very slow at 8 C and increased sharply when the temperature was increased to 21 C and 30 C. Bailey (1921) also observed that maize seed respiration almost doubled with a temperature rise from 27.8 C to 37.8 C.

The effect of temperature also has a direct bearing on the activities of storage fungi and insects which damage seeds in storage. Christensen (1973) reported that the optimum temperature for the growh of most storage fungi is about 30 - 33 C, the maximum about 50 - 55 C and the minimum about 0 - 5 C. Some species of Penicillium, which

require a higher moisture content than the drought resistant species of Aspergillus can grow at a temperature several degrees below freezing (Christensen and Kaufmann, 1968).

Storage insect activity is also temperature dependent. A seed temperature of 70 F (21.1 C) is considered to be favourable for insects and constitutes the danger line for their activity in stored seeds (Cotton and Wilbur, 1974). Decreasing the temperature decreases the rate of development and reproduction of insects. Data by Cotton (1950) has shown that most storage insects die after only a few weeks exposure to about 0 C temperature, irrespective of their stage of development.

CHAPTER 2
Seed Processing Effects On Seed Viability and Storage Performance

A. Introduction

In this era of highly scientific and mechanised agriculture, it has become increasingly important for seed producers to be aware of the damage to seeds due to mechanisation and the measures which can be taken to avoid or minimise such damage. As harvesting and processing machines came into general usage, damage to seeds increased accordingly (Justice and Bass, 1978). Since most seed maize is picked, husked, dried, shelled, cleaned, graded, and treated mechanically, the amount of physical damage occurring on seeds is undoubtedly greater than prior to the period of mechanisation (Wortman and Rinke, 1951).

The most serious cause of mechanical injury during processing is considered to occur during the shelling process (Tatum, 1942). However, serious mechanical damage has also been reported to occur during harvesting, transporting, conveying and other handling operations in a seed processing plant (Sands and Hall, 1971; Pierce and Hanna, 1985; Hall, 1974; Fiscus, Foster and Kaufmann, 1971). Drying damage may also occur, particularly when high temperatures are used which damage the embryo and cause a reduction in viability (Brown et al., 1979; Peplinski et al., 1975; Navratil et al., 1951; Gausman et al., 1952).

The present experiment was carried out to assess the effects of the various stages of processing in causing a reduction in seed germination following processing and during subsequent storage.

B. Materials and Methods

I. Trial 1

Seed samples were obtained by the Seed Technology Centre from a commercial seed company (HBF Dalgety Ltd) situated in Gisborne, New Zealand. These samples were obtained from a sequence of different points or stages of the maize seed processing sequence.

The main stages of the processing system from the field to the production of the final product (Figure 1 and Plates 1 - 12) are as follows: 1) receiving or unloading of the maize ears in the processing plant, 2) husking or removal of the leaves from maize ears, 3) ear drying to about 18% seed moisture at a temperature of 30 C, 4) shelling or separation of maize seeds from the ears, 5) seed drying to about 12.0% moisture at a temperature of 30 C, 6) short term storage for about 7 days prior to dressing and 7) dressing, grading and treating (these processes were each considered to be one stage in the present study with one last sample being taken, as the final saleable product).

Below is the coding and sample description used in this study of seed samples taken from the various stages of processing:

Seed Samples	Stages of Processing or Sampling Points	Possible Causes of Damage
1	A - Handpicked from the field (Control)	
2	B - Receiving or intake to processing plant	Mechanical Picker
3	C - Husking (sampled at the ear inspection belt after the husker)	Mechanical husker
4	D - Ear drying (sampled at the outlet of the dryer after ear drying)	Ear dryer
5	E - Shelling (sampled at the outlet of the sheller after shelling)	Mechanical sheller
6	F - Sample in the seed dryer prior to seed drying	Handling machine

7	G - Seed drying (sampled at the outlet of the seed dryer after seed drying)	Seed dryer
8	H - Seed storage (sampled in the seed storage silo before dressing)	Handling/Storage
9	I - Dressing, grading and treating (sampled in the dressing plant after the operation)	Dressing plant

In this experiment, sample A was hand-picked from the field to serve as a control sample. All subsequent samples starting from sample B, were machine handled. A mechanical picker was used in harvesting the ears at about 26 - 30% seed moisture content. The ears after picking were loaded onto a truck and transported to the processing plant. The ears and seeds were mechanically conveyed from one point or stage to the next until the final stage of processing.

The seeds in the final stage (Sample 'I') were treated with the seed treatment chemical 'Vitaflo' applied as fungicidal slurry involving a mixture of 20 litres of 'Vitaflo' and 20 litres of water for every 8 tonnes of seed.

Figure 1: Seed flow diagram showing seed processing sequence at the HBF Dalgety seed processing plant in Gisborne, New Zealand. The letters designate the points where seed samples were taken. (Trial 1).

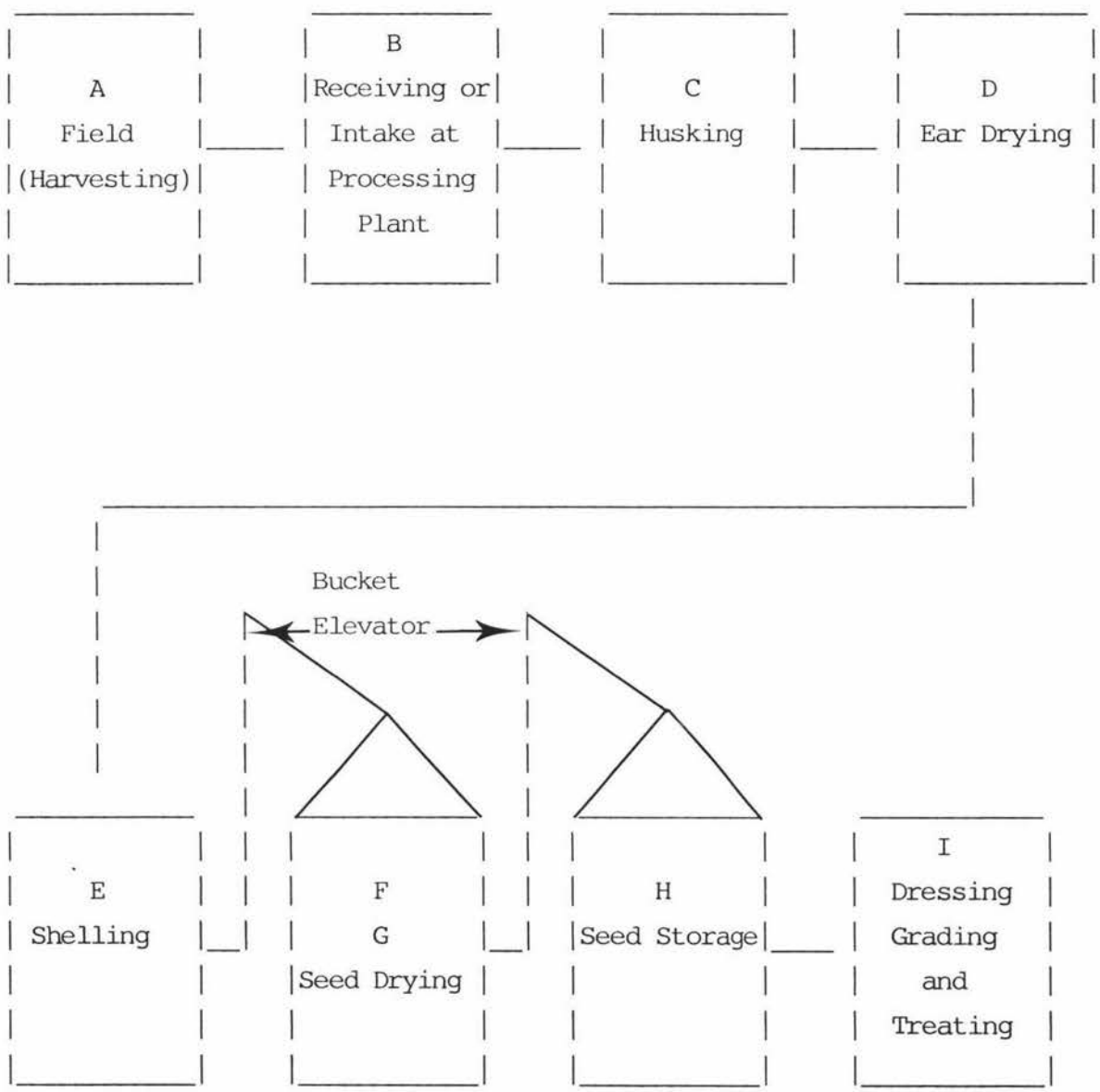


Plate 1: Mechanical harvesting of maize

Plate 2: Harvested maize ears as received at the processing plant

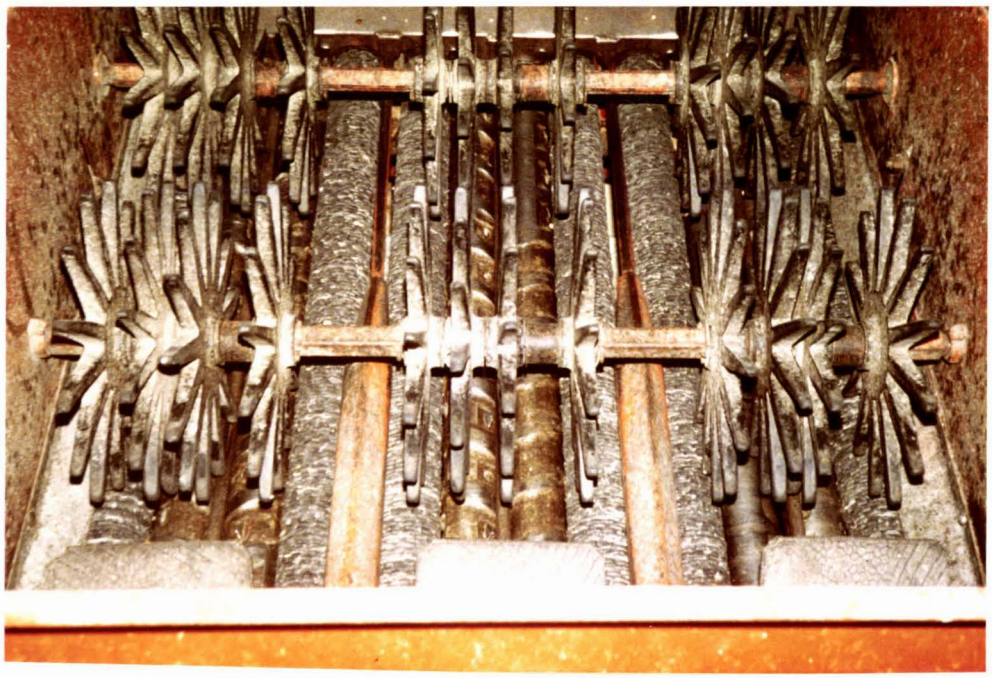


Plate 3: Mechanical husker

Plate 4: Ear selection after husking. Undesirable ears are selected and discarded. Good ears are transported by conveyor belt to the bin ear dryer

Plate 5: Bin ear dryer. After ear drying (18% m.c.), the ears are transported to the sheller

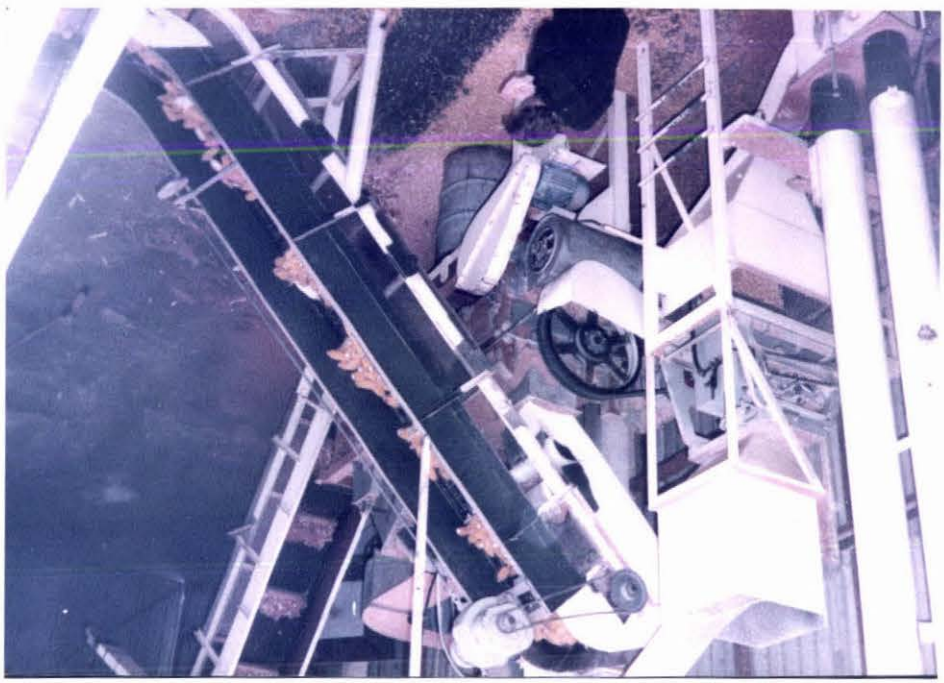


Plate 6: The mechanical sheller. After shelling, the seeds are transported to the seed dryer

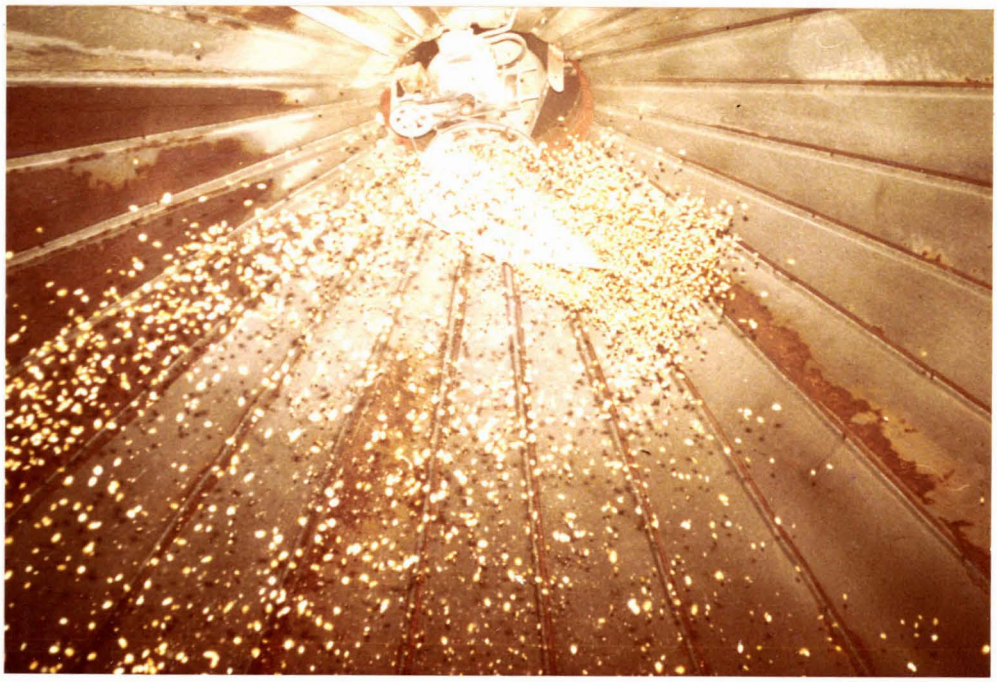


Plate 7: The inside (top) of the seed dryer with the spinner rotating to distribute seeds evenly into the dryer

Plate 8: The inside (bottom) of the seed dryer with the seeds just dropping from the spinner above

Plate 9: Exterior view of the seed dryer. The seeds are dried to about 12% moisture content

Plate 10: Seed storage bins into which seeds are transported after drying

Plate 11: A part of the dressing, grading and treating plant

Plate 12: Bagged maize seeds ready for market or storage

The seed samples submitted by the commercial seed company included 3 hybrid cultivars of maize i.e. XL 72aa, XL 81, and D 54. When the samples were received at the Seed Technology Centre, seed moisture contents were found to range from 12.0% to 29.5%. These samples were placed in open plastic boxes and exposed to ambient conditions at a temperature of 20 - 25 C and relative humidity of 60-70% to allow all samples to equilibrate moisture content. The seed samples (Samples 'A' to 'F') collected before the seed drying stage were very wet. These samples were dried by air drying to about 12% moisture to examine the effect of artificial drying (Sample 'G') in the processing system. After about 3 weeks, equilibrium moisture content was attained at about 12%. Standard laboratory germination and accelerated ageing tests were then carried out. Seed samples were stored for 5 months under ambient conditions.

Determination of Germination:

Samples of 2 x 50 seeds were germinated on wet rolled paper (BP) at 20 C. The rolls were held vertically in wire baskets, each basket being covered with a large plastic bag to reduce moisture loss. Seedling evaluation was done after 7 days.

The Accelerated Ageing Test

Seed moisture contents were determined to calculate the amount of water to be added to the seed to raise its moisture content to 20% using the following formula:

$$Y = \frac{MC\ (X + DW) - X}{1 - MC}$$

where: Y = the required quantity of water to be added
X = initial weight of water in the sample
DW = dry weight of the seed
MC = required moisture content, i.e. 20%

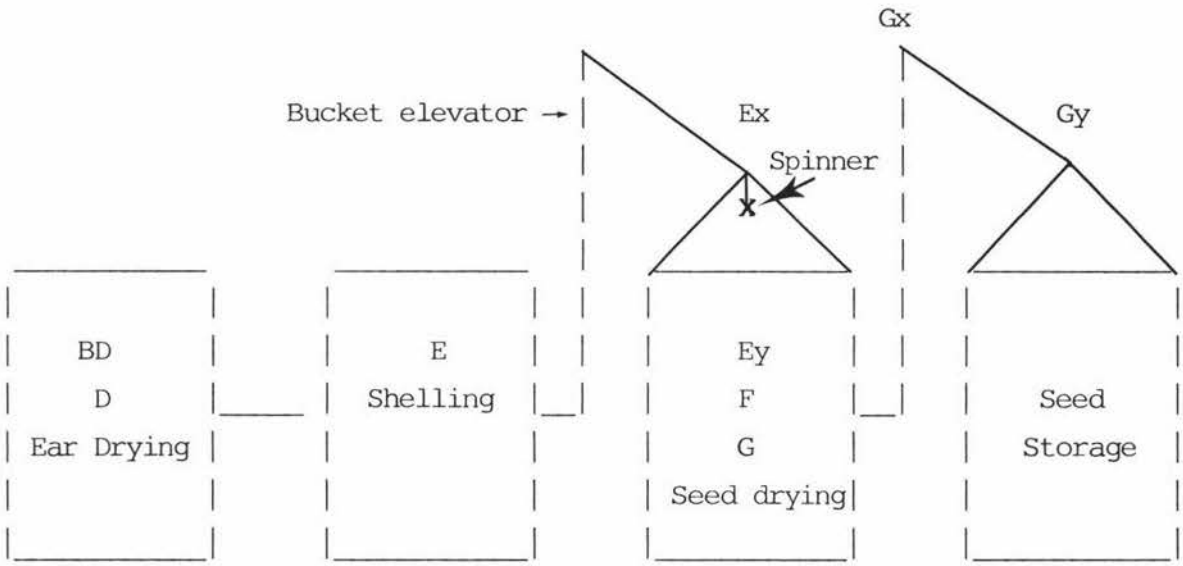
Samples of 100 seeds for the test were placed in aluminium foil packets. The calculated amount of water was added to the seed. Seeds and water were thoroughly mixed and the aluminium foil packets were sealed using a plastic heat sealer. The packets were then held at 5 C for 24 hours for slow imbibition. The samples were then placed in an oven at 45 C for 48 hours. Samples of 2 x 50 seeds were germinated using the wet roll paper method.

II. Trial 2

In addition to the samples submitted by HBF Dalgety Ltd, Gisborne, tests were also carried out on samples of Hybrid XL 72aa seed maize collected from the various points in the processing system. Further samples were also collected from other points which were suspected to have caused serious seed damage but which had not been included in trial I as shown in Figure 2.

The seed samples were then dried by exposure to ambient conditions similar to those in Trial 1. When the seeds had air-dried to equilibrium moisture content, they were placed in cloth bags and stored at 20 C under ambient relative humidity conditions for 15 months. Standard laboratory germination and accelerated ageing tests were done using 4 x 50 seed samples.

Figure 2: Diagram identifying the position of samples drawn from the processing plant (Trial 2).



Stages of Processing or Sampling Points

BD - Sampled just before ear drying

D - Ear drying (sampled at the outlet of ear dryer after ear drying)

E - Shelling (sampled at the outlet of sheller after shelling)

EX - Sampled on top of the seed dryer

Ey - Sampled in the seed dryer as seeds dropped without the spinner moving; before seed drying

F - Sampled in the seed dryer as seeds dropped with the spinner moving (normal procedure); before seed drying

G - Seed drying (sampled at the outlet of seed dryer after seed drying)

Gx - Sampled at the top point of bucket elevator

Gy - Sampled on top of storage silo.

C. Results

I. Trial 1

1. Seed Viability Before Storage

The effects of various stages of processing on the seed viability of 3 maize hybrids before storage are presented in Tables 1, 2 and 3. Statistical analysis showed no significant differences in normal germination for the seed tested soon after sampling from the different stages of processing (Table 1). No particular stage in the processing system had caused any reduction in germination. Similarly, no significant differences in the numbers of abnormal seedlings and dead seeds were detected (Tables 2 and 3). The most common seedling abnormalities found involved seedlings with decayed roots, unbalanced development with either shortened roots or plumule, split and twisted coleoptile or with roots or plumule which failed to emerge or stunted roots (Table 4). Weak and unbalanced seedlings and seedlings showing decayed and split coleoptiles were common in samples A to D (stages before shelling). After the shelling stage, the most common abnormalities included seedlings with a stunted plumule, broken coleoptile, no roots, no plumule and a few showing unbalanced development and decayed mesocotyl. The succeeding stages after seed drying showed similar abnormalities with the appearance of seedlings with no plumule or roots, weak and unbalanced development, split and twisted coleoptile and stunted roots. However, the level of these abnormalities was very low in all hybrids with no significant mean differences between different stages of processing.

However, significant differences were observed on the main effects of hybrids on normal germination. Hybrid D 54 was superior to the other 2 hybrids having an average normal germination percentage of 98.0%. Hybrid XL 72aa had the lowest average germination of 89.4%, while Hybrid XL 81 had 95.2%. Hence, as could be expected, Hybrid XL 72aa had the highest number of abnormal seedlings and dead seeds (Tables 2 and 3).

Table 1: Normal seedling germination before storage (Trial 1).

Stages of Processing or Sampling Points *	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	90.0	99.0	99.0	96.0
B	90.0	99.0	97.0	95.3
C	91.0	100.0	96.0	95.7
D	91.0	97.0	97.0	95.0
E	90.0	97.0	94.0	93.7
F	88.0	97.0	93.0	92.7
G	87.0	98.0	93.0	92.7
H	88.0	98.0	96.0	94.0
I	90.0	97.0	92.0	93.0
Mean	89.4c	98.0a	95.2b	

LSD Hybrids 5% = 2.6, 1% = 3.5; Stages = NS; Stages x Hybrids = NS. Numbers having different letters are significantly different at P = .05.

* A - Handpicked samples from the field
  B - Receiving or intake to the processing plant
  C - Husking
  D - Ear drying
  E - Shelling
  F - Sample in seed dryer before seed drying
  G - Seed drying
  H - Seed storage; after seed drying but before dressing
  I - Dressing, grading and treating.

Table 2: Abnormal seedling percentage before storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	4.0	0.0	0.0	1.3
B	6.0	0.0	2.0	2.7
C	4.0	0.0	4.0	2.7
D	4.0	3.0	3.0	3.3
E	5.0	3.0	4.0	4.0
F	6.0	1.0	3.0	3.3
G	6.0	1.0	5.0	4.0
H	9.0	2.0	1.0	4.0
I	6.0	2.0	4.0	4.0
Mean	5.6a	1.3c	2.9b	

LSD Hybrids 5% = 1.46; 1% = 1.98; Stages = NS; Stages x Hybrids = NS. Numbers having different letters are significantly different at P = .05.

Table 3: Dead seed percentage before storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	6.0	1.0	1.0	2.7
B	4.0	1.0	1.0	2.0
C	5.0	0.0	0.0	1.7
D	5.0	0.0	0.0	1.7
E	5.0	0.0	2.0	2.3
F	6.0	2.0	4.0	4.0
G	7.0	1.0	2.0	3.3
H	3.0	0.0	3.0	2.0
I	4.0	1.0	4.0	3.3
Mean	5.0a	0.7b	1.9b	

LSD Hybrids 5% = 1.63; 1%= 2.21; Stages = NS; Stages x Hybrids = NS. Numbers having different letters are significantly different at P = .05.

Table 4: Types of abnormal seedlings observed at various stages of processing before seed storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids		
	XL 72aa	D 54	XL 81
A	weak unbalanced	-	-
B	weak unbalanced twisted coleoptile	-	decayed roots
C	unbalanced	-	decayed mesocotyl unbalanced split coleoptile
D	unbalanced	weak unbalanced	decayed mesocotyl weak
E	stunted plumule decayed mesocotyl broken coleoptile	unbalanced broken coleoptile	no plumule no roots
F	unbalanced stunted plumules	unbalanced	weak unbalanced
G	weak twisted coleoptile unbalanced no plumule no root	stunted plumule	weak no plumule
H	stunted roots split twisted coleoptile unbalanced	twisted coleoptile weak unbalanced	no plumule
I	unbalanced twisted split coleoptile stunted roots	weak unbalanced	no plumule twisted coleoptile unbalanced

2. Seed Viability Following Storage

Significant differences in normal germination percentage were observed in the main effects and interactions between hybrids and stages of processing of maize after 5 months storage (Table 5). In Hybrid XL 72aa, percentage germination was similar for stages A to F (Hand Harvesting to Before Seed Drying) ranging from 89.0% to 93.0%. Subsequently, germination dropped to 72.0% at stage G (After Seed Drying). Further processing caused no further reduction in germination. Conveying or transporting the seeds of Hybrid XL 72aa from one point or stage to another also did not cause any significant reduction in germination. Even after the seeds had passed through the processing machinery in the dressing plant, no reduction in germination was observed. A significant reduction in seed germination for Hybrid XL 72aa only occurred after the seed drying stage (Stage G).

On the other hand, Hybrid D 54 showed a different response. Stages A to E (Hand Harvesting to Shelling Stages) recorded a germination percentage ranging from 92.0% to 96.0%. The value dropped to 89.0% at sample F (after transporting to dryer silo but prior to drying) but was not significantly different from those of the previous stages including sample A (Hand Harvesting). Seed germination continued to fall after seed drying (Stage G) with a germination of 85.0% although this value did not differ significantly from the germination before seed drying (sample F = 89.0% germination). When seeds were transported to the storage silo (Stage H) a further drop in germination occurred (79.0%) which was significantly lower in relation to the control and the rest of the stages but was not significantly different from that of stage G (Seed Drying Stage) (85.0% germination). At the final stage of processing, when the seeds passed through the dressing plant, the germination abruptly dropped to a significantly lower level of 62.0%.

Table 5: Normal seedling germination percentage after 5 months storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Means
A	91.0a	95.0a	100.0a	95.3a
B	93.0a	95.0a	98.0a	95.3a
C	90.0ab	94.0ab	92.0ab	92.0ab
D	90.0ab	92.0ab	85.0bc	89.0b
E	89.0ab	96.0a	85.0bc	90.0ab
F	89.0ab	89.0ab	88.0bc	88.7b
G	72.0c	85.0bc	80.0cd	79.2c
H	79.0c	79.0c	73.0de	77.0c
I	81.0bc	62.0d	65.0e	69.3d
Mean	86.0	87.4	85.1	

LSD Hybrids = NS; Stages 5% = 5.72; 1% = 7.73;
Stages x Hybrids 5% = 9.91; 1% = 13.38.
Numbers having different letters are significantly different at P = .05.

In Hybrid XL 81, the response was also different. Germination percentages (92.0% - 100.0%) from stages A to C (Hand Harvesting to Husking) were not significantly different. A drop in germination to 85.0% occurred after ear drying which was significantly different from the control (Stage A) but not from stage C (Husking). The seed germination level after ear drying (Stage D) was maintained through to stage G (Seed Drying) although a slight drop in germination to 80.0% occurred after seed drying. When the seeds were transported to the storage silo after seed drying the germination dropped to 73.0% which was significantly lower than the germination values for samples before seed drying (Stages A to F) but did not differ significantly from the sample after seed drying (Stage G). At the final stage of processing, i.e. the dressing, grading and treatment stage, seed germination again dropped to a very low level of 65.0% which was significantly lower than results obtained from the previous stages except that of stage H with 73.0% germination.

These results suggest that Hybrids XL 81 and D 54 are more sensitive to processing damage than Hybrid XL 72aa. When compared to the control, the germinations of Hybrids D 54 and XL 81 were reduced after processing by 33.0% and 35.0%, respectively. This compared with a reduction of only 10.0% germination after storage for 5 months following processing in seed of hybrid XL 72aa.

The different stages of processing resulted in significant differences in abnormal seedling development. On average, the levels of seedling abnormality ranged from 2.7 to 24.0% (Table 6). The main types of abnormal seedlings observed in germination tests following storage included unbalanced development with abnormally short roots or shoots which occurred following almost all stages of processing; as well as seedlings with a split coleoptile, absence of roots or plumule, stunted roots or plumule, weak roots or with decayed roots or plumule (Table 8). The levels of these abnormal seedlings tended to increase sharply after seed drying although the types of seedling abnormality found after drying were also common in samples from previous stages. The percentage of dead seeds showed no significant differences between different stages of processing in all hybrids. However, Hybrid XL 72aa showed significantly higher numbers of dead seeds than the other 2 hybrids (Table 7).

Table 6: Abnormal seedling germination percentage after 5 months storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	5.0	3.0	0.0	2.7d
B	3.0	4.0	1.0	2.7d
C	3.0	4.0	7.0	4.7cd
D	5.0	8.0	15.0	9.3c
E	9.0	4.0	10.0	7.7c
F	9.0	10.0	8.0	9.0c
G	22.0	14.0	18.0	18.0b
H	17.0	20.0	23.0	20.0ab
I	14.0	31.0	27.0	24.0a
Mean	9.7	10.9	12.1	

LSD Hybrids = NS; Stages 5% = 4.99, 1% = 6.74; Stages x Hybrids = NS. Numbers having different letters are significantly different at P = .05.

Table 7: Dead seed percentage after 5 months storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	4.0	2.0	0.0	2.0
B	4.0	1.0	1.0	2.3
C	7.0	2.0	1.0	3.3
D	5.0	0.0	0.0	1.7
E	2.0	0.0	5.0	2.3
F	2.0	1.0	4.0	2.3
G	6.0	1.0	2.0	2.7
H	4.0	1.0	4.0	3.0
I	5.0	7.0	8.0	6.7
Mean	4.3a	1.7c	2.8b	

LSD Hybrids 5% = 1.34; 1% = 1.81; Stages = NS; Stages x Hybrids = NS. Numbers having different letters are significantly different at P = .05.

Table 8: Types of abnormal seedlings observed at various stages of processing after seed storage (Trial 1).

Stages of Processing or Sampling Points	Hybrids		
	XL 72aa	D 54	XL 81
A	decayed roots weak stunted roots	no root unbalanced	-
B	no plumule unbalanced	unbalanced	weak
C	unbalanced twisted coleoptile	unbalanced stunted roots	decayed roots stunted plumule unbalanced
D	not recorded	split coleoptile stunted plumule unbalanced	broken coleoptile decayed coleoptile stunted plumule
E	stunted coleoptile decayed roots unbalanced	unbalanced decayed roots	no roots decayed plumule broken coleoptile unbalanced
F	stunted plumule unbalanced decayed mesocotyl	stunted roots split coleoptile unbalanced	decayed mesocotyl broken coleoptile decayed coleoptile
G	stunted roots stunted plumules unbalanced	split coleoptile unbalanced	decayed roots no plumule unbalanced
H	unbalanced stunted plumule stunted root	stunted roots split coleoptile unbalanced	split coleoptile decayed mesocotyl decayed roots stunted roots
I	split coleoptile no roots unbalanced decayed roots	unbalanced stunted roots stunted plumule decayed roots	decayed mesocotyl unbalanced

3. Seed Viability After Accelerated Ageing

The results of accelerated ageing tests surprisingly did not follow the same pattern as those obtained after natural ageing. No significant differences were observed in the normal germination of the 3 maize hybrids studied as influenced by different stages of processing (Table 9).

However, abnormal seedling germination levels did show significant differences (Table 10). Interactions occurred, showing that Hybrid D 54 had the highest level of abnormal seedlings (33.0% - 40.0%) following seed drying (G). Increased levels of abnormal seedlings were also obtained in samples from stages D to F (Ear Drying Stage to Before Seed Drying) (15.0% - 20.0%). All stages before ear drying produced only 4.0% - 7.0% abnormal seedlings. Hybrid XL 81 tended to produce higher levels of abnormal seedlings after shelling but the values were not significantly different from those in stages prior to shelling. The levels of abnormal seedlings after seed drying were also higher than those prior to shelling but statistically similar to the percentage of abnormal seedlings present in samples obtained from the shelling stage and in all stages after shelling. No definite changes in abnormal seedling levels were observed in Hybrid XL 72aa. However, this hybrid (XL 72aa) had the highest number of abnormal seedlings (25.4%) followed by Hybrids D 54 (20.1%) and XL 81 (12.7%).

Accelerated ageing tests showed a general decrease in dead seed levels after the seed drying stage (49.0% - 53.7%) (Table 11). Higher amounts of dead seeds were observed from stages A to F (57.0% - 67.3%). Hybrid XL 81 showed the highest average amount of dead seeds (64.2%) followed by Hybrids D 54 (56.8%) and XL 72aa (54.7%).

Table 9: Normal seedling percentage after accelerated ageing (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	21.0	28.0	18.0	23.3
B	20.0	32.0	29.0	27.0
C	23.0	19.0	22.0	21.3
D	18.0	30.0	28.0	25.3
E	21.0	22.0	27.0	23.3
F	12.0	23.0	20.0	18.3
G	18.0	20.0	30.0	22.7
H	21.0	15.0	16.0	17.3
I	25.0	19.0	18.0	20.7
Mean	19.9	23.1	23.1	

LSD Hybrids = NS; Stages = NS; Stages x Hybrids = NS.

Table 10: Abnormal seedling percentage after accelerated ageing (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	23.0ab	4.0d	6.0c	11.0c
B	22.0ab	6.0cd	5.0c	11.0c
C	20.0b	7.0cd	7.0c	11.3c
D	25.0ab	15.0bc	10.0bc	16.7bc
E	24.0ab	20.0b	15.0abc	19.7b
F	30.0ab	18.0b	12.0abc	20.0b
G	29.0ab	38.0a	18.0ab	28.3a
H	25.0ab	40.0a	22.0a	29.0a
I	31.0a	33.0a	19.0ab	27.7a
Mean	25.4a	20.1b	12.7c	

LSD Hybrids 5% = 3.51, 1% = 4.74; Stages 5% = 6.08, 1% = 8.22,
Stages x Hybrids 5% = 10.54, 1% = 14.23.
Numbers having common letters are not significantly different at P = .05.

Table 11: Dead seed percentage after accelerated ageing (Trial 1).

Stages of Processing or Sampling Points	Hybrids			
	XL 72aa	D 54	XL 81	Mean
A	56.0	68.0	76.0	66.7a
B	58.0	62.0	66.0	62.0ab
C	57.0	74.0	71.0	67.3a
D	57.0	55.0	62.0	58.0abc
E	55.0	58.0	58.0	57.0abc
F	58.0	59.0	68.0	61.7ab
G	53.0	42.0	52.0	49.0c
H	54.0	45.0	62.0	53.7bc
I	44.0	48.0	63.0	51.7c
Mean	54.7b	56.8b	64.2a	

LSD Hybrids 5% = 5.52, 1% = 7.45; Stages 5% = 9.54, 1% = 12.89, Stages x Hybrids = NS.
Numbers having common letters are not significantly different at P = .05.

II. Trial 2

1. Seed Viability Following Processing and Storage

Before seeds were stored, germination tests showed no definite effects of processing on normal seed germination percentage. Although normal germination tended to decrease after the ear drying stage, the differences were only slight, and not statistically significant (Table 12). Surprisingly, however, seeds obtained before ears were dried (BD) showed the lowest germination (80.5%) and the highest percentage of dead seeds (16.0%) (Table 12). Seeds exposed to those processing stages where damage could be expected to occur showed higher germination percentages.

Highest germination (91.5%) before seed storage was observed in seed samples after cob drying although this value was statistically similar to those obtained from tests on samples obtained from succeeding stages in the production system. The abnormal seedling germination percentage was similar at all stages of processing (Table 12).

After several months of storage, changes in seed viability as affected by the different stages of processing became evident as seed deterioration progressed. The germination tests carried out on seed which had been stored for 3 months to 15 months showed that seed lots obtained before ear drying (BD) which had the lowest germination (80.5%) before storage, surprisingly showed an increase in germination percentage to 87.5% - 91.0% after storage. The reason for this is not clear. But it was observed that the samples obtained before ear drying were very wet when brought to the laboratory. During the germination test done before storage, after the seeds were air dried, high levels of Fusarium spp were observed growing on the germination rolls which were not observed in other samples. After storage for 3 months or more, this heavy occurrence disappeared. It seems likely that field fungi may have been killed or inactivated by dry storage for a few months.

Table 12: Germination test results on normal and abnormal seedlings and dead seeds percentage after different storage periods (Trial 2).

Stages of Processing or Sampling Points	Normal Seedling Percentage					Abnormal Seedling Percentage					Dead Seed Percentage				
	Months Storage					Months Storage					Months storage				
	0	3	7	11	15	0	3	7	11	15	0	3	7	11	15
BD	80.5c	91.0a	91.0a	90.0a	87.5a	3.5	3.5c	4.0	3.5e	7.5b	16.0a	5.5	5.0	6.5	5.0c
D	91.5a	91.0a	93.0a	89.0a	83.5a	1.0	5.0bc	2.5	4.5de	10.5b	7.5bc	4.0	4.5	6.5	6.0c
E	87.0ab	86.5bc	86.5b	78.5b	71.5b	5.0	5.5bc	7.5	9.0bc	11.5b	8.0bc	8.0	6.0	12.5	17.0b
Ex	86.5ab	88.5ab	86.5b	81.0b	69.0b	7.0	5.0bc	5.5	8.0cd	12.0b	6.5c	6.5	8.0	11.0	19.0b
Ey	89.0ab	86.0bc	86.5b	80.0b	67.0b	4.0	6.0bc	6.0	8.5c	14.0b	7.0bc	8.0	7.5	11.5	19.0b
F	85.5bc	88.5ab	87.0b	77.0b	68.0b	4.5	5.5bc	5.0	12.5ab	15.0b	10.0b	6.0	8.0	10.5	17.0b
G	87.5ab	86.5bc	86.5b	79.5b	51.0c	5.0	6.0bc	5.5	11.0abc	32.0a	7.5bc	7.5	8.0	9.5	17.0b
Gx	85.0bc	86.0bc	85.0b	75.5b	48.5c	5.5	7.0ab	8.0	14.0a	27.0a	9.5bc	7.0	7.0	10.5	24.5a
GY	88.5ab	84.5c	84.5b	77.5b	52.0c	4.0	10.0a	7.0	13.5a	33.0a	7.5bc	5.5	8.5	9.0	15.0b
LSD 5%	5.68	2.60	3.15	5.75	8.09	NS	3.32	NS	3.86	8.34	4.35	NS	NS	NS	6.01
1%	7.67	3.52	4.25	7.76	10.93		4.48		5.21	11.36	5.88				8.11

Numbers having common letters are not significantly different at P = .05.

See page 37 for description of Stages of Processing

From the 3rd to the 11th month of storage, significant reductions in normal germination among the different stages of processing were observed after shelling. No further reduction in normal germination was noted with further processing after the shelling stage.

After 15 months storage severe reduction in germination was observed. Germination percentages of seed samples obtained after the seed drying stage (G) ranged from 48.5 to 52.0% while the seed germination percentages at stages following shelling (E) ranged from 67.0 to 71.5%. Highest germinations (83.5 - 87.5%) were obtained before and after ear drying. Conveying or transporting seeds before and after shelling and after seed drying did not reduce normal germination percentage.

The critical stages which contributed greatly to the reduction of normal germination after 15 months storage were found to be the shelling and seed drying stages.

Before seed storage, no statistical differences were observed in the levels of seedling abnormality (Table 12). Different trends were obtained after only 3 and 7 months storage. After storage for 3 months abnormal seedling levels significantly increased only after seeds were transported to the storage silo (Gy). However, after 7 months, no statistical differences were noted in all stages of processing. After 11 months storage, seedling abnormalities increased after shelling. A further increase occurred when seeds were transported to the dryer (F) and after drying. After 15 months storage, the levels of abnormal seedlings were observed to be highest after the seeds were dried. Transport of seeds after seed drying to the storage silo did not cause any increase in the level of abnormal seedlings in the final period of storage (11 - 15 months).

The distribution of different types of seedling abnormalities at different stages of processing is shown in Appendix Table 5. The main types of abnormal seedlings present in seed samples before shelling (BD and D) comprised only a few weak and decayed seedlings. But following shelling, seedling abnormalities which showed embryo damage were observed. These included seedlings with stunted roots, absence of roots or plumule, and decayed or unbalanced development. Similar types of abnormalities were observed when seeds were transported from

the sheller to the dryer but these processes were also associated with other abnormalities including split coleoptile, no primary roots, weak and unbalanced seedling development. Following drying, similar types of seedling abnormalities were evident.

After a period of storage, the types of seedling abnormalities were found to vary from weak and unbalanced seedlings to the absence of roots or plumule even at stages prior to shelling and despite the fact that seedlings from the same samples showed no root or plumule abnormality prior to storage. This indicates that ageing deterioration had already occurred.

Differences in the levels of dead seeds were observed at various storage periods. Before storage, the highest level of dead seeds was only noted in samples before ear drying (BD) which was reflected in a low normal germination percentage. After 3, 7 and 11 months storage, however, no statistical differences were observed on the levels of dead seeds among the various stages of processing (Table 12). But after 15 months storage, significantly higher amounts of dead seeds were observed at all stages starting from the shelling stage. The levels of dead seeds before shelling ranged from 5 - 6%, but increased to 17 - 24.5% after shelling. Lower levels of dead seeds were observed during the 3rd and 11th months of storage (4.0 - 12.5%).

2. Seed Viability After Accelerated Ageing

Accelerated ageing test results are shown in Table 13. Generally, the changes in germination values obtained after accelerated ageing did not follow the same trends obtained following natural ageing. However, the technique was a reasonable indicator of seed damage since the reduced germination in some stages of processing after accelerated ageing was also observed after natural ageing.

Before seed storage, accelerated ageing tests showed significant reductions in normal germination in samples tested after the shelling stage. Before shelling, the normal germination ranged from 69.3% to 75.3%. After shelling, the germination fell to 32.0% to 58.7%. When seeds were transported into the dryer after shelling (Ex and Ey) the germination level dropped to 32 - 34%. Surprisingly, it increased to 58.7% in samples obtained at the seed dryer just before drying, but dropped again to 35.3% after seed drying.

Table 13: Accelerated ageing test results on normal and abnormal seedlings and dead seeds percentage at different storage periods (Trial 2).

Stages of Processing or Sampling Points	Normal Seedling Percentage				Abnormal Seedling Percentage				Dead Seed Percentage			
	Months Storage				Months Storage				Months Storage			
	0	3	7	11	0	3	7	11	0	3	7	11
BD	75.3a	68.5	48.5a	13.0a	9.3e	12.5	5.0	19.0	15.4g	19.0ab	46.5d	68.0
D	69.3ab	72.5	50.0a	10.5ab	12.0de	15.0	3.5	18.5	18.7fg	12.5b	46.5d	71.0
E	49.3c	77.0	46.0a	7.0bc	20.0bcd	7.5	2.5	22.0	30.7cd	15.5b	51.5bc	71.0
Ex	34.0e	66.0	47.0a	4.5c	23.3abc	11.5	6.0	23.0	42.7a	22.5a	47.0d	72.5
Ey	32.0e	58.0	42.0a	5.0c	28.0ab	13.5	3.5	19.5	40.0ab	28.5a	54.5bcd	75.5
F	58.7bc	69.0	45.0a	8.0bc	15.3cde	15.5	4.5	15.5	26.0de	15.5b	50.5c	76.5
G	35.3de	57.0	30.5b	6.0bc	30.7a	15.5	7.0	14.0	34.0bc	27.5a	62.5abc	80.0
Gx	54.0c	68.0	22.0b	8.5bc	21.3abcd	16.5	10.0	18.0	24.7ef	15.5b	68.0a	73.5
Gy	47.3cd	60.0	27.5b	7.0bc	19.3bcde	11.5	8.0	16.0	33.3c	28.5a	64.5ab	77.0
LSD 5%	12.37	NS	11.39	4.88	10.04	NS	NS	NS	6.37	11.78	13.36	NS
1%	16.95		15.38	6.59	13.76				8.72	15.91	18.04	

Numbers having common letters are not significantly different at P = .05.

The abnormal seedling germination levels before storage showed a general increase from 9.3% - 12.0% before shelling to 15.3% - 30.7% after shelling (Table 13). Similarly, the levels of dead seeds also increased from 15.4 - 18.7% before shelling to 24.7% - 42.7% subsequently (Table 13). When the seeds were transported after shelling (Ex and Ey) the levels of dead seeds significantly increased (40.0%) - 42.7%) but surprisingly dropped to significantly lower levels (24.7% - 34.0%) in succeeding stages.

Although no significant differences in normal germination occurred among the different stages of processing after 3 months storage (57% - 77%), after 7 months storage, the accelerated ageing test results showed significant differences. Germination percentages after drying (22% - 30.5%) were significantly lower than those before drying (42% - 50%).

After 11 months storage, the accelerated ageing test results showed that normal germination was generally lower at all stages after shelling (4.5% - 8.5%) than before shelling (10.5% to 13.0%). The levels of abnormal seedlings were similar at all storage periods.

The levels of dead seeds from 7 months of storage were generally increased following shelling and rose further after seed drying. By the 11th month, dead seed percentages were similar at all processing stages.

D. Discussion

It is generally thought that much of the reduction in germination of seed maize may be caused by inferior or weakened seed conditions when planted (Wortman and Rinke, 1951). Such weakening of seed condition has been attributed to several factors. Commercial seed processing has been suggested as a major contributor to reduced vigour in seeds as a result of mechanical damage. Both seed viability and storage life can be implicated (Tatum and Zuber, 1943; Moore, 1972, 1963). Moore (1972) stated that although small injuries may not cause immediate loss of viability, intensive mechanical injuries are immediately important.

The present study shows that particular stages in the seed processing sequence can greatly affect the quality of maize seeds, particularly when processing is followed by a period of storage. It was observed that all stages of seed processing, including husking, ear drying, seed drying, shelling, handling, conveying or transporting, dressing, grading and treating, did not necessarily reduce the viability of maize seeds immediately after treatment in any of the 3 hybrids studied.

However, often the effects of seed processing became very apparent after a period of seed storage. In Trial 1, the differential response of hybrids to processing was clearly shown. Hybrid XL 72aa showed a reduced germination after seed drying but further processing did not cause further reduction in germination. Hybrid D 54 also tended to show lower germination after seed drying but germination percentage also fell dramatically (62.0%) after the seeds had passed through the dressing plant. Hybrid XL 81 showed a tendency to drop in germination after ear drying and also after seed drying. Seed germination in this hybrid also fell after seed had passed through the dressing plant (65.0%).

It is possible that the seed damage incurred by Hybrids XL 81 and D 54 after dressing, treating and grading, included the cumulative effects of damage due to the impact caused by shelling and transporting as well as the drying process. This was shown by the general decline in germination as processing proceeded. The drop in germination of Hybrids XL 81 and D 54 after dressing, grading and treating was thought not to be due to phytotoxicity caused by the seed treatment fungicide 'Vitaflo'. The types of abnormal seedlings which occured indicated no sign of chemical toxicity. Thompson (1979) reported that in cereals, a toxic effect of chemicals on seed is exhibited by seedlings with short thickened or swollen leaf sheath and roots. This was not observed in the treated samples used in this study.

This observation indicates that Hybrids XL 81 and D 54 were more sensitive to impact damage shown after storage than Hybrid XL 72aa. It is interesting that Hybrid XL 72aa had the lowest initial germination before storage but eventually proved to be more resistant

to impact damage compared to the other 2 hybrids. This result generally agrees with data obtained from the commercial lots of seed maize reported by HBF Dalgety Ltd.

The findings of Wortman and Rinke (1951), have also shown that there are two distinct characteristics of maize hybrids which affect their performance, i.e. susceptibility to mechanical injury and potential ability to germinate. In this study, Hybrid XL 72aa had the lowest potential ability to germinate as indicated by its lower initial germination following processing but before storage. Conversely, Hybrid D 54 had the highest initial germination followed by Hybrid XL 81. However, these 2 hybrids were more sensitive or susceptible to processing damage. In fact, the seed germination of Hybrids D 54 and XL 81 was reduced by 33.0% and 35.0%, respectively, compared with only 10.0% for Hybrid XL 72aa after 5 months storage. From the point of view of the plant breeder, it is desirable to combine both quality characteristics in hybrids, since the mechanical processing of seed maize undoubtedly inflects seed damage regardless of the care exercised by the processor (Wortman and Rinke, 1951). A hybrid must have the potential for high germination and be relatively resistant to mechanical impact damage.

In Trial 2, it was shown that before storage, seed germination prior to ear drying (BD samples) was low (80.5%). But the germination of seed samples obtained after ear drying (D) rose to 91.5%. This discrepancy could be probably due to the activity of field fungi (particularly Fusarium sp) which were present on seeds during harvest at about 29.0% moisture content. When the seeds on the ears were dried to 18.0% moisture content, fungal activity would be expected to be reduced; an effect which could be further reduced when the seeds after shelling were dried to 12.0% moisture. In fact, as storage progressed, the germination obtained rose to 91.0% after 3 months. This result is surprising. However, it is speculated that during the germination test, before storage, fungi were still active and were observed growing on the germination paper. Fusarium species in particular, produced mycelium which often completely covered dead seeds. This activity may have been responsible for seed death during the 7-day germination period when the presence of high moisture and

warm temperatures would favour fungal growth (Christensen and Kaufmann, 1969). Following storage, since the seeds were already dried to 12.0%, these fungi may have been slowly inactivated or killed (Christensen and Kaufmann, 1969), allowing higher germination of seeds after storage than before storage.

Although seed germination percentage was not greatly affected by seed processing when tests were carried out immediately and prior to storage, a clearer picture of the processing effects was observed as natural ageing of the seeds occurred during storage for up to 15 months. After 11 months storage, seed damage due to processing was observed in samples taken after shelling. By the 15th month of storage, however, further changes in the levels of seed germination occurred. In particular, damage due to seed drying which was not evident until the seeds deteriorated severely in storage became obvious. Nevertheless, the main processing stage which resulted in reduced seed germination after storage was the shelling stage, followed by the seed drying stage.

Similar reports had been made. Various workers have also shown that damaged seeds have reduced seed vigour and deteriorate faster in storage than undamaged seeds (Waelti et al., 1969; Justice and Bass, 1978; Nikilov and Kirilov, 1983; Brooker et al., 1974).

A number of workers have also reported that during seed processing, seed damage occurs following seed drying, impact in conveying, handling or dropping of the seeds, shelling or impact due to cleaning, treatment or dressing machinery (Chowdhury and Buchele, 1978; Hall and Johnson, 1970; Wortman and Rinke, 1951; Byg and Hall, 1968; Pickard, 1956; Fiscus et al., 1971; Winter, 1968; Sands and Hall, 1971; Hall, 1974). Undoubtedly, the seed damage caused by seed processing, one way or another, will eventually lead to reduced germination either before or after storage (Livingston, 1952; Wortman and Rinke, 1951; Pana, 1977; Koehler, 1954; Moore, 1972; Waelti and Buchele, 1969).

Depending on the hybrid studied, the stages of processing most likely to show a reduction in seed germination following storage are the shelling, cob and seed drying, and the final stage of dressing, grading and treatment of the seeds.

While seed damage did not cause an immediate loss of seed viability, it reduced seed vigour, thus shortening seed storage life. Seed lots with lower seed vigour at the time of storage are likely to decline rapidly in germination compared with high vigour seed lots (Justice and Bass, 1978).

Although seeds may appear to be sound and intact following processing, internal damage may have occurred as a result of impact caused by shelling and during the transporting and handling of the seeds. Moore (1972) emphasized that an impact can bring about disorganisation of cellular contents that results in processes leading to premature death. Iljin (1957) also proposed that structural modification in the protoplasm arises from mechanical action or mechanical vibration. It is assumed that this resultant disorganisation of cell contents due to impact, under severe conditions, would lead to immediate or early death of tissues. However, if only a minor injury occurred, loss of viability may not be observed until after period of storage. Tatum and Zuber (1943) suggested that seed vigour of maize is affected by mechanical damage to the seed and that such seeds need special care in storage. In the study of Verma (1978), embryo disorientation due to mechanical shelling was observed in X-ray photographs which was a contributory factor to loss of viability.

Seed drying also caused a reduction in seed germination following storage in this experiment. This damage was not severe enough to be detected before seed storage, but contributed greatly to loss of germination during storage. Harrington (1972) mentioned that if drying temperature is high but not high enough to kill the seeds, seed vigour may be reduced and seed longevity decreased. Some workers reported immediate loss of seed germination due to artificial seed drying (Brown et al., 1979; Peplinski et al., 1975; Gausman et al., 1952). Higher drying temperatures ranging from 49 C to 60 C were used by these workers. However, when a lower drying temperature (44 C) was used, no loss of germination was reported (Gausman et al., 1952; Peplinski et al., 1975; Hukill, 1974; Justice and Bass, 1978; Kiesselbach, 1939; Roberts et al., 1972).

Kiesselbach (1939) observed that seed viability and vigour were not injured by artifical drying at a temperature of 42 C to 44 C. However, Navratil and Burris (1984) have subsequently shown that while some maize inbreds show no reduction in germination at 45 C drying temperature, seed vigour was reduced. The average drying temperature used in the present study was 30 C. This did not cause any reduction in seed germination after seed drying. But after storage, the germination of artificially dried seeds fell in relation to seeds which were not dried artificially, the extent depending on the hybrid. This indicates a reduction of seed vigour after drying at 30 C in this particular experiment. Visual and X-ray examination of the seeds showed stress cracks in the endosperm to be a contributory factor to the reduction of seed longevity. This subject of seed cracking is considered in more detail in Chapter 3.

It was also observed in this study that ear drying contributed to the decrease in germination of Hybrid XL 81. Probably, this hybrid was more susceptible to drying stress even when seeds were still on the cob while the other hybrids were not. Certainly, a drying stress during ear drying may be detrimental to the seed longevity of susceptible hybrids. Thompson and Foster (1963) also observed drying stress during ear drying when they found 3% cracking in kernels dried on the cob at 71 C compared with 100% cracking of shelled kernels.

In this experiment, the percentage of abnormal seedlings produced following processing before seed storage did not differ significantly between samples. However, the types of abnormal seedlings did vary according to the stage of seed processing. The most critical stage of seed processing affecting seedling abnormality was the shelling stage. Immediately after shelling, different types of abnormal seedlings were fist noticed. The most common abnormalities prior to shelling included seedlings with weak and unbalanced development, a few decayed roots, decayed and split coleoptiles, and seedlings with a decayed mesocotyl. After shelling, abnormal seedlings included stunted plumules, broken, split coleoptiles, no roots, stunted roots, no plumules and a few unbalanced and decayed seedlings. Following seed drying and in succeeding stages similar types of seedling abnormalities were noticed including seedlings with no roots, stunted roots, no plumule, coleoptile damage and unbalanced and weak seedlings.

The results of this study confirm findings by previous workers that mechanically damaged cereal seeds produce abnormal seedlings with root damage, split coleoptiles and broken shoots (MacKay and Flood, 1968; Moore, 1968; Verma, 1978. Pollock and Roos (1972) also reported that injury to meristematic tissue of the plumule or radicle is a common result of mechanical damage. MacKay (1972) stated that mechanical injury during threshing may result in root damage in cereals in which only the plumule develops. Thompson (1979) also reported rootless seedlings of cereals due to threshing damage. Coleoptiles may also be injured by splitting so that the leaves emerge from the base instead of from the tip.

Apart from mechanical damage, artificial seed drying may cause the production of higher levels of abnormal seedlings (Heydecker, 1972). In this study, the types of seedling abnormalities observed after seed drying were similar to those caused by shelling. Wellington and Bradnock (1964), reported that barley seedlings showed poorly developed primary roots or seminal roots, short coleoptiles, or plumules which do not elongate or fail to emerge following artificial drying. Thompson (1979) also reported that artificial drying can produce defects in cereal seedlings such as poor root growth and inhibition of shoot growth.

There was no evidence of phytotoxicity caused by the fungicidal seed dressing applied at the end of seed processing. Certainly no phytotoxic effects were revealed by the types of abnormal seedlings, present in germination tests. The typical symptoms of the toxic effects of fungicides on seeds of cereals such as short thickened or swollen roots and plumules (Thompson, 1979; Colbry et al., 1961; Justice, 1972) were also not observed in this study.

The results of this experiment may be surprising since processing produced different types of abnormal seedlings, but the levels were similar between those samples which had passed the critical stages of processing and those which had not. It is likely that those seeds that produced weak or unbalanced seedlings prior to shelling were the seeds most affected by subsequent processing. Such an effect was readily observed after storage.

As seed ages during storage, germination capacity declines, but complete death is usually preceded by the production of abnormal seedlings whose development is weak or unbalanced because the loss of vital functions does not occur simultaneously in the different tissues (Moore, 1972). Typical symptoms include stunting of the plumule or failure of the first leaf to develop within the coleoptile (Griffiths and Pegler, 1964; Kearns and Toole, 1939; MacKay and Flood, 1969). Similarly, Justice (1972) reported that seeds which are aged or have been subjected to unfavourable storage conditions are usually slow to germinate and one or more essential parts are frequently stunted or lacking. In the present study, it was noticed that at the end of storage (15 months), the common abnormalities included weak small seedlings, seedlings without roots, and seedlings without primary roots but with the secondary roots which were also weak and insufficient.

In this experiment, the results of accelerated ageing tests did not show close agreement with the results of natural ageing of seeds in storage. In Trial 1, for example, the seeds showed significant differences in germination after natural ageing in storage. However, accelerated ageing did not reflect these differences. In Trial 2, in particular, significant differences in seed germination after accelerated ageing were observed but again they did not closely conform to the results following natural ageing. Nevertheless, the results did indicate that some stages of processing (e.g. shelling and seed drying) caused significantly lower germination percentages in relation to other previous stages.

Anderson (1970) also observed in barley that results of accelerated ageing were not directly associated with natural seed deterioration. Similarly, Abdul-Baki and Anderson (1972) found that barley seeds which were aged for up to 12 days by accelerated ageing did not leach sugars, unlike seeds which were aged under natural conditions for 2, 5 and 8 years. They concluded that accelerated ageing conditions are not identical to normal ageing conditions even though the final result, loss of germination, may be the same. However, in soybeans, Egli et al., (1979) found a direct association between accelerated and natural ageing germination test results. They

concluded that accelerated ageing was an excellent predictor of seed storability. Similarly, Delouche and Baskin (1973) and Pili (1967) observed high correlations between natural and accelerated ageing of several seed species including maize. However, they also noted that in some seed lots accelerated ageing did not show close association with natural ageing. Some lots of maize showed higher germination after accelerated ageing but had poor storage performance in relation to other seed lots. Delouche and Baskin (1973) stated that while the reasons for these exceptions from the general pattern are not known, varietal differences, mechanical damage and other factors are operative in exceptional responses.

E. Conclusion

Seed processing did not cause a significant reduction in seed germination before seed storage. However, when seeds had undergone deterioration during storage, severe reductions in both seed vigour and germination due to processing were observed.

In general, the degree of reduction in seed gemination due to processing varied among hybrids. Hybrids D 54 and XL 81 were more susceptible to processing damage with reductions in germination of 33.0% and 35.0%, respectively, compared to only a 10.0% reduction in Hybrid XL 72aa observed after 5 months storage. Although Hybrid XL 72aa had less potential ability to germinate as indicated by its lower initial germination, it was also less susceptible to processing damage than the other 2 hybrids.

The specific stages of processing which caused a significant reduction in seed germination after storage also varied with the different hybrids. Hybrid XL 72aa suffered significant reduction in seed germination particularly due to seed drying. On the other hand, Hybrids D 54 and XL 81 showed only a minor reduction in germination due to seed drying but germination drastically dropped after the final stage of dressing, grading and treating. These 2 hybrids were also shown to be susceptible to impact damage caused by machinery in the dressing plant. Cumulative effects of the other stages of processing including transporting or conveying of the seeds contributed much to the reduction of seed germination of the latter 2 hybrids (D 54 and XL

81) as they passed through the dressing plant. Seeds of Hybrid XL 81 also showed reduced germination after cob drying, showing the sensitivity of this hybrid to drying stress even while on the cob. Shelling also caused a serious reduction in seed germination as observed in Hybrid XL 72aa after storage.

The stages of processing which were most likely to contribute to a reduction in seed germination following storage, were cob drying, seed drying, shelling, and the final stages of dressing, grading and treating.

The accelerated ageing test used in this study did not give a reliable indication of potential storability and vigour in maize as affected by processing.

CHAPTER 3

Stress Cracking in Maize Seeds

A. Introduction

In commercial maize seed production, the need for artificial seed drying is considered to be an essential part of the production system. Newly harvested seeds are generally too wet for ordinary storage without reduction in seed moisture content to safe storage levels. As a result, the use of heated air in drying seed maize has become a common practice by seed producers.

The use of heat in seed drying, especially when high temperatures are used, results in rapid drying of the seeds. This causes seed injury by cracking of the endosperm as a result of rapid shrinking of outer parts of the seed while the inner parts are still undried (Harrington, 1972). Such a situation is brought about by the creation of a moisture gradient stress in seed during drying (Ekstrom et al., 1966). This type of injury was termed by Thompson and Foster (1963) as stress cracking. Stress cracks are fissures in the endosperm which occur even though the seed coat remains intact and unruptured.

Several investigators have shown the deleterious effects of seed damage on viability and storage performance of maize seeds (Justice and Bass, 1978; Wortman and Rinke, 1951; Livingston, 1952; Nikilov and Kirilov, 1983; Waelti and Buchele, 1969; Moore, 1972) and reported such damage to be a major cause of reduction in seed germination (Pana, 1977).

Moore (1972) stated that seed damage may not cause immediate loss of seed viability but it can become critical with the ageing of the seed. Hence, reduction in seed germination due to injury is often only noticed following seed ageing even though such seed injury is not detected in an immediate loss in viability before the seed has undergone deterioration in storage.

It was shown in Chapter 2 that seed processing did not cause any immediate loss in seed viability before storage. Stress cracks, although they occurred during processing, were not implicated as a cause of reduction in seed germination before storage. The present

study was done to determine the occurrence of stress cracking in maize seeds as affected by processing and to determine the relationship of stress cracking in artificially dried seeds to loss of seed viability after storage.

B. Materials and Methods

To determine which stage of the processing system stress cracking occured, seeds from samples A to I previously used and discussed in Chapter 2 were examined for cracking both visually and by the use of the X-ray radiography.

Samples of fifty seeds were set on the X-ray film. The 'Faxitron' X-ray machine was operated using 30 kvp for 2.5 minutes at 3 MA. The same set of seed samples were also examined visually for cracking. Visual examination was done under a tungsten bulb filament to enhance the detection of cracking. Seed cracking was expressed as a percentage of fifty seeds.

In order to assess the independent effects of the levels of stress cracking on seed viability following storage, seed samples from the previously used artificially dried seed lot (Sample G) which showed different levels of seed cracking were tested for germination.

The seeds used were selected from previously artificially dried seeds which had been stored for 12 months. The seeds were X-rayed and examined for stress cracks. Samples of 4 x 50 seeds each with different levels of stress cracking, were also tested for germination. Levels of stress cracking ranged from 0 - 70% as follows:

Sample no.	Percentage of Cracked Seeds (X-ray)
1	0
2	13
3	24
4	37
5	47
6	58
7	70

Correlation analysis was carried out to determine the relationship between seed germination following storage and different levels of cracking.

To determine the significance of the location or position of stress cracks within the seed as seen by X-ray photographs, separate seed samples exhibiting different positions of seed cracking were tested for germination.

The artificially dried seed lot (Sample G) was also used in this test. Seeds were examined to determine the precise location of internal cracks as revealed by X-ray photograph. Samples of 25 x 3 seeds of each type or position of cracks were tested for germination and compared to the control (no cracks). The following types or positions of cracks were compared to determine their effect on seed viability following storage:

Sample Number	Type or Position of cracks
1	No cracks (Control)
2	Visual - crack seen visually but not detected by x-ray
3	Position 1 - crack with its length situated outside of the embryo area and detected by X-ray
4	Position 2 - crack along the side of the embryo area and detected by X-ray
5	Position 3 - crack along the middle of the embryo area and detected by X-ray.

To obtain seed samples exhibiting different crack positions, a number of seeds were X-rayed and selected until a sample of 25 x 3 seeds with similar position of cracks was obtained. These different types or positions of cracks are shown in Plates 13 - 15. Analysis of variance was done to determine the effect of the various types of cracks on seed germination following storage.

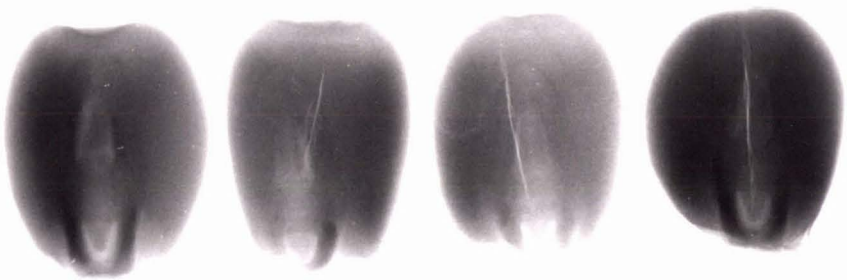


Plate 13: X-ray photograph showing different positions of cracks in maize seeds.
Left to right: No cracking, longitudinal crack outside the embryo, longitudinal crack along the side of the embryo, longitudinal crack along the middle of the embryo.

Plate 14: Maize seeds showing visual cracking in the endosperm.
Left and Middle: Seeds with cracks both seen visually
Right: A sound seed without sign of visible cracking.

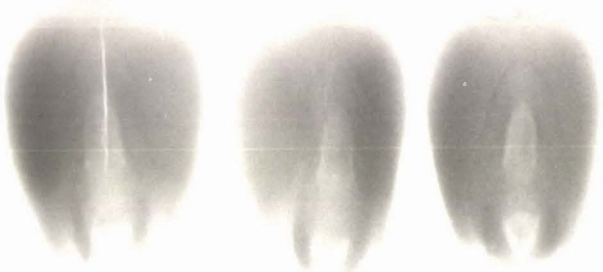


Plate 15: X-ray photograph of the same maize seeds in Plate 14.
Left: Seed with visual crack also seen by X-ray
Middle: Seed with visual crack but not seen by X-ray
Right: Sound seed without evidence of cracking under X-ray.

C. Results

1. The Occurrence of Stress Cracking

The occurence of seed cracking as affected by processing is shown in Figures 3 and 4. The X-ray results showed that large amounts of stress cracks were associated with the seed drying stage of processing (Sample G). No stress cracks were detected following X-ray analysis of seeds from samples obtained prior to seed drying.

The results of the visual determination of stress cracks were very variable as clearly shown in Figure 3. Although some relatively minor amount of visual cracking was observed in some parts of the processing system before seed drying, a dramatic increase in the percentage of cracking was observed in seed samples which had been dried (Sample G). Subsequently however, the levels of visual cracks surprisingly dropped to a lower level. This showed the high degree of variation in the results obtained by visual examination of maize seed for internal stress cracking. The X-ray analysis revealed that the three maize hybrids (XL 72aa, D54 and XL 81) showed similar levels of cracking within the range 44 - 54% (Appendix Table 8).

When the levels of seed cracking were assessed in seed samples taken before and after storage, the results showed no dramatic change in the levels of stress cracking as revealed by X-ray analysis (Figure 4). The stress cracks which occurred immediately after seed drying as revealed by the X-ray test ranged from 28 - 34%. Seeds from the same samples which had been stored for 12 months showed similar levels of cracking (28% to 32%).

Visually detected cracks, however, showed a sharp rise after seed storage as clearly shown in Figure 4. Before the seeds were stored, the percentage of visual cracks ranged from 44% - 48%. After 12 months storage, the levels of visual cracking had risen to between 64% and 70%. The levels of visual cracking in this test were less variable than those obtained in previous tests (Figure 3). The percentage of visual cracks was consistently higher than the percentage of cracks detected following X-ray analysis. Since some visual cracks were not visible under X-ray radiography it was considered that they were unlikely to be important in affecting seed germination following storage as observed in this experiment.

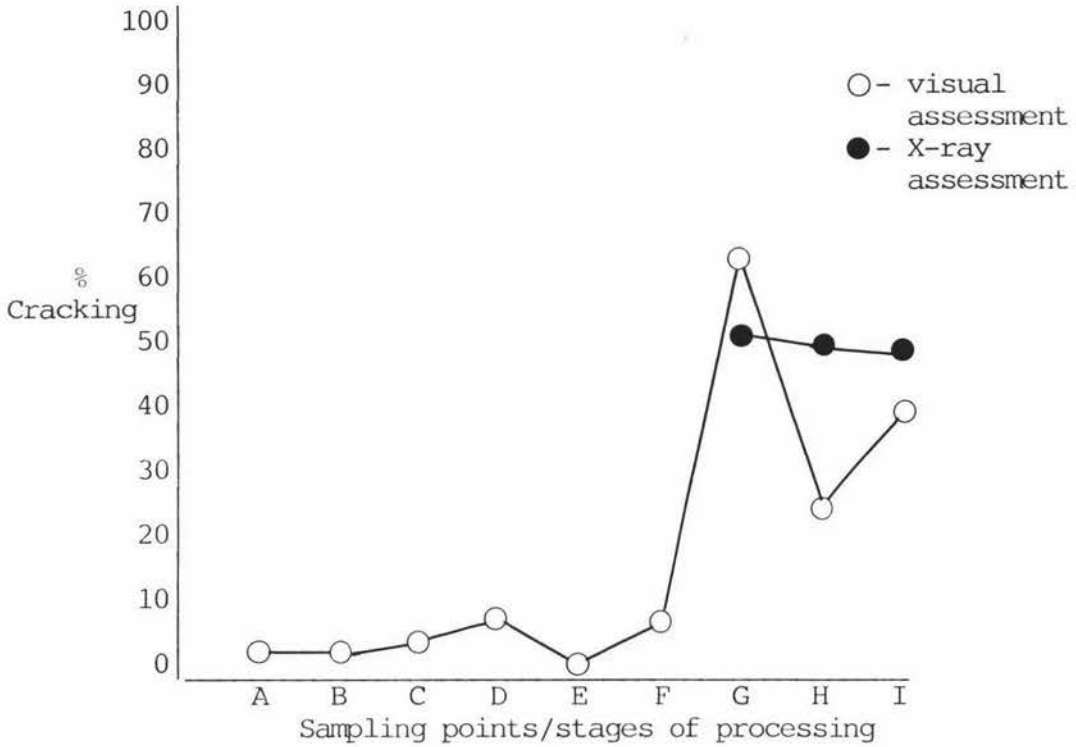


Figure 3: Differences in the levels of seed cracking at various points of processing in trial 1 (average of Hybrids XL 72aa and D 54)

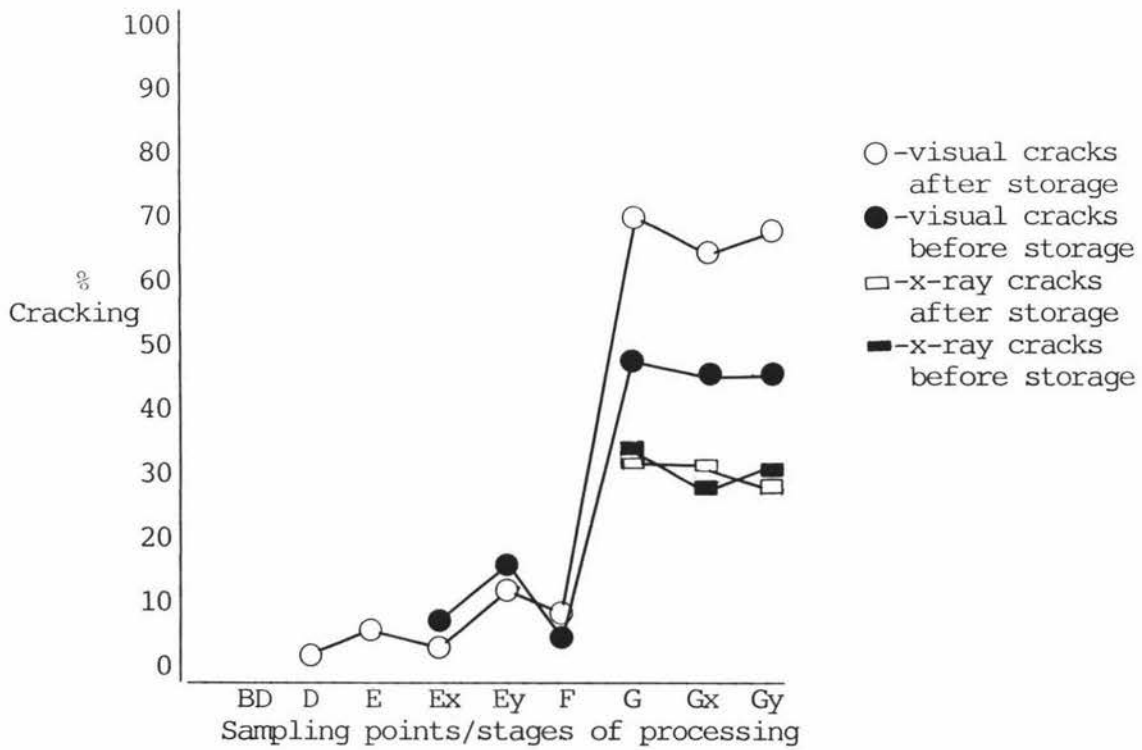


Figure 4: Differences in the levels of seed cracking at various points of processing before and after storage (data from trial 2).

2. The Significance of Stress Cracks on Seed Viability

The effects of stress cracking on seed germination after storage of artificially dried seeds are shown in Tables 14 and 15 and Figure 5. The results show that increased levels of stress cracking detected by X-ray radiography (Table 14) resulted in a subsequent reduction in seed germination. A high negative correlation, $r^2 = -0.86$, was noted between stress cracking and seed germination (Figure 5). Increasing levels of stress cracking from 0.0% to 70.0%, were accompanied by a corresponding decrease in seed germination from 74.5% to 47.5%.

The effects of stress cracks on seed germination after storage, however, depended on the position of the cracks in the seed as shown by X-ray test (Table 15). The X-ray examination had shown that some cracks in seeds which were seen visually may not also be seen by X-ray photographs taken of seeds in the normal longitudinal position. This type of cracking, however, was seen as very tiny cracks in the endosperm when seeds were X-rayed in the transverse position on the X-ray plate (Plates 16 and 17). The data showed that this type of crack did not cause any significant reduction in seed germination after seed storage. Similarly, cracks with their length situated outside the germ area, even though the tip of the crack may have touched the margin of the plumule, did not reduce seed germination after storage (Position 1). However, those cracks situated alongside the germ area (Position 2) and cracks which extended into the middle of the germ area (Position 3) did cause a significant reduction in seed germination after storage. These results suggest that cracks must impinge on the germ area before they can be implicated as a cause of reduction in seed germinability following storage.

Table 14: Percentage germination after storage of artificially dried maize seeds as influenced by different levels of stress cracking detected by X-ray radiography (Hybrid XL 72aa).

Seed sample	% Seeds with stress cracks	% Germination
1	0	74.5
2	13	72.5
3	24	63.5
4	37	61.0
5	47	52.0
6	58	50.5
7	70	47.5

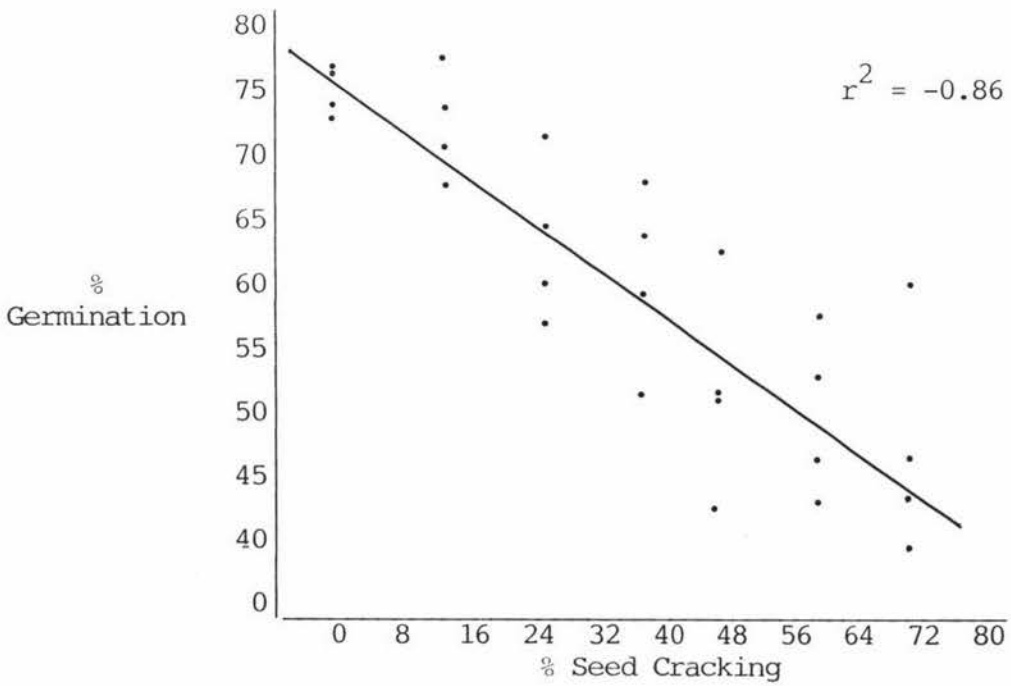


Figure 5: Correlation between percentage germination after storage and levels of cracking of artificially dried maize seeds.

Table 15: The influence of seed crack position on the germination of artificially dried seeds following storage for 12 months.

Seed Samples	Crack Positions *	% Normal Seedlings	% Abnormal Seedlings	% Dead Seeds
1	No Cracks	73.3a	13.3b	13.3b
2	Visual Cracks only	68.0a	17.3b	14.7b
3	Crack Position 1	69.3a	17.3b	13.3b
4	Crack Position 2	45.3b	34.7a	20.0a
5	Crack Position 3	42.7b	33.3a	24.0a
L.S.D. 5%		7.51	7.75	6.51
1%		10.68	11.03	ns

Numbers within a column having common letters are not significantly different at P = .05%.

* No Cracks = no cracks on seeds observed visually and by X-ray
  Visual cracks = cracks seen visually but not by X-ray
  Crack Position 1 = cracks situated outside the germ area as seen by X-ray
  Crack Position 2 = cracks along the side of the germ area as seen by X-ray
  Crack Position 3 = cracks along the middle of the germ area as seen by X-ray.

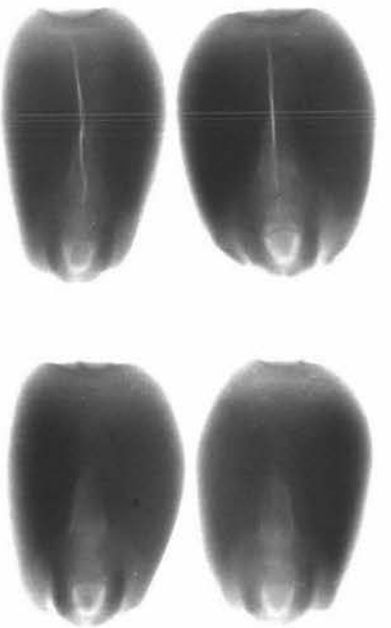


Plate 16: Photograph of maize seeds X-rayed in the longitudinal position.
Top: Seed cracks seen by both X-ray and visual examination
Bottom: Seeds showing no cracks under X-ray but hairline cracks detected visually.

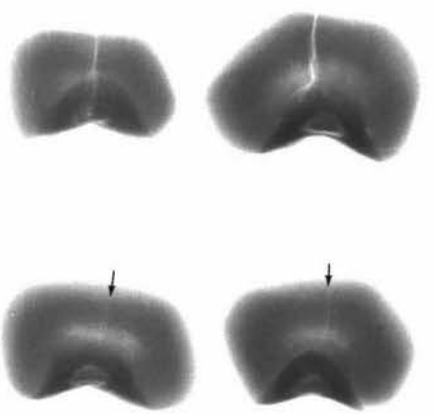


Plate 17: Photograph of the same seeds in Plate 16 X-rayed in the transverse position. The visual cracks not seen by X-ray in the longitudinal position are seen as tiny cracks in the transverse position (bottom seeds).

The number of abnormal seedlings and dead seeds following seed storage significantly increased in seed lots bearing cracks along the side of the germ area or extending into the middle of the embryo (Positions 2 and 3) (Table 15). However, although the number of abnormal seedlings did increase, the types of seedling abnormalities were generally similar regardless of the position of the cracks (Table 16). This indicated that the degree of cracking in this particular study hastened seed deterioration or death of seeds which was preceded by the production of abnormal seedlings.

The common seedling abnormalities observed in all seed lots regardless of the position of cracks included some minor splitting of coleoptiles, seedlings with no roots, seedlings with stunted or no primary root, stunted or no plumule and weak seedlings (Table 16). Surprisingly, the same types of abnormal seedlings observed in cracked seeds were also commonly observed in non-cracked seeds. However, the percentage of seedling abnormalities increased with increased cracking. Plate 18 shows an X-ray photograph of seeds exhibiting cracking in the germ area. When these same cracked seeds were germinated according to the position of the seeds in the X-ray plate, some cracked seeds produced normal plumules or normal seedlings although in the whole population increased numbers of abnormal seedlings were observed as shown in Plate 19. These included seedlings without roots or with stunted roots and weak development which are an indication of seed ageing.

D. Discussion

Internal stress cracking in maize seeds has been shown to occur due to the stress created by moisture gradient during seed drying (Thompson and Foster, 1963). This internal fissuring of the endosperm is readily detected by X-ray radiography (Milner and Shellenberg, 1953).

Table 16: Types of abnormal seedlings observed from seeds with different types or position of cracks.

Types or Position of Cracks	Observed Types of Abnormal Seedlings
1. Seeds without cracks	Stunted or no primary roots No roots Stunted or no plumule Weak seedlings Split coleoptile
2. Seeds with visual cracks only	Stunted or no primary roots No roots Stunted or no plumule Weak seedlings Split coleoptile
3. Seeds with cracks with their length situated outside of the germ area as seen by X-ray (Crack Position 1)	Stunted or no primary root No roots Stunted plumule Weak seedlings
4. Seeds with cracks situated along the side of the germ area as seen by x-ray (Crack Position 2)	Stunted or no primary root No roots Weak seedlings Split coleoptile
5. Seeds with cracks situated along the middle of the germ area as seen by x-ray (Crack Position 3).	Stunted or no primary root No roots Weak Seedlings Split coleoptile.

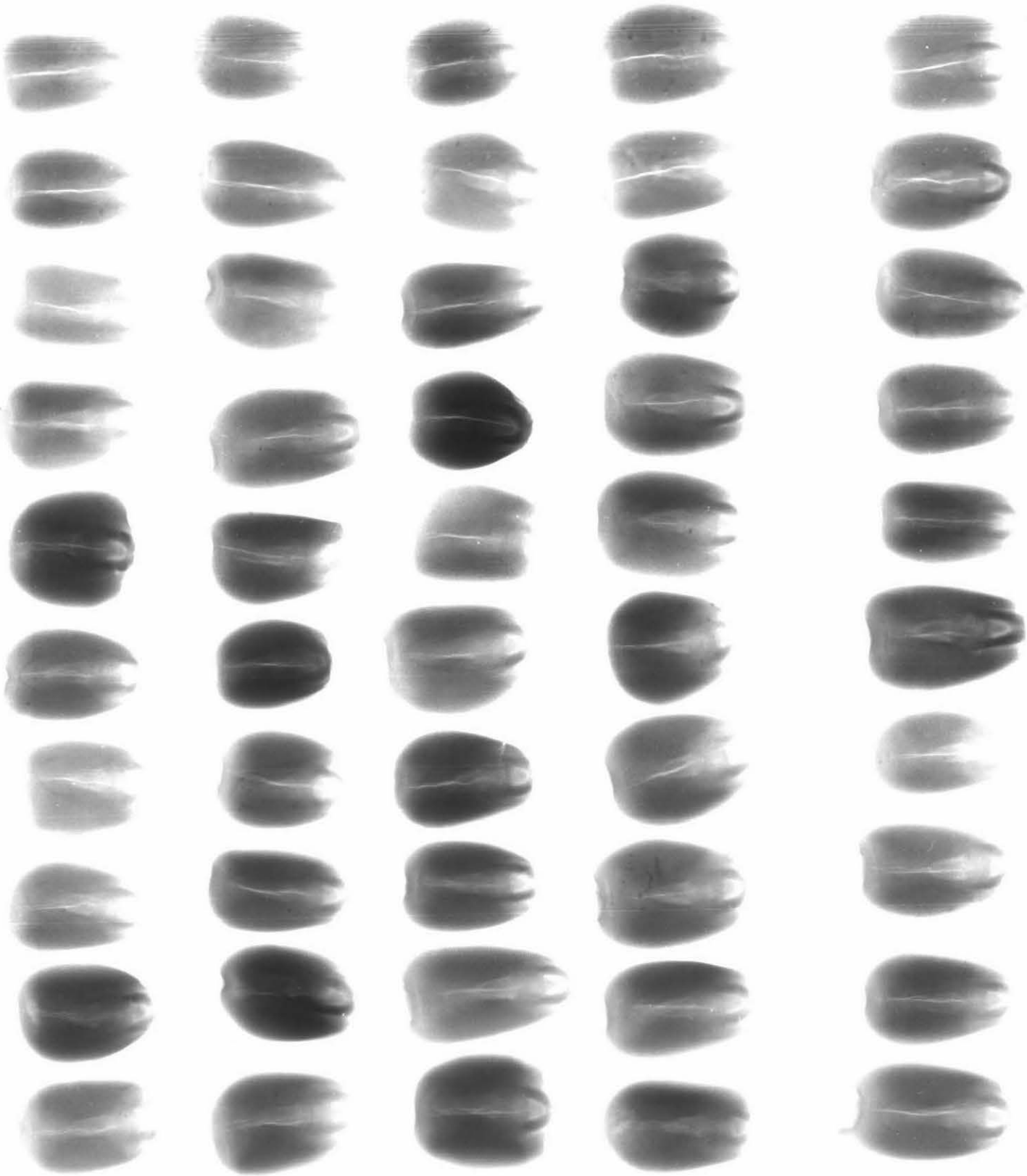


Plate 18: Maize seeds displaying seed cracks in the germ area as seen by X-ray photograph

Plate 19: Positional germination test showing normal and abnormal seedlings and dead seeds from the cracked seeds in Plate 18

In this study, cracking detected by x-ray radiography occurred in the seed drying stage of the seed processing. An assessment of the effect of seed cracking on seed viability showed great reduction in germination following storage with an associated increase in the amount of seed cracking. However, the extent of this effect depended on the position of the crack in the seed. Longer cracks extending down the side and the middle of the germ area as seen by X-ray photography had a most serious effect on seed germination. Cracks which were observed to be of smaller magnitude and which were situated outside the germ area and those cracks which were seen visually but not by X-ray did not cause significant reduction in seed germination following storage.

Some cracks in the seeds which were visually observed could not also be seen by X-ray when seeds where photographed longitudinally (Plates 14 and 15). However, when X-ray photographs were taken on seeds in a transverse position, visual cracks appeared in the X-ray picture as very tiny white lines. This suggests that visual cracks which are not detected by X-ray radiography are small and superficial.

Milner and Shellenberg (1953) reported that the detection of internal flaws in solid bodies by X-ray radiography is limited by the ratio of the void to the total diameter of the body. They found in wheat that X-ray radiography apparently permitted visualisation of fissures greater than approximately 2% of the kernel diameter. Smaller internal cracks did not impart a radiographic shadow. The results in the present study revealed that some cracks, while they could be seen visually, were not detected by X-ray when seeds were photographed in the normal longitudinal position. However, such cracks could be detected as shallow, small fissures under X-ray radiography carried out on seeds in the transverse position. These visual cracks were found to be non-destructive to seed germination even following storage. The germination of the seeds with visual cracks and even seeds with cracks seen by X-ray but occurring outside

the embryo area was similar to that of non-cracked seeds. This suggests that those visual cracks observed in some stages of processing prior to seed drying which were not subsequently detected by X-ray are of no importance in affecting seed viability even following a period of storage. Similarly, the sharp rise in visual cracks found to occur after seed storage had no significant effect on viability. Conversely, internal cracks detected by X-ray photography did not show any dramatic change in numbers or extent after seed storage.

This experiment did not show any evidence of direct damage by seed cracking on the essential structures of the seedlings obtained from germination tests carried out before the seeds were stored. In fact, most seeds with cracks seen by X-ray photograph were still capable of producing some normal seedlings. However, following seed storage, increased numbers of seedling abnormalities and dead seeds were observed from seeds having cracks alongside and in the middle of the germ area as seen by X-ray photography. Generally, the number of abnormal seedlings following seed storage increased with increased levels of cracking. The types of seedling abnormalities consisted mainly of root stunting or absence of roots and weak seedling development, which are indications of the ageing of seeds (ISTA, 1976). Some minor splitting of coleoptiles was observed and occurred not only in cracked but also in non-cracked seeds.

Although the number of abnormal seedlings after seed storage increased with increased seed cracking, some seeds with cracks were still able to produce normal seedlings. Therefore, it is deduced that in this particular experiment, the amount of seed cracking did not cause direct damage to the seed embryo but drastically enhanced the seed ageing process. Further, some cracks which appeared on X-ray photographs were probably of sufficiently low magnitude that they did not cause severe seed deterioration during the period of 12 months storage considered in this study. Perhaps, abnormalities due to this

type of cracking may appear after a much longer storage period. The reason why there was no direct damage to the embryo was suggested in X-ray photographs of seeds in the transverse position. In this case the seed cracks which were seen both visually and by X-ray, while they were relatively large, were seen not to extend into the embryo itself although they may have reached the scutellum area. It is thought that larger cracks extending into the scutellum area of the seed would cause a faster rate of seed deterioration during storage. Moore (1972) stated that if an injury is non-critical' in that it has no immediate effect on seed viability, but is located on or near an essential part of the embryo structure, a seed can readily become non-viable with only a minor amount of deterioration. During storage, these injured areas apparently promoted rapid weakening and early death of surrounding normal tissue. Certainly, large and deep-seated injured areas are much more destructive to seed germination than are small injuries located in less important areas of the seed.

E. Conclusion

Considerable levels of stress cracking in seeds occurred during the seed drying stage of seed processing. Some cracks caused a significant reduction in seed germination following storage while other cracks did not, depending on the type or location of the cracks in the seed. Cracks in the endosperm alongside or extending into the middle of the embryo area as shown by X-ray radiography caused a significant reduction in seed germination following storage. This reduction in seed germination was mostly due to the enhancement of the rate of deterioration of cracked seeds and not to the direct destruction of essential structures of the seedlings or embryo. Cracks observed visually but not detected by X-ray in a normal longitudinal seed position and those outside the embryo area did not cause significant reduction in seed germination even after a period of storage.

Visual cracks not detected by X-ray photograph of seeds in a longitudinal position may be seen by X-ray photograph of seeds in a transverse position. These may be seen as very minute cracks in an X-ray photograph. Cracks seen both visually and by X-ray in longitudinal and transverse positions of seeds are relatively large and deep.

The results of this study support the use of X-ray radiography as a very useful technique for determining the specific location or magnitude of seed cracking in maize and suggest the technique can be used to more critically assess the likely effects of seed cracking on seed storage longevity.

CHAPTER 4

Maize Seed Quality as Influenced by Shelling, Drying Temperature, Tempering and Different Levels of Seed Moisture Content during Shelling

A. Introduction

The factors affecting seed quality have been extensively studied. Mechanical shelling, drying temperature, and the level of seed moisture content at shelling are among the more important post-harvest factors implicated in determining seed quality of maize after processing and its performance in storage (Bunch, 1960; Justice and Bass, 1978; Moore, 1972). Some workers have also shown that 'tempering' of artificially dried maize seeds affects seed quality by its influence in reducing the degree of internal stress cracking (Winfield, 1969; Thompson and Foster, 1963; Hall, 1980).

In the previous chapters, seed damage during seed processing was strongly implicated in seed deterioration during storage. Significant degrees of stress cracking in seeds occurred after drying which contributed to the early seed deterioration. In view of these facts, an attempt was made to reduce this problem. This study was therefore done to determine the effects of 'tempering', shelling, drying temperature, and different levels of seed moisture content during shelling on the viability, stress cracking, and storage performance of maize seeds.

B. Materials and Methods

Seeds of maize Hybrid XL 72aa were used in this study. The experiment was carried out immediately after harvesting with the following arrangement:

Factor A - Seed Moisture Levels, 22%, 18%, 14%

Factor B - Shelling

Machine - Machine shelled immediately after ear drying

Hand - Hand shelled immediately after ear drying

Tempered-Machine - Ears were tempered for 19 hours after ear drying and then machine shelled.

Tempered-Hand - Ears were tempered for 19 hours after ear drying then hand shelled.

Factor C - Seed Drying Temperatures, 40 C, 30 C, 20 C

Factor D - Seed Tempering, (tempered, not tempered)

Harvested ears of about 27% seed moisture content were dried at 30 C to 3 different seed moisture levels (22%, 18%, and 14%).

The ears in each group were then shelled using the 4 different systems described above. Ear tempering was done in sealed plastic bags after the desired seed moisture contents were reached. These sealed ears were placed back to the dryer at the same drying temperature for a tempering duration of 19 hours, before shelling.

After shelling, a portion of each seed lot was dried at each of 3 different seed drying temperatures (40 C, 30 C and 20 C) to a seed moisture content of about 12%. After seed drying, one-half of each seed lot was tempered for 14 hours, then blown with ambient air for about 5 minutes to cool the seeds. A seed tempering period of 14 hours was selected for convenience in the conduct of the experiment. Seed tempering was done in the same way as ear tempering. The other half of the seeds were not tempered, but were blown with ambient air for cooling immediately after drying.

All seed samples were placed in cloth bags and stored at 20 C at ambient relative humidity for 5 months.

Before storage, sub-samples of 4 x 50 seeds were taken for the measurement of germination as described in Chapter 2. Three lots of 25 seeds were also used for stress cracking analysis by X-ray radiography as described in Chapter 3. After seed storage for 5 months, germination tests were done to assess seed storage performance. Accelerated ageing tests were also carried out as described in Chapter 1.

Analysis of variance was carried out with the least significant difference (LSD) method being used to calculate statistical differences due to the effects of various pre-storage treatments.

C. Results

1. Stress Cracking and Breakage of Seeds

The levels of broken seeds measured following shelling are presented in Table 17. These included seeds exhibiting chipped crowns, kernels broken into halves, and some seeds broken into small pieces (Plate 20). The results show no significant differences in seed breakage between non-tempered and tempered ears before shelling or between ear tempering and the level of moisture content. However, the main effect of seed moisture content was significant. Seeds with 22% moisture content had significantly more broken seed (13.42g of broken seed per kilogram of whole seed) compared to those with 18% (6.99 g) or 14% (5.80 g) moisture content. The levels of broken seeds in samples shelled at 18% or 14% moisture content did not differ significantly.

The levels of stress cracking as influenced by moisture content during shelling, drying temperature, shelling, and seed tempering are presented in Table 18. The main effects of these factors on seed cracking was highly significant. In general, seeds processed at an initial moisture content of 22% had the highest percentage of stress cracking (21.76%). The lowest level of stress cracking (12.35%) was obtained at the lowest level of preshelling moisture content (14.0%). No statistical differences in the percentage of cracking were observed between machine shelled and hand shelled seeds.

However, when the ears were tempered before shelling, stress cracking was significantly reduced in both machine shelled and hand shelled samples.

Table 17: The effects of different moisture contents and ear tempering before shelling on the amount of seed breakage due to machine shelling.

Moisture Content	Broken Seeds (g/kg)*		Mean
	Tempered Ears	Non-tempered Ears	
22%	12.48	14.36	13.42a
18%	7.72	6.26	6.99b
14%	6.58	5.02	5.80b
Mean	8.93	8.55	

LSD. Moisture 5% = 2.80; 1% = 3.93; Tempering = NS;
Moisture x Tempering = NS.
* grams of broken seeds per kilogram of whole seeds.
Numbers having different letters are significantly different at P = .05.

Plate 20: Broken seeds of maize caused by mechanical shelling

Table 18: The effects of moisture content, shelling, drying temperature, and seed tempering on stress cracking of maize seeds after seed drying.

A. Main Effects

Moisture Content	22%	18%	14%
Seeds with stress cracks (%)	21.76a	15.22b	12.35c

LSD. 5% = 2.48, 1% = 3.26

Shelling	Machine	Hand	Tempered-Machine	Tempered-Hand
Seeds with stress cracks (%)	20.06a	19.17a	13.33b	13.22b

LSD. 5% = 2.86; 1% = 3.76

Drying Temperature	40 C	30 C	20 C
Seeds with stress cracks (%)	26.35a	15.32b	7.67c

LSD. 5% = 2.48; 1% = 3.26

Seed Tempering	Tempered	Untempered
Seeds with stress cracks (%)	15.19b	17.69a

LSD. 5% = 2.02; 1% = 2.66

B. Interactions

Drying Temperature X Moisture Content		40 C	30 C	20 C
	22%	34.29a	21.83a	9.17a
	18%	22.17b	15.17b	8.33a
	14%	22.58b	8.96c	5.50a

LSD. 5% = 4.29; 1% = 5.64

Drying Temperature X Shelling		40 C	30 C	20 C
	Machine	25.33a	23.72a	11.11a
	Hand	25.72a	20.00a	11.78a
	Tempered-Machine	27.11a	8.67b	4.22b
	Tempered-Hand	27.22a	8.89b	3.56b

LSD. 5% = 4.96; 1% = 6.51

Drying Temperature X Seed Tempering		40 C	30 C	20 C
	Tempered	25.61a	12.19b	7.78a
	Untempered	27.08a	18.44a	7.56a

LSD. 5% = 3.50; 1% = 4.61

Numbers having different letters are significantly different at P = .05.

The main effects of drying temperature and seed tempering also showed significant differences. Drying seeds at 40 C resulted in the highest amount of cracking (26.35%). Reduced percentage of seed cracking occurred at lower drying temperature. Seeds dried at 30 C or 20 C showed stress cracking levels of 15.32% and 7.67%, respectively. Similarly, seed tempering significantly reduced the level of stress cracking. Tempered seeds showed 15.19% cracking, while untempered seeds had 17.69%. Although this difference is only slight, it is statistically significant.

Significant interactions were observed between drying temperature and moisture content. Seeds dried at 20 C showed no difference in stress cracking at all levels of moisture content from 14% to 22%. However, seeds dried at 30 C showed a decreasing amount of cracking as the moisture content fell. At moisture contents of 22%, 18% and 14%, the levels of cracking were 21.83%, 15.17% and 8.96% respectively, at 30 C drying temperature. At 40 C, seed cracking levels rose to 34.29% at a moisture content of 22%. This amount of cracking was reduced to 22.17% at 18% moisture content, but no further reduction was observed when the initial moisture content was decreased to 14%.

The interaction between drying temperature and shelling also showed significant differences. At 40 C drying temperature, no differences were observed in stress cracking between the machine shelled and hand shelled seeds with or without tempering. However, at 30 C and 20 C drying temperature, stress cracking was significantly reduced when seeds were tempered on the ears prior to shelling.

Interactions between drying temperature and seed tempering also occurred. At a drying temperature of 20 C no differences were observed in seed cracking between the tempered (7.78%) and untempered (7.56%) seeds. However, after drying at 30 C, the level of stress cracking was 18.44% for untempered seeds but significantly reduced (12.19%) when seeds were tempered. At 40 C, the level of stress cracking was similar although tempered seeds had a slightly lower percentage of cracking (25.61%) compared to untempered seeds (27.08%).

2. Seed Viability Before Storage

The effects of shelling moisture content, drying temperature, shelling, and seed tempering on the germination of maize are presented in Table 19. Levels of moisture content, drying temperature, and seed tempering had no effect on seed viability. However, shelling by machine caused a significant reduction in germination percentage (92.17%) which was statistically lower than the germination (94.08%) obtained from hand shelled seeds. This difference, however, is unlikely to be of any agricultural significance.

Significant interactions between shelling and moisture content also occurred. Hand shelled seeds showed no difference in viability regardless of the levels of moisture content. But machine shelled seeds showed higher germination (93.67%) at 18% moisture content compared to those at 22% (91.58%) or 14% (91.25%) moisture contents when ears were not tempered. Surprisingly, a different trend was obtained when the ears were tempered before shelling. Tempered machine shelled seeds showed higher germination (93.92%) at 14% moisture content than at 18% moisture content (91.08%) or 22% moisture content (91.58%). Again, however, these differences are comparatively minor. More surprising was the result in tempered but hand shelled seeds, lowest germination of 90.25% being obtained at 18% moisture content, compared to 94.25% and 93.50% at 22% and 14% moisture contents, respectively. These differences, although statistically significant, were again not dramatic. In all seed samples, the levels of germination were consistently over 90%.

3. Seed Viability After Storage

Results showing the viability of maize seed after 5 months storage are presented in Table 20. The main effects of moisture content during shelling, drying temperature, and shelling showed significant differences, but no significant main effect was observed due to seed tempering.

Seeds with an initial moisture content of 22% during shelling had significantly reduced germination (83.40%) compared with the percentage germination at 18% moisture content (86.60%) and 14%

Table 19: The effects of shelling moisture content, shelling, drying temperature and seed tempering on germination percentage of maize before seed storage.

A. Main Effects

Moisture Content	22%	18%	14%
Germination (%)	92.77	92.38	93.19

LSD. 5% = not significant

Shelling	Machine	Hand	Tempered-Machine	Tempered-Hand
Germination (%)	92.17b	94.08a	92.19b	92.67b

LSD. 5% = 0.79; 1% = 1.04

Drying Temperature	40 C	30 C	20 C
Germination (%)	93.04	92.29	93.00

LSD. 5% = not significant

Seed Tempering	Tempered	Untempered
Germination (%)	92.76	92.79

LSD. 5% = not significant

B. Interactions

Shelling X Moisture Content	Machine	Hand	Tempered-Machine	Tempered-Hand
22%	91.58b	93.67a	91.58b	94.25a
18%	93.67a	94.50a	91.08b	90.25b
14%	91.25b	94.08a	93.92a	93.50a

LSD 5% = 1.37; 1% = 1.80

Numbers having different letters are significantly different at P = 0.05.

Table 20: The effects of shelling moisture content, shelling, drying temperature and seed tempering on germination percentage of maize after seed storage for 5 months.

A. Main Effects

Moisture Content	22%	18%	14%
Germination (%)	83.40b	86.60a	85.88a

LSD. 5% = 1.30; 1% = 1.71

Shelling	Machine	Hand	Tempered-Machine	Tempered-Hand
Germination (%)	80.44c	86.42b	85.44b	88.86a

LSD. 5% = 1.52; 1% = 1.99

Drying Temperature	40 C	30 C	20 C
Germination (%)	82.88c	85.13b	87.88a

LSD. 5% = 1.30; 1% = 1.71

Seed Tempering	Tempered	Untempered
Germination (%)	85.64	84.94a

LSD. 5% = not significant

B. Interactions

Drying Temperature X Seed Tempering	40 C	30 C	20 C
Tempered	81.63b	87.08a	88.21a
Untempered	84.13a	83.17b	87.54a

LSD. 5% = 1.84; 1% = 2.42

Numbers having different letters are significantly different at P = .05.

moisture content (85.88%). The germination of hand shelled seeds (86.42%) was significantly higher than that of the machine shelled seeds (80.44%) without ear tempering. In both machine shelled and hand shelled seeds, germination was higher when ears were tempered before shelling. Machine shelling immediately after ear drying showed a germination of 80.44% which significantly increased to 85.44% when the ears were tempered before shelling. The main effect of seed tempering however, was not significant (average germination of 85.64% for tempered seeds compared with 84.94% for untempered seeds).

Significant interactions occurred between seed tempering and drying temperature on seed viability after storage. Seed tempering had no effect at a drying temperature of 20 C. But when seeds were dried at 30 C, the germination of tempered seeds (87.08%) was significantly higher than that of untempered seeds (83.17%). Conversely, however, at a drying temperature of 40 C, tempered seeds showed a significantly lower germination (81.63%) than that of untempered seeds (84.13%) showing that seed tempering at 40 C caused a reduction in seed storage performance.

The percentage germination of seeds after accelerated ageing (Table 21) showed no effects of the different factors studied. The effects of moisture content during shelling, drying temperature, shelling and seed tempering, surprisingly did not differ significantly. However, the interactions between seed tempering and drying temperature followed a similar trend to that shown by natural ageing in storage for 5 months. The accelerated ageing germination tests on seeds dried at 20 C showed no effects from seed tempering. However, at 30 C, tempered seeds had a germination of 55.04% which was significantly higher than that for untempered seeds (45.29%). At a 40 C drying temperature, the reverse happened, with tempered seeds showing a significantly lower germination (45.62%) than the germination (56.71%) of untempered seeds. This was the only instance where seed germination after accelerated ageing confirmed results following natural ageing in storage.

Table 21: Percentage germination after accelerated ageing of maize stored for 5 months as affected by moisture content during shelling, drying temperature, shelling and seed tempering.

A. Main Effects

Moisture Content	22%	18%	14%
Germination (%)	50.17	51.25	51.52

LSD. 5% = not significant

Shelling	Machine	Hand	Tempered-Machine	Tempered-Hand
Germination (%)	49.61	52.00	50.75	51.56

LSD. 5% = not significant

Drying Temperature	40 C	30 C	20 C
Germination (%)	51.17	50.17	51.60

LSD. 5% = not significant

Seed Tempering	Tempered	Untempered
Germination (%)	51.08	50.88

LSD. 5% = not significant

B. Interactions

Drying Temperature X Moisture Content		40 C	30 C	20 C
	22%	47.88a	59.69a	48.94b
	18%	53.75a	49.38ab	50.63ab
	14%	51.88a	47.44b	55.25a

LSD. 5% = 6.05; 1% = NS

Drying Temperature X Seed Tempering		40 C	30 C	20 C
	Tempered	45.62b	55.04a	52.58a
	Untempered	56.71a	45.29b	50.63a

LSD. 5% = 4.94; 1% = 6.49

Numbers having different letters are significantly different at P = .05.

D. Discussion

The production of high quality seeds is always a major concern to seed producers. A seed is a fragile miniature plant which needs constant protection from any external forces that hasten seed deterioration. Although the pre- and post-harvest areas of production can both have a major influence on ultimate seed quality the sequence of seed processing can play a major role in determining the quality of the seed which goes into storage or to the field for planting in the following season.

Seed drying and mechanical damage to seeds during processing are among the major causes of seed damage. The moisture content of individual seeds within a lot at the time of mechanical impact influence the nature and seriousness of injury (Moore, 1972). In this study, the level of broken seeds was 47.9% higher for seeds shelled at 22% moisture content than for those shelled at 18%. There was no difference in the levels of broken seeds between those shelled at 18% and 14% moisture contents. Similar results were reported by Pierce and Hanna (1985) who observed that breakage susceptibility levels for maize processed at 24% moisture were 65% higher than those processed at 19% moisture. Bunch (1960) also found that maize seeds at 14% and 18% moisture contents were injured less than seeds at 20% moisture contents. The results show that seeds at 22% moisture are too wet for shelling resulting in easy fracturing or breakage of seed tissues during mechanical impact. Seed moisture contents of 18% or 14% may probably be within the optimum range for safe shelling of maize without excessive amounts of damage. Seeds at optimum levels of moisture are, no doubt, dry enough to prevent cell rupturing and the release of destructive, hydrolytic liquids upon impaction, and yet not dry and brittle enough to promote fracturing (Moore, 1972).

Aside from the effects on seed breakage during shelling, moisture content also influenced the levels of stress cracking during artificial seed drying. It was found in this study that generally, reducing the initial seed moisture content during seed drying from 22% to 14% reduced the level of stress cracking by nearly 50%. This result corroborates findings by other workers who have shown that

stress cracking is reduced when seed drying is started at lower initial moisture levels. Pierce and Hanna (1985) found 86% cracked maize seeds following drying at an initial moisture level of 24%. However, the level of stress cracking was still relatively high in seeds dried from an initial moisture content of 19%. Similarly, Ross and White (1972) reported that at 37.7 C drying temperature, stress cracking was reduced from approximately 50% at starting moisture contents of 35% to approximately 10% at starting moisture contents of 20%.

These results suggest that during drying, seeds with higher initial moisture contents experience greater drying stress due to the larger quantities of water removed. The establishment of steep moisture gradients is apparently responsible for the increased tendency for seeds to crack internally.

However, in this study, the reduction in stress cracking which occurred by lowering the initial moisture content during drying, depended on the drying temperature used. At a drying temperature of 20 C, the levels of stress cracking were statistically similar at all levels of moisture content. However, at 30 C stress cracking was reduced with subsequent reductions in the initial seed moisture content. At 40 C, stress cracking was only reduced when the initial seed moisture content was also decreased to 18%, although no further reduction occurred when the initial moisture content was further reduced to 14%. This implies that at 20 C, drying stress may not be sufficiently high to create differences in the level of stress cracking although some stress cracks may still occur. At 40 C, the stress may be sufficiently high to override the moisture effect on stress cracking. Generally, reducing the drying temperature from 40 C to 20 C reduced the level of stress cracking, the highest level of stress cracking (26.35%) occurring at 40 C and the lowest (7.67%) at 20 C.

Shelling by machine did not increase internal cracking. Hand shelled and machine shelled seeds had similar levels of stress cracking. Generally, in both hand shelled and machine shelled seeds, stress cracking was greatly reduced when the ears were 'tempered'

before shelling. However, this result depended on the drying temperature used. Although the amount of stress cracking after drying at 40 C was not reduced even when ears were tempered before shelling, reduction in stress cracking with tempering of ears before shelling was achieved at seed drying temperatures of 30 C and 20 C.

The tempering of ears for 19 hours before shelling provided time for moisture within the kernel to move from the interior to the surface where it was readily evaporated. This prevented the formation of steep moisture gradients. After shelling, the seeds were immediately further dried to about 12% moisture. This condition may be similar in principle to the multipass drying operation in rice. In this system, rice seeds are exposed for 15 to 30 minutes to heated air and moisture is reduced by 2 to 3% during each pass. Between passes, rice is removed from the dryer and stored in a bin for 4 to 24 hours tempering, and then placed back into the dryer. This process is repeated until drying is complete. Such a process helps prevent stress cracking of the kernels (Hall, 1980).

In maize, when seeds were first placed into the seed dryer after shelling, little or no moisture gradient may have existed due to 19 hours of prior ear tempering. In the case of untempered ears, it is highly probable that the moisture gradient within the seed created during ear drying still existed during shelling and continued through the seed drying stage. This is likely because the ears were shelled immediately after reaching the desired moisture content for shelling, and seed drying was done immediately after shelling. The creation of a continuous moisture gradient throughout the drying process resulted in more stress cracks than the situation where the moisture gradient was broken or stopped before seed drying was continued at an appropriate seed drying temperature.

Although the main effect of seed tempering after seed drying was to reduce the level of stress cracking, an interaction existed between seed tempering and drying temperature. The effect of seed tempering after seed drying varied with the drying temperature used. At 20 C and 40 C, there was no advantage from seed tempering. It was only at the 30 C drying temperature that the level of stress cracking was

reduced in tempered seeds. It is likely that at a low drying temperature (20 C), drying stress is relatively mild with a resultant low level of stress cracking (7.67%). At 40 C, the drying temperature is apparently too high so that even the tempering of seeds exposed to 40 C for 14 hours was not effective in reducing the level of cracking.

It should be noted that the tempering of seeds in this study was done in a different way from that used by other workers. In other studies, maize seeds were tempered by removing them while hot from the dryer and transferring them to a closed bin without providing an outside source of heat (Thompson and Foster, 1963; Winfield, 1969). After a few hours in the closed bin, the seeds were cooled slowly by blowing ambient air through them.

In this study, tempering was done by putting the seeds back into the dryer in closed plastic bags at the same drying temperature for 14 hours. It was possible that for this particular maize hybrid (XL 72aa), that long seed exposure to 40 C still created a temperature gradient which offset the effect of tempering. Ekstrom et al., (1966) reported that stress cracks in maize kernels are not only created by moisture gradient stress but also by temperature stress during seed drying. The model presented by Ekstrom et al., showed that a temperature gradient at 90 C in the maize kernel was required to create stress cracks. Nevertheless, it is speculated that for the particular hybrid studied, continued exposure to 40C for 14 hours during tempering must have caused a high temperature stress offsetting the potential stress crack reduction capacity of tempering.

The seed viability of maize after seed drying was very high regardless of the treatments applied. No dramatic changes in seed viability before storage were observed. Although machine shelled seeds showed a statistically lower germination (92.17%) than hand shelled seeds (94.08%) the difference was sufficiently small to suggest they are likely to be of only limited agricultural importance. The different treatments which affected the level of stress cracking in seeds did not affect seed viability after seed drying and before the seeds were stored. The results were a direct indication that stress cracking had no immediate detrimental effect on seed viability after processing as observed in this study.

When seeds had undergone deterioration in storage, some seed lots with higher levels of stress cracking had lower germinations than those with lower levels of stress cracking. Seeds with 22% initial moisture content have a statistically lower germination than seeds with 18% or 14% moisture. The germination of seeds with 18% and 14% initial moisture contents did not differ significantly. It was also found that seeds with an initial moisture of 22% during shelling or seed drying had the highest level of stress cracking. Although the levels of stress cracking between seeds with 18% or 14% initial moisture contents were significantly different, variation in the percentage germination were not. Possibly, the 5 months in storage was insufficient to allow deterioration to be reflected in real differences considering that the levels of cracking in seeds threshed at either 18% or 14% moisture contents were only slightly different (15.22% and 12.35%, respectively).

Machine shelled seeds had significantly lower germination than hand shelled seeds after storage. Tempering the ears before shelling however, was a useful technique, resulting in higher seed germination after storage than untempered seeds. Ear tempering may have reduced the moisture gradient stress during drying of the seeds with a resultant reduction in damage to the embryo. Iljin (1957) has indicated that mechanical impact can be particularly destructive to cell membranes under drying stress conditions.

The results show that although the levels of stress cracking in machine shelled and hand shelled seeds were similar, seed viability after storage differed significantly. This suggests that the reduction of seed germinability during storage was not due to damage caused solely by stress cracking but may also have been due to damage caused by mechanical impact during machine shelling. Such impacts have been shown to bring about disorganisation of cellular contents which result in processes leading to premature seed death (Moore, 1972).

Significantly lower germination percentages were observed after storage at higher drying temperatures. The highest germination (87.88%) was obtained from seeds dried at 20 C and the lowest (82.88%)

following 40 C drying. This result could be directly associated to the stress cracking of the seeds. However, a comparison of tempered and untempered seeds did not show a germination advantage from tempering even though tempered seeds had a significantly fewer stress cracks than untempered seeds. This effect however, depended on the drying temperature used due to the interaction effect observed between seed tempering and drying temperature on seed viability after storage. At a drying temperature of 20 C, no differences were observed between the germination of tempered and untempered seeds. At 30 C, however, tempered seeds had a significantly higher germination than untempered seeds. This effect was closely related to the levels of stress cracking. Surprisingly, following drying at 40 C, tempered seeds had a significantly lower germination than untempered seeds although stress cracking levels were similar. This suggested that seed damage due to tempering at 40 C subsequently reduced the germinability of seeds in storage. The reason for this is not clear. Most probably, this may be attributed to the method of tempering as explained earlier. Also, 40 C may be too high for seed of this hybrid to be exposed for 14 hours longer than untempered seeds without subsequent deterioration.

Generally, the differences in the germination levels between treatments is relatively small for a storage duration of 5 months but the results suggest that some effects occur as a direct result of the treatments applied. The results of accelerated ageing tests, however, were quite different. None of the factors involved had affected seed germination after accelerated ageing except in the interaction between drying temperature and seed tempering. This interaction after accelerated ageing followed the same trend as natural ageing.

E. Conclusion

Mechanical shelling and seed drying were both implicated as causes of seed damage. Both had an adverse effect on maize seed quality. Although seed viability following treatment was not dramatically affected, subsequent seed storability was reduced.

Machine shelling at a moisture content of 22% produced more broken seed than shelling at either 18% or 14%.

The formation of stress cracks was not affected by machine shelling as revealed by X-ray radiography. However, machine shelled seeds had lower viability than hand shelled seeds after storage, although there were no differences in the levels of stress cracking. Tempering of ears before shelling reduced the level of stress cracking at drying temperatures of 20 C and 30 C but not at 40 C. Generally, seeds from ears tempered before shelling had a higher germination percentage after storage than those from untempered seeds.

Stress cracking was drastically reduced when seed drying temperature was reduced from 40 C to 20 C and seed viability after storage increased. Seed drying from an initial seed moisture content of 14% at 30 C and 18% at 40 C also reduced the level of stress cracking but this effect was not obvious when seed was dried at 20 C. Seed viability after storage was similar in seeds with an initial 18% or 14% moisture content but was significantly higher than seeds with a 22% initial moisture content.

Seed tempering at 30 C reduced internal stress cracking in maize seeds. This effect did not occur at drying temperatures of 20 C or 40 C. Similarly, at 30 C, tempered seeds had higher seed viability after storage than untempered seeds. While seed tempering did not affect seed viability following drying at 20 C, it did significantly reduce the viability of seeds dried at 40 C.

CHAPTER 5

General Discussion and Conclusion

In common usage, the term seed processing refers to the preconditioning, drying, cleaning, size-grading, treating and general 'upgrading' of seed. In its broadest sense, it encompasses all the steps involved in the preparation of harvested seed for marketing (Vaughan, Gregg and Delouche, 1968). Although all of these activities may contribute to seed damage, shelling has been found to be the most serious source of mechanical injury (Wortman et al., 1951). The ability of a seed to germinate can be reduced or destroyed completely by mechanical injuries (Gregg et al., 1970).

In this study, seed damage due to processing has been observed. Although broken seeds resulted from the mechanical shelling operation, internal stress cracking of seeds also occurred particularly as a result of seed drying. The damage of seeds during processing, however, did not cause any dramatic reduction in seed viability immediately after processing. The most obvious effects became apparent following seed storage. This corroborates similar findings reported by Moore (1972) and Brooker et al. (1974) who have also shown that seed damage may not immediately affect seed viability but increases seed deterioration rate in storage.

The different hybrids of maize studied showed varied responses to seed processing. Hybrids D 54 and XL 81 were more susceptible to processing damage than Hybrid XL 72aa. Although Hybrid XL 72aa had less potential ability to germinate as shown by its lower initial germination, it was the least susceptible hybrid to processing damage. After seed storage, a more severe reduction in seed viability occurred in Hybrids D 54 and XL 81 than in XL 72aa.

A considerable amount of stress cracking occurred during seed drying. Stress cracks did not cause an immediate loss in seed viability but certainly hastened the rate of deterioration in storage depending on the nature of the cracks. Visual cracks, which were not also detectable by X-ray photography when viewed longitudinally, did not affect seed viability after storage. These cracks however, were

detectable as tiny shallow fissures when viewed in a transverse position of the seed on the X-ray plate. Internal cracks present in the endosperm and outside the germ area also did not affect seed viability after storage. Those cracks located alongside or extending into the middle of the germ area, however, were identified as a major cause of loss of seed viability after storage. Pana (1977) also reported a decrease in germinability due to seed cracking, but that this effect was dependent on the type and position of cracks in the seed. Deep cracks most seriously reduced seed germinability.

The seed processing system of HBF Dalgety Ltd, in Gisborne, New Zealand was shown to cause seed damage which subsequently reduced the storability of maize seeds, although it did not adversely affect immediate seed viability.

Seed deterioration was very apparent after only 5 months storage and continued to occur in samples stored for up to 15 months. The storage conditions imposed in this study involved ambient conditions, and therefore were considered to be a fair measure of deteriorative damage due to seed processing. Although the storage temperature was only 20 C the relative humidity of 75 - 80% resulted in equilibrium moisture contents within the range 14 - 15% even though the initial seed moisture content during storage was about 12.0%.

Although some mechanical damage to seeds processed mechanically is unavoidable (Moore, 1972), the present investigation has shown that although the final stages of processing, i.e. grading and treating, caused a reduction in seed viability, this effect also implicated the cumulative effects of damage caused by mechanical impact.

It is possible that factors contributing to seed deterioration caused by the seed processing system can be reduced. Of the factors considered in the present investigation, drying temperature, tempering of the ears before shelling, tempering of the seeds after drying and shelling or drying at different initial seed moisture contents could be implicated.

General observation showed better seed germination after storage of seed which had been tempered before shelling. Stress cracking was also reduced by this process, particularly at a seed drying

temperature of 30 C. Reducing the seed drying temperature to 20 C from 40 C or 30 C significantly reduced the level of stress cracking and resulted in better seed viability after storage. Seed drying starting with initial seed moisture contents of 14% or 18% also reduced the level of stress cracking.

Although some of the results of this study agree with reports of other workers and clearly indicate ways of reducing seed processing damage in maize, some caution must be exercised when applying these results to processing involving a large bulk of seed due to the interactions of various factors. Most particularly, care must be taken when trying to evaluate the role of seed cracking on seed deterioration. Many workers have suggested that stress crack levels in seed maize vary with cooling procedures. White and Ross (1972), for example, reported that artificially dried maize seeds showed more cracks when rapidly cooled than when cooled slowly. It has also been reported that more stress cracks occur after cooling than immediately after seed drying (Thompson and Foster, 1963). Much of this damage occurs when the moisture gradient stress due to rapid cooling is added to the stress built up during heated air drying (Thompson and Foster, 1969). Slow cooling is therefore essential to reduce stress cracking of seeds after drying. In this study, 'cooling' was not included as a specific treatment for investigation. However, seeds were nevertheless cooled for a short period of about 5 minutes by blowing ambient air through seed immediately after seed drying.

Conclusion

The damage due to seed processing did not cause an immediate reduction in seed viability but hastened seed deterioration in storage. The stages of seed processing which most likely contributed to a reduction in seed germination following storage were ear drying, seed drying, shelling and the final stages of seed dressing, grading and treating.

Seed drying encouraged stress cracking. Cracks located outside the germ area as revealed by X-ray radiography and cracks seen visually but not by X-ray had no adverse effects on seed viability after 12 months storage. However cracks along the side or along the middle of the germ area reduced seed viability after storage.

Shelling should be carried out within the range of 14% to 18% seed moisture content. If ear drying down to 14% seed moisture content is feasible, such extra drying has the advantage of reducing stress cracking. Also, seed drying starting at a lower initial seed moisture content, ie. 14% reduces stress cracking. Caution must be exercised when dealing with different hybrids because of their differential response to drying temperature.

After ear drying, the ears should be tempered before shelling. A duration of 19 hours is sufficient. It is not always necessary to continue supplying heat as long as the hot ears are in sealed bins to prevent moisture evaporation when ear drying is stopped. This would ensure that the seeds are not under moisture gradient stress when shelled. Mechanical impact is particularly destructive when the seeds are under drying stress.

Safe seed drying temperature should not exceed 30 C. Seed drying at 20 C temperature certainly reduces stress cracking but obviously increases seed drying time and cost. A seed drying temperature of up to 30 C dries seed more quickly although more stress cracks may result. However, with appropriate tempering, stress cracking levels may be reduced.

This investigation has also highlighted the effects of various interacting factors. Results may differ due to various factors such as drying temperature, hybrid, tempering and initial seed moisture content. Nevertheless, the results have shown that generally, seed drying at relatively lower temperature and lower initial moisture content plus tempering greatly reduced the levels and extent of seed damage caused during seed processing which have been implicated in seed deterioration during storage.

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Appendix 1: Maize seed germination after storage. Data supplied by HBF Dalgety Ltd, Gisborne, New Zealand.

Seed lot/Hybrid	Percentage Germination					
	Grade	Initial	4-5 mths	8-14 mths	15-17 mths	19 mths
1. XL 81	Large Round	93.0	95.0 (4)*	96.0 (8)	79.0 (15)	60.0
2. XL 81	Large Flat	93.0	96.0 (4)	96.0 (11)	80.0 (17)	69.0
3. XL 81	Medium Flat	93.0	97.0 (4)	71.0 (11)	52.0 (17)	61.0
4. XL 72aa	Large Flat	89.0	88.0 (5)	91.0 (11)	74.0 (17)	75.0
5. XL 72aa	Small Flat	89.0	86.0 (5)	89.0 (14)	81.0 (17)	71.0
6. XL 72aa	Medium Flat	89.0	82.0 (5)	85.0 (13)	81.0 (17)	83.0
Fungi		Nil	Nil	Nil	Nil	Nil

* A figure within a parenthesis indicates the number of months that a sample was stored and tested.

Key to Appendices 2, 3 and 8

A - Handpicked samples from the field

B - Receiving or intake to the processing plant

C - Husking

D - Ear drying

E - Shelling

F - Sample in seed dryer before seed drying

G - Seed drying

H - Seed storage; after seed drying but before seed dressing

I - Dressing, grading and treating.

Appendix 2: Percentage germination prior to storage of 3 maize hybrids as affected by processing (Trial 1).

Stages of Processing	Hybrid XL 72aa		Hybrid D 54		Hybrid XL 81	
	Replicates		Replicates		Replicates	
	I	II	I	II	I	II
A	92.0	88.0	100.0	98.0	100.0	98.0
B	86.0	94.0	98.0	100.0	96.0	98.0
C	96.0	86.0	100.0	100.0	98.0	94.0
D	88.0	94.0	96.0	98.0	98.0	96.0
E	86.0	94.0	98.0	96.0	94.0	94.0
F	86.0	90.0	98.0	96.0	96.0	90.0
G	80.0	94.0	96.0	100.0	94.0	92.0
H	86.0	90.0	98.0	98.0	98.0	94.0
I	86.0	94.0	96.0	98.0	96.0	88.0

Appendix 3: Percentage germination after 5 months storage of 3 maize hybrids as affected by processing (Trial 1).

Stages of Processing	Hybrid XL 72aa		Hybrid D 54		Hybrid XL 81	
	Replicates		Replicates		Replicates	
	I	II	I	II	I	II
A	90.0	92.0	94.0	96.0	100.0	100.0
B	92.0	94.0	96.0	94.0	100.0	96.0
C	92.0	88.0	94.0	94.0	92.0	92.0
D	90.0	90.0	92.0	92.0	84.0	86.0
E	84.0	94.0	96.0	96.0	80.0	90.0
F	86.0	92.0	82.0	96.0	86.0	90.0
G	74.0	70.0	88.0	82.0	82.0	78.0
H	80.0	78.0	70.0	88.0	66.0	80.0
I	80.0	82.0	58.0	66.0	60.0	70.0

Key to Appendices 4, 5 and 9

BD - Sample just before ear drying

D - Ear drying

E - Shelling

Ex - Sample on top of the seed dryer

Ey - Sample in the seed dryer as the seeds dropped without the spinner moving; before seed drying

F - Sample in the seed dryer as the seeds dropped with the spinner moving (normal procedure); before seed drying

G - Seed drying

Gx - Sample at the top point of bucket elevator

Gy - Sample on top of storage silo.

Appendix 4: Percentage germination of maize (Hybrid XL 72aa) at various storage periods as affected by processing (Trial 2).

Stages of Processing	Before Storage				3 months				7 months			
	Replicates				Replicates				Replicates			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
BD	78	76	82	86	92	92	90	90	90	90	92	92
D	92	92	92	90	92	90	90	92	94	90	94	94
E	88	90	80	90	88	88	84	86	86	88	84	88
Ex	92	76	88	90	90	88	86	90	84	86	88	88
Ey	92	86	88	90	86	86	88	84	88	86	86	86
F	86	88	82	86	88	86	90	90	86	88	88	86
G	86	90	88	86	90	88	84	84	90	86	86	84
Gx	80	88	84	88	86	84	86	88	86	84	84	86
Gy	88	92	84	90	84	84	86	84	90	80	82	86

Appendix 4: continued

Stages of Processing	11 months				15 months			
	Replicates				Replicates			
	I	II	III	IV	I	II	III	IV
BD	98	92	90	90	94	92	96	68
D	84	82	94	96	84	84	86	80
E	76	78	82	78	70	70	66	80
Ex	86	76	84	78	66	70	72	68
Ey	78	82	80	80	66	68	60	74
F	74	80	76	78	72	70	66	64
G	76	80	84	78	50	52	50	52
Gx	76	78	72	76	48	46	50	50
Gy	84	78	78	70	56	50	52	50

Appendix 5: Types of abnormal seedlings observed at various stages of processing after different storage periods (Trial 2).

Stages	Before storage	Storage period (months)			
		3	7	11	15
BD	decayed roots decayed coleoptile	unbalanced weak no root or plumule	unbalanced split coleoptile no primary root no roots stunted primary root	no roots weak unbalanced stunted root	weak no roots no primary root
D	weak	no roots weak unbalanced no plumule decayed coleoptile	weak broken coleoptile unbalanced	weak no roots stunted root unbalanced twisted split coleoptile	weak no roots
E	no plumule unbalanced decayed coleoptile decayed roots no roots stunted roots	twisted split coleoptile no roots unbalanced weak no plumule stunted root	unbalanced no primary root stunted roots twisted coleoptile no plumule split coleoptile	weak no plumule no primary root split coleoptile no roots	weak no primary root no plumule no roots
Ex	decayed mesocotyl weak split coleoptile no primary root swollen mesocotyl	split coleoptile stunted plumule unbalanced weak no roots	no primary root weak split coleoptile unbalanced	no roots no plumule weak twisted coleoptile	no roots no primary root weak

Appendix 5 continued..

Ey	weak no primary root decayed coleoptile no roots decayed plumule swollen mesocotyl	decayed unbalanced no roots no plumule split coleoptile	weak no roots no primary root unbalanced swollen mesocotyl stunted plumule	no roots weak split coleoptile stunted plumule	weak no plumule no roots no primary root
F	decayed mesocotyl weak no plumule unbalanced weak roots	unbalanced weak split coleoptile	weak no primary root no plumule stunted roots no roots twisted coleoptile	no roots weak no primary root no plumule split coleoptile	weak no roots no primary root
G	curled coleoptile no plumule split coleoptile unbalanced weak	unbalanced broken coleoptile no root stunted plumule weak	curled split coleoptile decayed coleoptile no plumule	weak stunted primary root twisted split coleoptile stunted plumule	weak no roots
Gx	unbalanced twisted coleoptile no roots weak no plumule decayed roots	unbalanced split coleoptile twisted coleoptile no roots broken coleoptile	no plumule no primary root unbalanced twisted coleoptile weak	weak stunted roots unbalanced split coleoptile no roots	weak no roots
Gy	no plumule twisted coleoptile split coleoptile unbalanced decayed mesocotyl	weak no roots broken coleoptile unbalanced no plumule	split coleoptile no roots no primary root unbalanced stunted primary root no plumule weak	stunted primary root weak stunted plumule unbalanced broken coleoptile no primary root curled coleoptile	weak no roots no plumule twisted coleoptile

Appendix 6: Percentage germination after 12 months storage of artificially dried seeds as affected by different levels of stress cracking.

Seed Samples	% seeds with stress cracks	% Germination			
		Replicates			
		I	II	III	IV
1	0	76.0	76.0	72.0	74.0
2	13	76.0	68.0	72.0	74.0
3	24	58.0	66.0	60.0	70.0
4	37	64.0	52.0	68.0	60.0
5	47	60.0	52.0	44.0	52.0
6	58	58.0	54.0	44.0	46.0
7	70	60.0	44.0	40.0	46.0

Appendix 7: Percentage germination after 12 months storage of artificially dried seeds as affected by seed crack position.

Seed Samples	Crack Position *	% Germination		
		Replicates		
		I	II	III
1	No cracks	72.0	76.0	72.0
2	Visual cracks	64.0	72.0	68.0
3	Crack Position 1	72.0	72.0	64.0
4	Crack Position 2	48.0	44.0	44.0
5	Crack Position 3	44.0	36.0	48.0

* No cracks - No cracks seen visually and by X-ray
Visual cracks - Cracks seed visually but not by X-ray
Crack Position 1 - Cracks outside the germ area
Crack Position 2 - Cracks along the side of the germ area
Crack Position 3 - Cracks along the middle of the germ area.

Appendix 8: Percentage cracking of maize seeds as affected by processing (Trial 1).

Stages of Processing	% Visual cracks			% X-ray cracks		
	Hybrid XL 72aa	Hybrid D 54	Hybrid XL 81	Hybrid XL 72aa	Hybrid D 54	Hybrid XL 81
A	2	0	6	0	0	0
B	0	2	0	0	0	0
C	0	4	2	0	0	0
D	2	14	0	0	0	0
E	0	0	22	0	0	0
F	8	6	0	0	0	0
G	40	86	64	46	54	50
H	10	36	un-collected	48	46	un-collected
I	12	66	un-collected	44	48	un-collected

Appendix 9: Percentage cracking of maize seeds before and after storage as affected by processing (Trial 2).

Stages Processing	% Visual cracks		% X-ray cracks	
	Before Storage	After Storage	Before Storage	After Storage
BD	0	0	0	0
D	0	2	0	0
E	0	6	0	0
Ex	6	4	0	0
Ey	16	12	0	0
F	6	8	0	0
G	48	70	34	32
Gx	44	64	28	32
Gy	44	68	30	28

Appendix 10: Percentage cracking of maize seeds as affected by initial moisture content during shelling, drying temperature, shelling and tempering.

Initial Moisture	Shelling	Drying Temperature					
		40 C		30 C		20 C	
		T	N	T	N	T	N
22%	M	28.0	36.0	21.3	36.0	9.3	20.0
	H	36.0	33.0	28.0	40.0	20.0	10.7
	TM	26.7	45.3	8.0	17.3	5.3	4.0
	TH	36.0	33.3	13.3	10.7	1.3	2.7
18%	M	20.0	22.7	22.7	28.0	12.0	14.7
	H	17.3	17.3	13.3	26.7	8.0	12.0
	TM	25.3	29.3	6.7	9.3	5.3	2.7
	TH	22.7	22.7	5.3	9.3	9.3	2.7
14%	M	28.0	17.3	13.0	21.3	4.0	6.7
	H	24.0	26.7	8.0	4.0	10.7	9.3
	TM	20.0	16.0	4.0	6.7	5.3	2.7
	TH	23.3	25.3	2.7	12.0	2.7	2.7

T = Tempered
N = Non-tempered
M = Machine shelled without ear tempering
H = Hand shelled without ear tempering
TM = Machine shelled after ear tempering
TH = Hand shelled after ear tempering.

Appendix 11: Amount of broken seeds (g/kg) of maize as affected by different levels of moisture content during machine shelling and ear tempering.

Shelling Moisture	Cob Tempering					
	Tempered			Non-tempered		
	Replicates			Replicates		
	I	II	III	I	II	III
22%	11.38	11.32	14.75	17.76	11.68	13.64
18%	7.16	8.19	7.81	4.41	8.82	5.56
14%	9.33	3.70	6.70	5.03	3.33	6.69

Appendix 12: Percentage germination before storage of maize seeds as affected by initial moisture content during shelling, drying temperature, shelling and tempering.

Initial Moisture	Shelling	Drying Temperature					
		40 C		30 C		20 C	
		T	N	T	N	T	N
22%	M	92.0	91.0	92.5	91.5	87.5	95.0
	H	95.0	95.5	91.5	92.5	94.5	93.0
	TM	91.5	93.0	91.5	91.5	89.5	92.5
	TH	96.0	92.0	94.5	93.0	95.0	95.0
18%	M	93.0	93.5	93.5	95.0	94.0	93.0
	H	94.5	95.5	94.5	94.0	93.5	95.0
	TM	92.0	91.5	91.5	89.0	91.0	91.5
	TH	89.0	88.5	89.5	90.0	91.5	93.0
14%	M	95.0	90.5	88.5	92.0	93.0	88.5
	H	94.5	93.5	92.5	94.0	96.0	94.0
	TM	93.0	94.0	94.0	93.5	94.0	95.0
	TH	96.0	93.0	91.5	93.5	93.0	94.0

Appendix 13: Percentage germination after 5 months storage of maize seeds as affected by initial moisture content during shelling, drying temperature, shelling and tempering.

Initial Moisture	Shelling	Drying Temperature					
		40 C		30 C		20 C	
		T	N	T	N	T	N
22%	M	74.0	76.0	80.5	75.5	85.0	82.5
	H	81.0	82.5	84.5	80.5	87.5	89.0
	TM	77.5	81.0	86.5	85.0	86.5	82.5
	TH	86.0	89.5	87.5	83.5	90.5	89.5
18%	M	80.0	81.5	82.5	80.5	83.5	83.5
	H	86.0	88.5	88.5	84.0	91.5	91.0
	TM	83.0	87.0	90.0	86.0	88.0	85.5
	TH	85.5	90.0	93.5	88.0	90.0	91.0
14%	M	77.0	78.0	82.5	78.0	84.5	83.0
	H	84.5	87.0	86.5	85.5	86.5	91.0
	TM	82.0	83.0	89.5	86.0	92.0	89.5
	TH	83.0	85.5	93.0	88.0	93.0	92.5